TO IMPROVE THE POWER QUALITY IN GRID CONNECTED WIND ENERGY SYSTEM

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Abstract

The integration of wind energy into the power system is to minimize the environmental impact on conventional plant. In a grid connected wind power generation system, there are some power quality issues. The measurement and assessment of power quality characteristics of grid connected wind tur- bines are specified in International Electro-technical Commission standard IEC-61400-Part 21. The 275kW wind turbine capacity is implemented in this paper. In grid integrated wind power systems quality of power is measured by active power, reactive power and variation of voltages measured under guidelines in National/International standards. In this proposed method, STATCOM is connected at a point of common coupling. The STATCOM with Two Battery Energy Storage Sys- tem (TBESS) is used to compensate the reactive power demand in wind power generation system and improve the power factor. The STATCOM control scheme for the grid connected wind energy generation system for mitigating power quality issues is simulated using MATLAB/SIMULINK environment.

Keywords: Wind Energy Generation, Grid, IEC, STATic COMpensator, Two Battery Energy Storage, Power Quality.

I. Introduction

The value of wind power can be extensively increased if it is capable of contributing to the grid support. The wind energy is experiencing extraordinary growth. The worldwide capacity reached 159,213 MW out of which 38,312 MW was added. This environmentally friendly power source will be significantly improved for its long term goal. The increasing number of renewable energy sources and distributed generator requires a new strategy for operation and management of electric grid system. Today, wind energy generating system is connected into the power system to meet the consumers demand and to support the grid. The wind power generation has become a very attractive utilization of renewable energy becomes it is now possible to improve the capability of capturing wind energy. The integration of wind energy into existing power system presents a sideration of voltage regulation, stability, power quality prob- lems [1].

The wind power generation system with battery energy storage is become a most important with the increasing demand of power generation. The output power of wind genera- tor is affect the operation in distribution network. The power variations are mainly caused by the effect of turbulence, wind shear, tower shadow and of control system in the power sys- tem. Thus the networks need to manage for such fluctuations. The industrial and commercial customers are operating the sensitive loads that cannot accept voltage sags, swells and loss of power. The poor power quality is in terms of injected current harmonics, low efficiency and large size of ac and dc filters. The battery energy storage system is integrated to sustain the real power source under fluctuating wind power [2].

It used for sensitive load applications as it supplies the power for a short period of time. The wind energy generation system is response for either charging/discharging the battery and also acts as a constant voltage output for the critical load in the distribution system. The proposed STATCOM control system for grid connected wind energy generation with battery storage has the following objectives,

- Mitigating power quality issues in grid and improve power factor.
- Support real and reactive power from STATCOM to wind generator and load.
- Reduces the harmonics.

It describes as follows chapter II Standards of power quality and wind turbine, chapter III Grid connecting system, chapter IV STATCOM control scheme, chapter V Grid synchronization, chapter VI Simulation, Results and Conclusion.

II. Standards of Power Quality, Design and Its Controls

The International Electro-technical Commission (IEC) is a worldwide organization for Standardization of all National Electro-technical committees. The international standards are developed by a working group of technical committee-88, IEC Standard-61400 describes the same procedure for determining the power quality, wind design and its control methods [3]

- IEC 61400-2 Design requirements for small wind turbines.
- IEC 61400-12 Power performance measurements (power curve).
- IEC 61400-21 Measurement and assessment of power quality characteristics of grid connected wind turbines.
- IEC 61400-25-1 Communications for monitoring and control of wind power plants over all description of principles and models.

III. Grid Connecting Systems

A. Wind Generation:

The modeling of wind turbine generator is very difficult to know all parameters, because the wind turbine generator is very complex system [4]. The input is real time wind speed and the output being the power output resulting in the performance of power curve. The wind output power is

$$P_w = \frac{1}{2}\rho\pi R^2 V_{wind}^3 C_p(\lambda,\beta) \quad (1)$$

where ρ air density, R radius of rotor blade, V velocity of wind speed, Cp Co-efficient of power, λ tip speed ratio, β blade pitch angle.

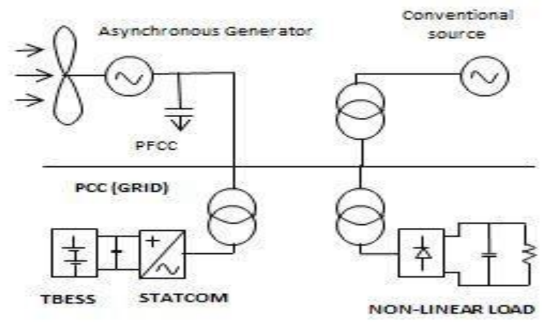
$$C_p = \frac{1}{2}(\lambda - 0.022\beta^2 - 5.6)e^{-0.17\lambda} \quad (2)$$

$$\lambda = \frac{V_w}{\omega_B} \quad (3)$$

where ω_B rotational speed of turbine. The Torque

$$T = \frac{1}{2}\rho(\pi R^2)\frac{C_p}{\lambda}V_{wind}^3 \quad (4)$$

A STATCOM with TBESS is improve the power quality in grid connected wind energy system is shown in Figure 1. The real time implementing wind turbine output power curve is shown in Figure 2.



B. Conventional Source:

The three phase source at specified base voltage. These parameters are available only specific impedance using short circuits level is selected [5]. The internal L in H is computed from the inductive three phase short circuit power P_{sc} in VA, base voltage V_{base} in V_{rms} phase-to-phase and source, f in Hz.

L=(5)

The phase angle of the internal voltage generated by phase A, in degrees. The three voltages are generated in positive sequence. Thus phase B and phase C internal voltages are lagging phase A respectively by 120° and 240°.

C. STATCOM:

The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at a point of common coupling. The capacitor is used as the intermediate element of STATCOM which couples the wind generating system and battery storage as

$CV_{dc}=I_{dc(rect)}I_{dc(inv)}$ (6) where C is circuit capacitance V_{dc} is rectifier voltage $I_{dc(rect)}$ is rectified dc-side current, $I_{dc(inv)}$ is inverter dc-side current.

$$V_{dc} = V_{inv} \quad (7)$$

where V_{inv} is line to neutral rms voltage of inverter , switching frequency 2kHz, inverter output frequency 50Hz and M_a is modulation index. The dc battery is design for 800Volt each.

D. Battery Energy Storage System

Bang-Bang current controller is implemented in the cur- rent control scheme. The reference current is generated in 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 phase „a" is expressed as

I^*_{sa} < (I^*_{sa} - HB)
☐SA=0

(8)

I^*_{sa} > (I^*_{sa} - HB)
☐SA=1

(9)

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

E. Reactive Power

The three phase injected current into the grid from STATCOM will cancel out the distortion caused by the nonlinear 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 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.

F. Non-Linear Load:

The non-linear load is considered for diode front-end rectifiers, which are widely used in power converters and ac machine drives with a dc-link capacitor [6]. A non-linear load causes a distorted voltage wave from (V_P) at the point of common coupling due to current (i_n). The voltage include odd harmonics with order 6n±(n = 1,2…) multiples of synchronous frequency(ωs).

$$V_P = V_S - V_{NS} = V_S - R_S i_S - L_S \frac{di_s}{dt} \quad (10)$$

where R_S stator resistance, V_P stator output voltage at the point of common coupling, V_{NS}

non-linear voltage, V_S induced stator voltage, i_S stator current.

IV. Statcom Control Scheme

A. Control System:

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator

and non-linear load at the PCC in the grid system. The current control scheme is included in the control system that defines

the functional operation of the STATCOM compensator in the power system [7]. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support to the asynchronous generator and non-linear load. The STATCOM control system circuit diagram is shown Figure 3.

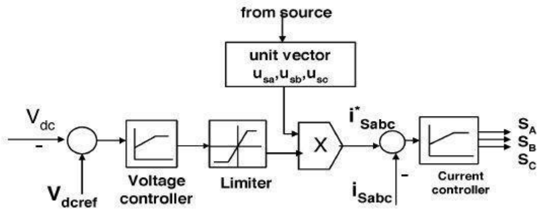


Figure 3. STATCOM Control System

B. 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. The STATCOM responds to the step change command for increase in additional load. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to mitigate reactive demand as well as harmonic current. The dynamic performance is also carried out by step change in a load. This additional demand is fulfilled by STATCOM compensator. Thus, STATCOM can regulate the available real power from source.

C. Voltage Regulator:

The effectiveness of the STATCOM is providing continuous voltage regulation for distribution system. The STAT- COM current of phase A lags behind the load voltage by 90° which illustrate the operation of the system as an inductive compensator, the dc voltage and reactive power response are measured with STATCOM connected and switched at t = 2.1ms, it can be seen that the dc power is reduced and the reactive power of the inductive load is absorbed by the STATCOM.

D. Sag Compensation:

The source bus voltage drops from 1pu to 0.9pu it represent heavy load or fault conditions in the grid. The STATCOM response to the voltage sag quickly and the PCC bus voltage restores to 1pu with in 0.21s. The recovery speed is actually limited by the ramp of Q reference inside the control to avoid current distortion at the transient [8]. When the STATCOM reactive power and current magnitude increases, the system capacitor voltage ripple increases. The capacitor voltages are well regulated and balanced throughout the voltage sag transient.

E. Power Factor

The power factor of an AC electrical power system is de- fined as the ratio of the real power flowing to the load to the apparent power in the circuit and is a dimensionless number between 0 and 1. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a nonlinear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power.

V. Grid Synchronization

A. Modeling of Grid:

Considering the grid connected voltage source connected as ideal voltage sources [9]. The relationship between the voltage and line current can be expressed in the αβ reference frame as

$$U_{g\alpha\beta} = V_{g\alpha\beta} + L_g \frac{dI_{g\alpha\beta}}{dt} + R_g I_{g\alpha\beta}$$

(11) where U_g, V_g grid and converter voltage vectors, I_g converter ac current vector, L_g, R_g line inductance and resistance, α,β stationary axis, g grid connected voltage source converter.

The grid connected intermittent wind energy characteristics of these resources largely affect the quality of power supply. The estimated grid voltage V_{gd}^e, V_{gq}^e is given by expression

$$\begin{bmatrix} V_{gd}^e \\ V_{gq}^e \end{bmatrix} = \begin{bmatrix} V_d \\ V_q \end{bmatrix} - \begin{bmatrix} R & 0 \\ 0 & R \end{bmatrix}\begin{bmatrix} I_d \\ I_q \end{bmatrix} - \begin{bmatrix} 0 & -\omega L \\ \omega L & 0 \end{bmatrix}\begin{bmatrix} I_d \\ I_q \end{bmatrix} \quad (12)$$

where V_d, V_q is applied voltage by the inverter in the IGBT control cycle, I_d, I_q is the inverter current transfer from STATCOM reference frame, V_d, V_q inverter output voltage.

Current Control: The grid is modeled as a voltage source of voltage V_g, and a coupling inductor of inductance L and resistance R is used [10]. It is assumed that the grid inductance will be significantly lower than that of the coupling inductor

$$V = \sum_{m=1}^{n} V_m \quad (13)$$

Control of the inverter current is primarily achieved using a feed forward system. This calculates the inverter voltage necessary to achieve the desired current based on reference values of the grid voltage magnitude and angle. The grid vol- tage is assumed to be sinusoidal, of the form

$$V_g = V_g \sin\theta \quad (14)$$

where V_g magnitude of grid voltage, θ angle

$$V = V_g + iR + L\frac{di}{dt} \quad (15)$$

where V, I is sinusoidal voltage and current. The value of the feed forward voltage required achieving an inverter current is given equation

$$\begin{bmatrix} V_{ffd} \\ V_{ffq} \end{bmatrix} = \begin{bmatrix} 0 \\ V_g \end{bmatrix} - \begin{bmatrix} R & 0 \\ 0 & R \end{bmatrix} \begin{bmatrix} I_d^* \\ I_q^* \end{bmatrix} - \begin{bmatrix} 0 & -\omega L \\ \omega L & 0 \end{bmatrix} \begin{bmatrix} I_d^* \\ I_q^* \end{bmatrix} \quad (16)$$

where I_d^*, I_q^* is inverter currents, Vffd, Vffq is feed forward voltage, R resistance, V_g magnitude of grid voltage.

B. Frequency Control:

The power system frequency through the modulation of both, the reactive component of the output current i_q, and the active component i_d. In the case of controlling i_q the set point of the voltage controller module. The voltage reference signal V_r is varied with a stabilizer voltage signal proportional to Δf which directly represents the power oscillation of the power system.

The power oscillation damping approach of the standard STATCOM is rather effective the most effective compensation action for power factor oscillations damping and thus for power factor correction is carried out by exchanging active with the activity system, that is to say by controlling the out- put direct current of the STATCOM id.

The frequency of the wind turbines is very stable in comparison to the wind turbines diesel operating mode. The aver- age value of the fundamental frequency measured over 0.21 seconds in distribution systems, with no synchronous connection to an interconnected system, is to be within the range of
49.7 Hz to 50.3 Hz (50 Hz ± 0.6 %) for 100 % time of the week or 42.5 Hz to 57.5 Hz (50 Hz ± 15 %) for 100 % time of the week.

VI. Simulation and Results

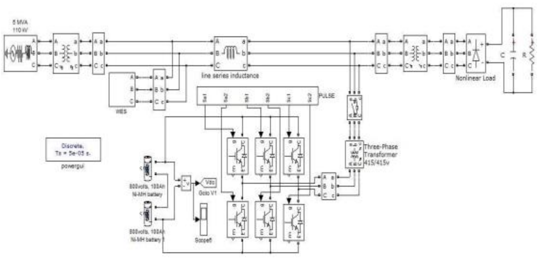
A. System Performance:

The Simulink model library includes the model of Conventional Source, Asynchronous Generator, STATCOM, Non- Linear Load, Inverter, Grid Voltage, Battery, Line Series In- ductance and others that has been constructed for simulation. The simulation parameter values for the given system are given in Table 1. In that system Turbine values are 275kW Single Unit Generating output Power is implemented. The implemented Real Time values are given Table 2.

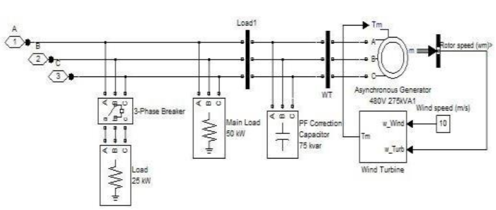
Table 1. System Parameters

S.No.	Parameters	Ratings
1.	Grid Voltage	3-phase, 415V, 50Hz
2.	Asynchronous generator	275kVA, 415V, P = 4, Rs = 0.01 , Rr = 0.015 , Ls = 0.06H, Lr = 0.06H
3.	Three phase source	110kVA, 50Hz
4.	Line series inductance	0.05mH
5.	Inverter para- meters	DC link Voltage = 800V, DC link Capacitance = 100μF, Switching fre- quency = 2kHz
6.	IGBT Rating	Collector Voltage = 1200V, Forward Current = 50A, Gate Voltage = 20V
7.	Load Parame- ter	Non-linear Load = 25kW
8.	Battery	800V, 50A

B .Overall Simulation:



The system having one conventional source, wind turbine generating system, STATCOM with Two Battery Energy Sto-rage System, IGBT pulse control subsystem and Non-linear Diode with capacitive, resistive load. The power factor correction capacitor is connected with wind generation system shown in Figure 4. The capacitor connected to asynchronous generator provides reactive power compensation. A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy; a process known as wind power. If the mechanical energy is used to produce electricity, the de- vice may be called wind turbine or wind power plant. The result of a millennium windmill development is now modern engineering. The smallest turbines are used for applications such as battery charging is shown in Figure 5. While large grid-connected arrays of turbines are becoming an increasingly important source of wind power-produced commercial elec- tricity.



Wind Energy Generating System

Figure 7. STATCOM Voltage and Current Ia, Ib, Ic

B. Results:

The effectiveness of the proposed method is demonstrated through simulation result of grid voltage and current shown in Figure 6. This is due to the reference derived from the grid voltage.

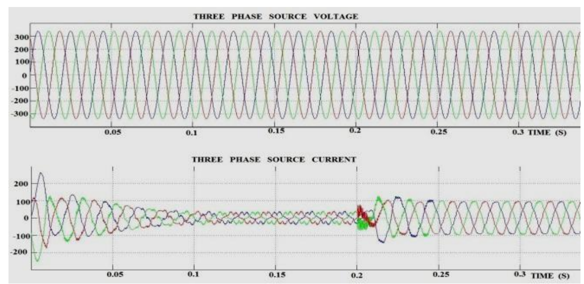
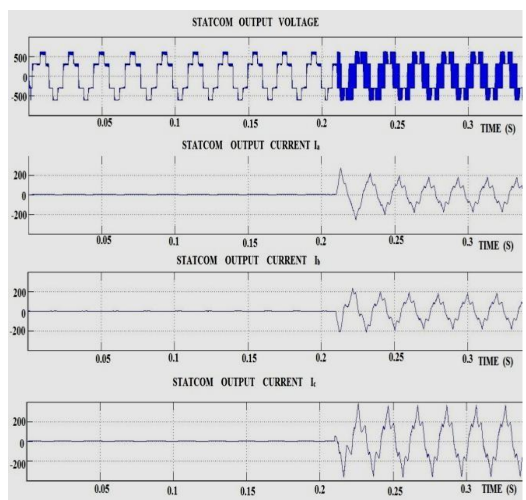


Figure 6. Grid Voltage and Current

The voltage and current waveform Ia, Ib, Ic for before 0.21s and after 0.21s of the STATCOM operation is analyzed. The inverter output voltage under STATCOM operation



The source current is maintained in phase with the source voltage indicating the 0.89 power factor at point of common coupling and satisfies power quality norm. The result of in-phase source current and source voltage are shown in Figure 8.This is due to the reference derived from the grid voltage. The dynamic load does affect the inverter output voltage.

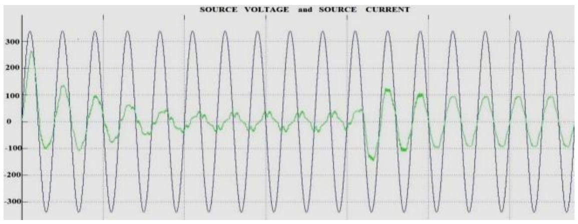


Figure Power Factor

The source current on the grid is affected due to the effect of non-linear load and wind generator, this purity of wave form is lost on both sides in the system. The dynamic performance is also carried out by step change in a load, when applied at 0.21s. The load current is shown in Figure 9.

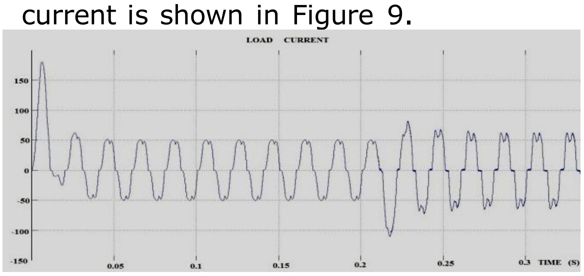


Figure 9. Load Current

Load voltage regulation is defined by the drop in voltage when going from a no load to full load condition on a power source. In more practical terms, it is often measured when going from a typical steady state load to a maximum load condition, realized under normal operating conditions. Load voltage regulation is used to evaluate the performance of an isolation transformer and distribution system under heavy step load changes. Load voltage regulation is critical before 0.21s and after the 0.21s voltage regulation" is the stand-by mode of operation is shown in Figure 10

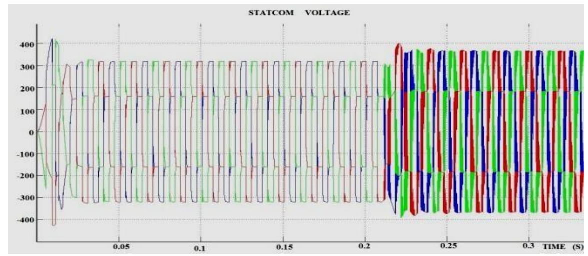


Figure 10. Load Voltage

The Fourier analysis of this waveform is expressed; the THD has been improved with in the standard level. The result of THD 0.10% is shown in Figure 11.

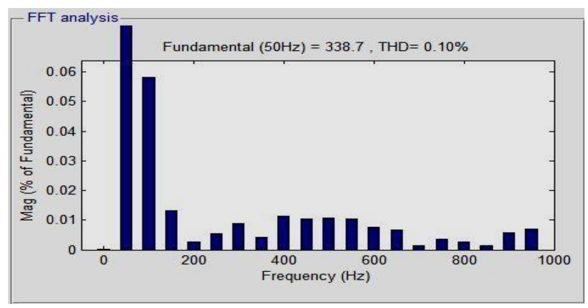


Figure 11. FFT Analysis

VII. Conclusion

In this work, to improve the power quality in grid connected wind generating system STATCOM based control scheme is proposed. The operation of the control system developed for the STATCOM-two battery energy storage system in MATLAB/SIMULINK for maintaining the power quality is simulated for 275kW capacity of wind turbine. It has a capability to cancel out the sag and swell of load voltage. It maintains the source voltage and current in-phase and supply reactive power for the wind generation during demand and STATCOM with two battery energy storage systems have shown the outstanding performance and improved the power factor to 0.89.

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