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EFFECTIVE INTEGRATION OF WIND GENERATING STATION TO POWER GRID WITH STATCOM

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Abstract

The causes of power quality problems are generally complex and difficult to detect when we integrate a wind turbine to the grid. Technically speaking, the ideal AC line supply by the utility system should be a pure sine wave of fundamental frequency (50 Hz in India). We can therefore conclude that the lack of quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. It is therefore imperative that a high standard of power quality is maintained. This paper demonstrates that the power electronic based power conditioning using custom power devices like STATCOM can be effectively utilized to improve the quality of power supplied to the customers. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. The influence of the wind turbine in the grid system concerning the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behaviour of switching operation and these are measured according to national/international guidelines. The paper study demonstrates the power quality problem solution due to installation of wind turbine with the grid. This paper is extension for the power quality improvement with THD reduction. THD is reduced to 3.91% from 11.2%.

Index Terms: *Statcom, bang controller, thd, bess.*

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1. INTRODUCTION:

Non renewable energy sources are exhausting in near future. So for the sustainable growth and social progress of an country, it is necessary that energy demand is meet by utility of renewable energy sources like wind, biomass, sun etc. the renewable sources are inexhaustible and therefore we can readily access to have the supply of energy from the renewable sources. The various advantages of renewable energy sources are as follows:

• The sun, wind, geothermal, ocean energy are available in the abundant quantity and free to use.
• The non-renewable sources of energy that we are using are limited and are bound to expire one day.
• Renewable sources have low carbon emissions, therefore they are considered as green & environment friendly.
• Renewable helps in stimulating the economy and creating job opportunities. The money that is used to build these plants can provide jobs to thousands to lakhs of people.
• You don't have to rely on any third country for the supply of renewable sources as in case of non-renewable sources.
• Renewable sources can cost less than consuming the local electrical supply. In the long run, the prices of electricity are expected to soar since they are based on the prices of crude oil, so renewable sources can cut your electricity bills.

The voltage of wind power generating station generally fluctuates due to nature of wind. When wind power generating station is integrated to the power grid power quality issues arises like injection of harmonics, poor power factor and distortion from pure sine wave of fundamental frequency. In this proposed scheme, to minimize the power quality problems at the common coupling point of the power grid, STATCOM with battery energy system storage is connected. The STATCOM relieves the load and main supply source from the reactive power demand. The proposed scheme is simulated in MATLAB/SIMULINK power lib. The proposed scheme has not only the effectiveness of relieving reactive power demand but also maintains unity power factor at the source side and has faster response of STATCOM by bang - bang controller as well as harmonics distortion reduction.

A. Guidelines of international electro technical commission

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 [8].
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 behaviour.

B. Voltage regulation

The voltage regulation 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. o 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.

C. Generation of 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.

D. 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.

E. 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 [4].

F. Consequences of the Issues

The voltage variation, flicker, harmonics causes the malfunction of equipments 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 equipments like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipments. Thus it degrades the power quality in the grid.

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3. GRID COORDINATION RULE

The American Wind Energy Association (AWEA) led the effort in the united state for adoption of the grid code for the interconnection of the wind plants to the utility system. 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.

1) Voltage Rise

The voltage rise (u) 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 θ [2], given in as follows.

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

Where Δu is voltage rise, U is the nominal Voltage of the grid. The Limiting voltage rise value is less than 2%

2) Voltage Dips

The voltage dips is due to start up 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 equation as follows.

$$d = K_u \frac{S_n}{S_K} \quad \text{-------- (2)}$$

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 less than or equal to 3%.

3) 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 equation as follows

$$V_{\text{THD}} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1} 100} \quad \text{-------- (3)}$$

Where V_n is the n^{th} harmonic voltage V_1 is the fundamental frequency voltage. The THD limit for 132 kV is less than 3%. The current THD can also be estimated similarly and the limit for 132 kV is less than 5%.

4) 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 0.5Hz/s

4. POWER QUALITY IMPROVEMENT CONCERN

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 below.

$$P_{\text{wind}} = \frac{1}{2}\rho A V_{\text{wind}}^3 \quad \text{------- (4)}$$

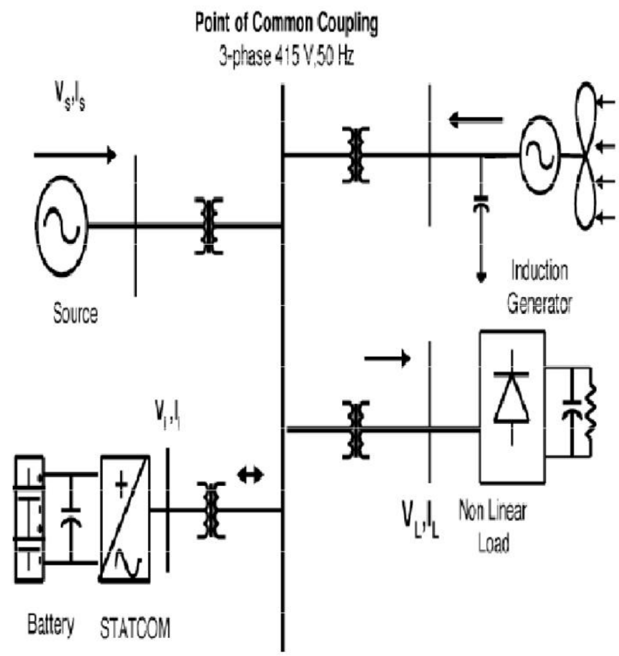

Figure.1 Grid connected System for Power Quality Improvement

Where ρ (kg/m) is the air density and A (m) is the area swept out by turbine blade, V is the wind speed in mtr/s.

The amount of air passing through an area A, with a velocity V, is AV, and its mass 'm' is equal to the product of volume and density 'ρ' of air, then

m = rAV ------ (5)

Substituting this value of mass in the kinetic energy equation,

Kinetic energy = ½ .ρ AV .V^2 =½ ρ AV^3 ------ (6)

This equation tells us that as the energy is directly proportional to cube of wind speed, a small increase in wind speed can have a marked effect on the power of the wind.

It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient

Cp of the wind turbine, and is given in equation below.

$$P_{mech} = C_p P_{wind}$$ ------ (7) where

Cp is the power coefficient, depends on type and operating condition of wind turbine.

B. Bess-Statcom

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It also control the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the BESS can be used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of STATCOM [1].

The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling.

C. System Operation

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 STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOM in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operational scheme is shown in Fig. 2.

5. CONTROL SCHEME

The control scheme approach is based on injecting the currents into the grid using "bang-bang controller." The controller uses a hysteresis current controlled technique.

Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation. The control algorithm needs the measurements of several variables such as three-phase source current (i_{Sabc}), DC voltage (V_{dc}), inverter current (i_{iabc}) with the help of sensor. The current control block, receives an input of reference current (i^*_{Sabc}) and actual current (i_{Sabc}) are subtracted [3] so as to activate the operation of STATCOM in current control mode. The control system scheme for generating the switching signals to the STATCOM is shown in Fig.2.

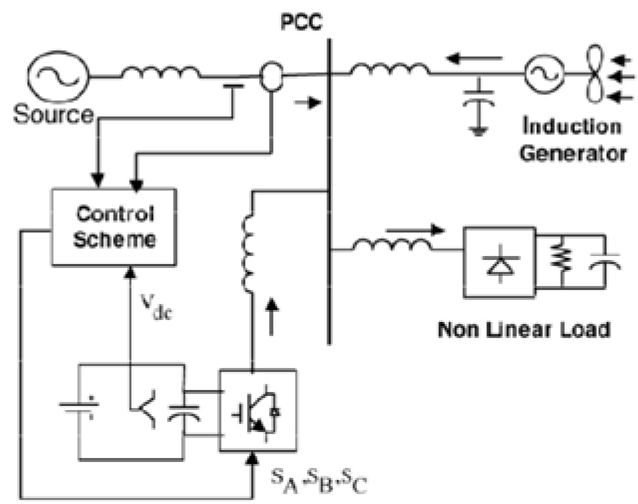

Figure.2 System operation with control scheme

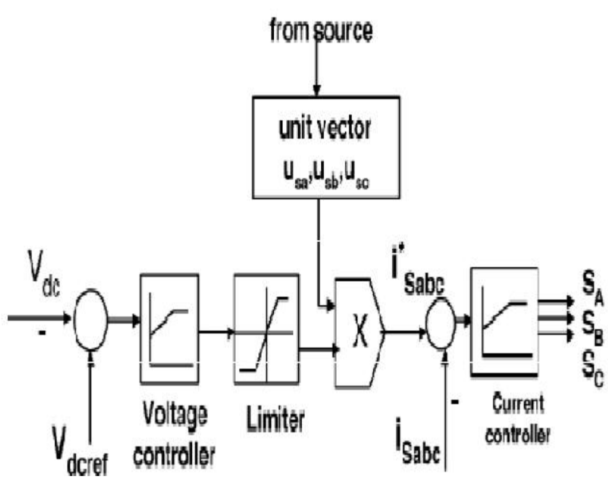

Figure.3 Control Scheme

A. Grid Synchronization

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 *Vsm*, sampled peak voltage, as in equation below

$$V_{sm} = \left\{ \frac{2}{3} \left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2 \right) \right\}^{1/2}$$ ------ (8) The in-phase unit vectors are obtained from AC source---- phase voltage and the RMS value of unit vector as shown in equation below

$$u_{sa} - \frac{V_{Sa}}{V_{sm}}, \quad u_{sb} - \frac{V_{Sb}}{V_{sm}}, \quad u_{sc} - \frac{V_{Sc}}{V_{sm}}.$$ ------- (9)

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

$$i_{Sa}^* = I.u_{Sa}, \quad i_{Sb}^* = I.u_{Sb}, \quad i_{Sc}^* = I.u_{Sc}$$ ------ (10)

where I is proportional to 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 synchronization for STATCOM [5].

Table. 1
System Parameters

S.No	Parameters	Rating
1.	Grid Voltage	3-phase 415 V, 50 Hz
.	Induction Machine	1.5 kVA, 415V, 50 Hz, P=4, L_s= 0.12, L_r = 0.19,
3.	Line Series Inductance	0.05 mH
4.	Inverter Parameters	DC Link Voltage: 800V DC Link Capacitance: 100µF Switching Frequency: 2kHz
5.	IGBT ratings	Collector Voltage: 1200V Forward Current: 50A Power Dissipation: 310W

B. Bang-Bang Current Controller

The reference current is generated as in equation below and 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 [6]. The switching function S_A for phase 'a' is expressed as in equation below.

when $i_{Sa} < (i^*_{Sa} - HB)$, $S_A = 0$
when $i_{Sa} > (i^*_{Sb} - HB)$, $S_A = 1$

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

6. 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.

A. Voltage Source Current Control----Inverter Operation

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.

7. RESULTS AND DISCUSSIONS

The wind energy generating system is connected with grid having the nonlinear load. The performance of the system is measured by switching the STATCOM at time0.1s in the system. When STATCOM controller is ON, without change in any other load conditions parameters, it starts to mitigate reactive as well as harmonic current. The dynamic performance can also be carried out by step change in load. Thus STATCOM can regulate the available real power from source. The result of source current, load current and generator current are as shown figure 4.

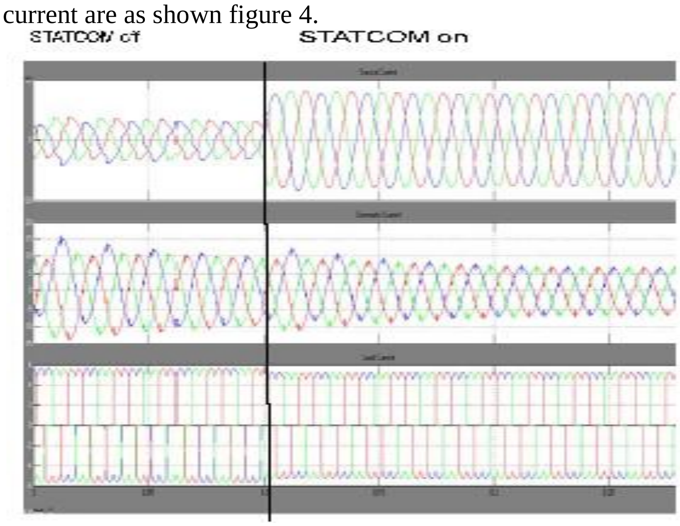

Fig.4 Source, Generator and Load Waveforms with STATCOM on and off

A. Power Quality Improvement:

It is observed that the source current is affected due to the effects of nonlinear load and wind generator, thus purity of waveform may be lost on both sides in the system. The source current with and without STATCOM operation is shown in Fig.5. This shoes that the unity power factor is maintained for the source power when the STATCOM is in operation. The current waveform before and after the STATCOM operation is analyzed. The Fourier analysis of this wave form is expressed and the THD of this source current at PCC without STATCOM is 11.20%, as shown in figure 5.

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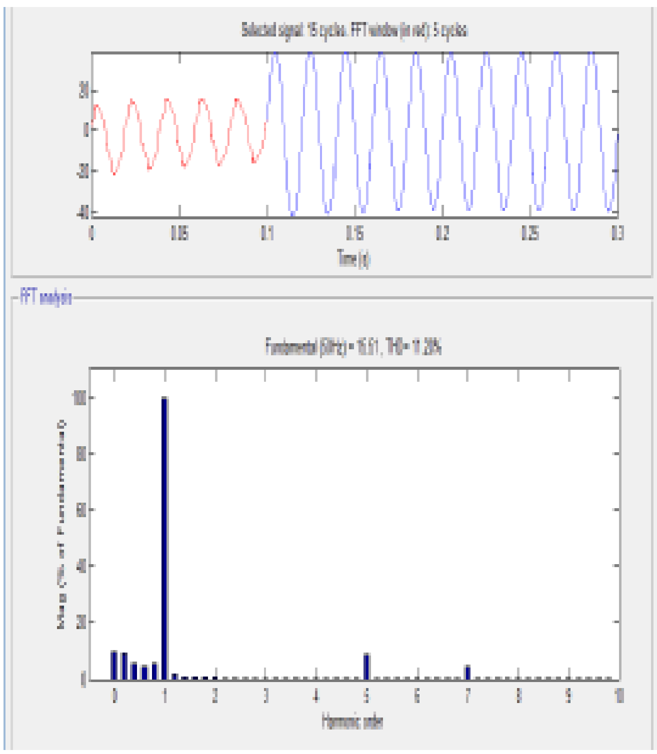

Figure.5 THD analysis of source current with STATCOM off (THD=11.20%)

The power quality improvement is observed at the point of common coupling, when the controller is in ON condition. The STATCOM is placed in operation at 0.1 s and source current waveforms shown in figure 6 with its FFT. It is shown that the THD has been improved to 3.91% and within the norms of standard.

The above tests with proposed scheme has not only power quality improvement feature but also has sustain capability to support the load through the batteries.

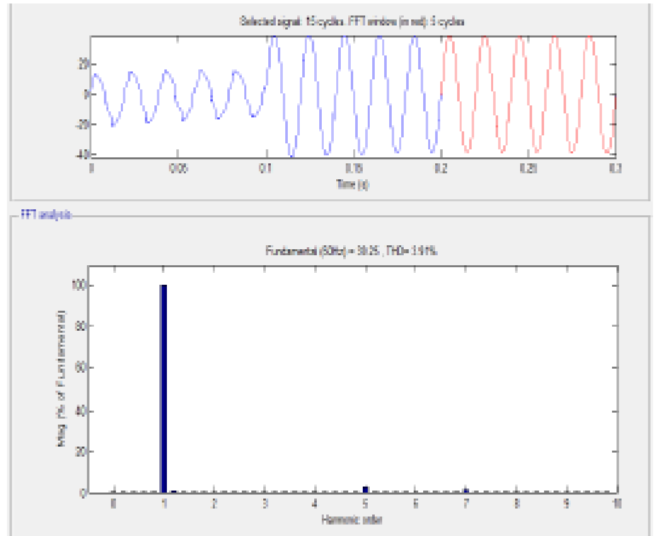

Figure6. THD analysis of source current with STATCOM (3.91%)

8. CONCLUSION

The paper presents the STATCOM-based control scheme for power quality improvement in grid connected wind generating system and with non linear 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-BESS in MATLAB/SIMULINK for maintaining the power quality is 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 STATCOM 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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