Power Quality Improvement of Grid Connected Wind Energy System by PI & Fuzzy Based STATCOM Controller

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ABSTRACT

This paper discuses about the improvement of grid power quality with aid FACTS devices on integration of wind energy system. The generated power from renewable energy source is always fluctuating due to the environmental conditions. Here renewable energy source consider is wind energy, which when connected to an electric grid affects the power quality. On the basis of measurement and norms followed according to the guidelines specified in IEC-61400(International Electro-technical Commission) standard, the performance of the wind turbine and there by power quality are determined. The power quality measurements are the active & reactive power, voltage sag, voltage swell, flickers, harmonics, and electrical behavior of switching operations. In this proposed scheme a STATCOM (Static Synchronous Compensator) is connected at a Point Of Common Coupling (PCC) with battery energy storage system (BESS) to mitigate the power quality problems is simulated using MATLAB/SIMULINK in SimPowerSystem block set. Fuzzy based controller is designed to improve the profile of source current in STATCOM. The intended result of proposed scheme relives the main supply source from the reactive power demand of the load and the induction generator, and the reduction in the THD (Total Harmonic Distortion) in the source current of the system.

Keywords: *FLC (Fuzzy Logic Controller), Power Quality, STATCOM (Static Synchronous Compensator), THD (Total Harmonic Distortion), WPGS (Wind Power Generating System)*

1. INTRODUCTION

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 manage the power level associate 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 from STATCOM to wind Generator and Load.
- Simple bang-bang controller for STATCOM to reduce the total harmonic distortion.

Today in wind turbine generating system pulse controlled inverters are used. Due to the improvement in switching techniques, the voltage and current at the point of common connection can be made more sinusoidal and unity power factor so as to improve the power quality at PCC. 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 along with wind energy generating system is generally required to compensate the fluctuation generated by wind turbine.

This paper is organized as fallows. The Section 2 introduces the power quality standards, concepts of Wind Energy generating System(WEGS) and its consequences on power quality issues. The Section 3 describes the topology for power quality improvement. The Sections 4, 5 describes the control scheme, simulation model of the conventional system and conclusion respectively.

2. POWER QUALITY IMPROVEMENT

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. 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.

2.1 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 [1].

2.2 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 [1].

2.3 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.

2.4 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.

2.5 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.

3. 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.1The grid connected system in Fig. 1(Simulation of this complete system as shown in fig.6) consists of wind energy generation system and battery energy storage system with STATCOM [1].

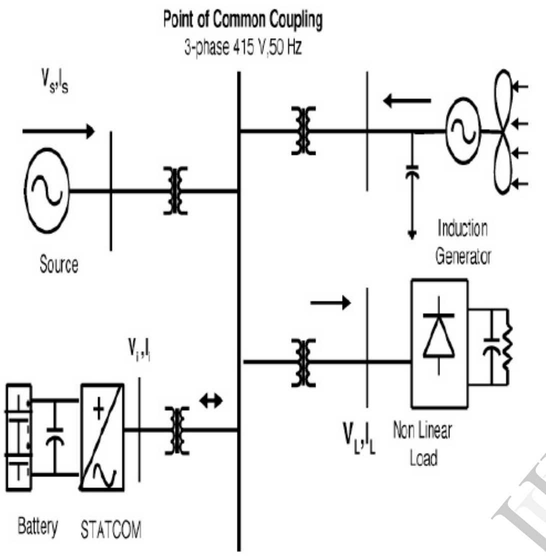

Fig. 1. Grid Connected System For Power Quality Improvement

3.1 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.1. [1]

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^{3} \tag{1}$$

Where 'ρ' (kg/m) is the air density,
A is the area swept out by turbine blade in m^2,
V_{wind} is the wind speed in m/s.

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 Eq.2:

$$P_{mech} = C_p P_{wind} \tag{2}$$

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. 3:

$$P_{mech} = \frac{1}{2}\rho \Pi R^2 V_{wind}^3 C_p \tag{3}$$

Where 'R' is the radius of the blade in meters.

3.2 STATCOM (Static Synchronous Compensator)

The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability of power grid. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM injects reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive).This function is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V_2 from a DC voltage source. The principle of operation of the STATCOM is explained on the figure below showing the active and reactive power transfer between a source V_1 and a source V_2. In Figure 2, V_1 represents the system voltage to be controlled and V_2 is the voltage generated by the VSC.

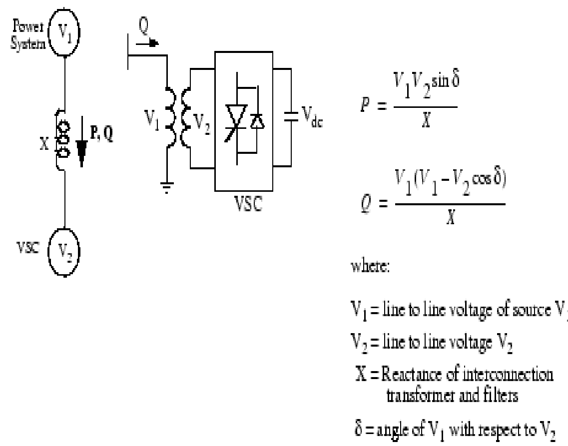

Fig. 2. Operating Principle of STATCOM

In steady state operation, the voltage V_2 generated by the VSC is in phase with V_1 (δ=0), Then active power becomes zero and only reactive power flow is observed (P=0). If $V_2<V_1$, Q is flowing from V_1 to V_2 (STATCOM is absorbing reactive power). On the other hand, if $V_2 > V_1$, Q is flowing from V_2 to V_1 (STATCOM is generating reactive power). A capacitor connected on the DC side of the VSC acts as a DC voltage source. In steady state the voltage V_2 has to be phase shifted slightly behind V_1 in order to compensate for transformer and VSC losses and to keep the capacitor charged [8].

4. 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 system scheme for generating the switching signals to the STATCOM is shown in Fig. 3. 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_{abc} are subtracted so as to activate the operation of STATCOM in current control mode. 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 template $V_{sm,}$ sampled peak voltage, as in (4).

$$V_{\rm sm} = \left\{ \frac{2}{3} \left(V_{\rm sa}^2 + V_{\rm sb}^2 + V_{\rm sc}^2 \right) \right\}^{1/2}. \quad (4)$$

The in-phase unit vectors are obtained from AC source—phase voltage and the RMS value of unit vector U_{sa}, U_{sb}, U_{sc} as shown in (5).

$$u_{\rm sa} = \frac{V_{\rm Sa}}{V_{\rm sm}}, \quad u_{\rm sb} = \frac{V_{\rm Sb}}{V_{\rm sm}}, \quad u_{\rm sc} = \frac{V_{\rm Sc}}{V_{\rm sm}}. \quad (5)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as, in (6)

$$i^*_{\rm Sa} = I.u_{\rm Sa}, \quad i^*_{\rm Sb} = I.u_{\rm Sb}, \quad i^*_{\rm Sc} = I.u_{\rm Sc} \quad (6)$$

Where 'I' is the 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. This method is simple, robust and favorable as compared with other methods [3][6].

Bang-Bang Current Controller

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated as in (6) 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 [4][1].The switching function S_a for phase 'a' is expressed as (7)[6].

$$\begin{aligned} i_{\rm sa} &< (i^*_{\rm sa} - HB) \rightarrow S_A = 0 \\ i_{\rm sa} &> (i^*_{\rm sa} - HB) \rightarrow S_A = 1 \end{aligned} \quad (7)$$

Where HB is a hysteresis current-band, similarly the switching function S_b, S_c can be derived for phases "b" and "c".

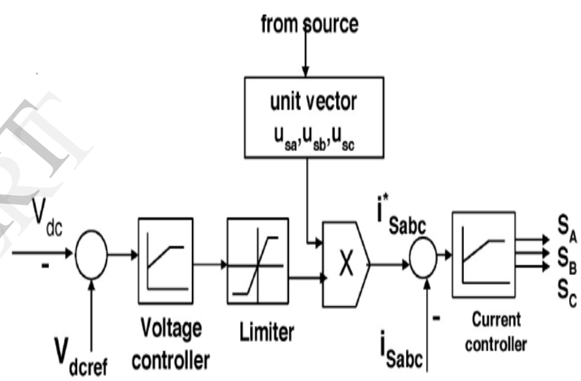

Fig. 3. Control System Scheme

(a) Using PI Voltage Regulator

The STATCOM control block diagram is shown in Fig. 4. The voltage regulator is of proportional plus integral type.

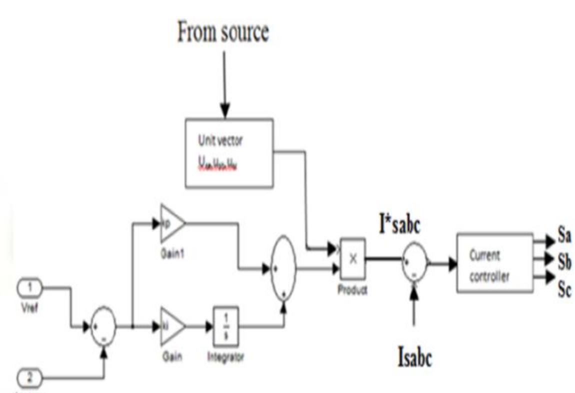

Fig. 4 STATCOM model with PI – Voltage Regulator block diagram

(b) Using FLC Voltage Regulator

FLC voltage regulator is fed with two inputs one of them is voltage error ($V_{ref\ or}$ V) and another one is change in voltage error (Vdc or ΔE). This gives the appropriate Reactive source current (Is), which is required to the system to improve the function of control system. It is shown below in Fig. 5.

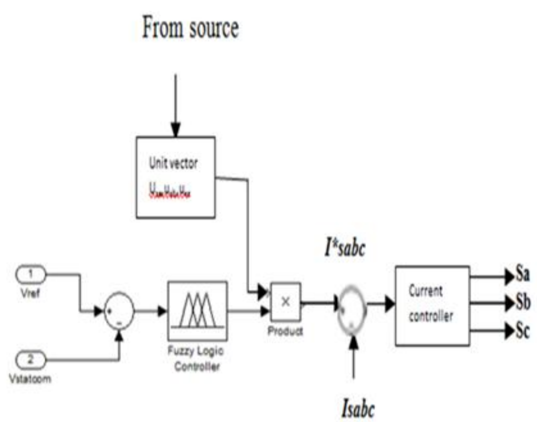

Fig. 5 STATCOM model with FLC- Voltage Regulator block diagram

5. SIMULATION MODEL OF THE CONVENTIONAL SYSTEM

Fig.6 shows the complete MATLAB model of STATCOM along with control circuit. The power circuit as well as control system are modeled using Power System Block set and Simulink.

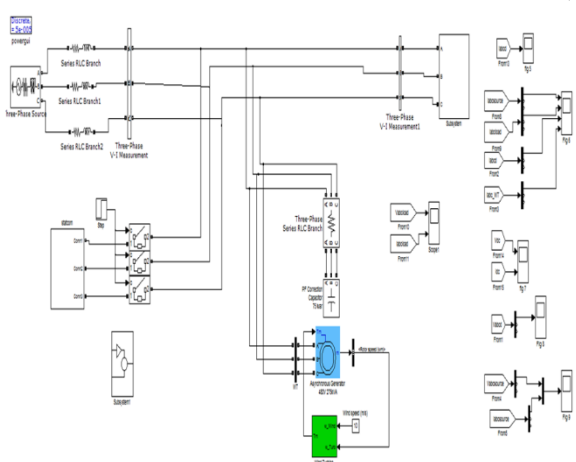

Fig. 6. Matlab/Simulink Model

The grid source is represented by three- phase AC source. A STATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. The bang-bang 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. In subsystem of the measurement having the control algorithm and generating the switching signals to the STATCOM by using measurement of several variables such as DC voltage, source current, inverter current with the help of sensors. The hysteresis current control block receives an input of reference current and actual current are subtracted then activate the operation of STATCOM by the given pulses. When the pulses are given to the converter it's automatically control the SATCOM current to maintain supply current in hysteresis band around the desired reference current values. Here the load is non-linear, In that two load resistors connected in parallel through uncontrolled (diode) rectifier. The resistor R_1 is always connected to the system another one R_2 is adding after some time by the given step value. Provision is made to connect the loads in parallel, So that the effect of sudden load addition and removal is studied.

A. PI Control

The integral term in a PI controller causes the steady state error to zero. The Proportional Integral (PI) algorithm computes and transmits a controller output signal every sample time to the final control element. The gains of PI controller can be selected by trial and error method. It performs lack of derivative action may make the system steadier in the steady state in the case of noisy data. PI controller have two tuning parameters to adjust parameters and integral action enables PI controller to eliminate offset, a major weakness of a P-only controller.

B. Fuzzy Control

Fuzzy logic controller manages to offer a very satisfactory performance, without the need of a detailed mathematical model of the system, just by incorporating the expert‘s knowledge into fuzzy rules. In addition, it has inherent abilities to deal with imprecise or noisy data thus, it is able to extend its control capability even to those operating conditions where linear control techniques fail. FLC voltage regulator is fed by one input that is voltage error (V) and another one is change in error (ΔE). The rules for the proposed FLC voltage controller are given table 1 shown below [7].

Table.1 Fuzzy Control Rule Base

ΔE / V	**LN**	**MN**	**SN**	**ZE**	**SP**	**MP**	**LP**
LN	LP	LP	LP	MP	MP	SP	ZE
MN	LP	MP	MP	MP	SP	ZE	SN
SN	LP	MP	SP	SP	ZE	SN	MN
ZE	MP	MP	SP	ZE	SN	MN	MN
SP	MP	SP	ZE	SN	SN	MN	MN
MP	SP	ZE	SN	MN	MN	MN	LN
LP	ZE	SN	MN	MN	LN	LN	LN

This paper focuses on fuzzy logic control based on mamdani's system. This system has four main parts. First, using input membership functions, inputs are fuzzified, then based on rule bases and inference system, outputs are produced and finally the fuzzy outputs are defuzzified and applied to the main control system. Error of inputs from is chosen as input. To avoid miscalculations due to fluctuations in wind speed and the effects of noise on data, triangular membership functions are chosen to have smooth and constant region in the main points.

5.1 SIMULATION RESULT

The wind energy generating system is connected with grid having the nonlinear load. It is observed that the source current on the grid 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 three phase injected current into the grid from STATCOM will cancel out the distortion caused by the non-linear load and wind generator.

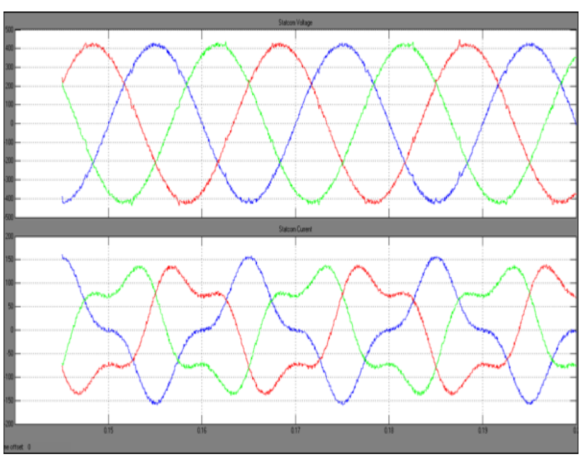

Fig. 7. Inverter Output Waveform with PI Controller

Fig. 7 shows the inverter output waveform of the test system with PI controller and the Fig. 8 shows the corresponding FFT analysis waveform. From FFT analysis, it is observed that the Total Harmonic Distortion (THD) of the inverter voltage waveform of the test system with PI controller is 2.33%.

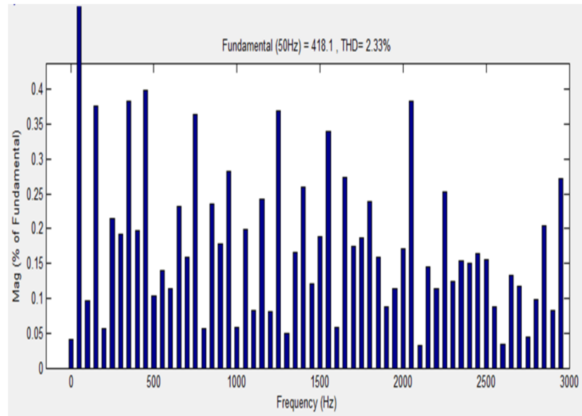

Fig. 8. FFT Analysis of inverter Voltage waveform with PI Controller

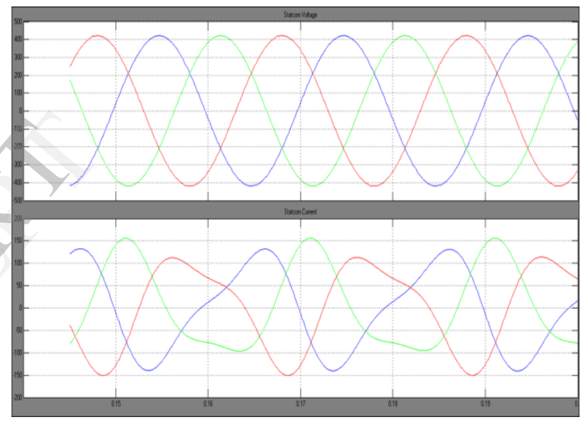

Fig. 9. Inverter output Waveform with Fuzzy Controller

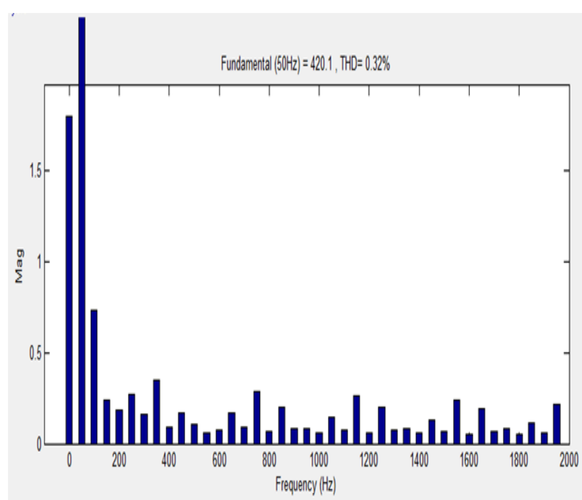

Fig. 10 FFT Analysis of inverter voltage waveform with Fuzzy Controller

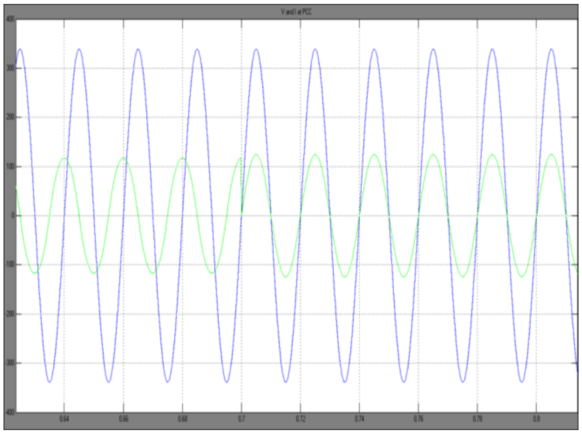

Fig. 11 Supply voltage and current at PCC

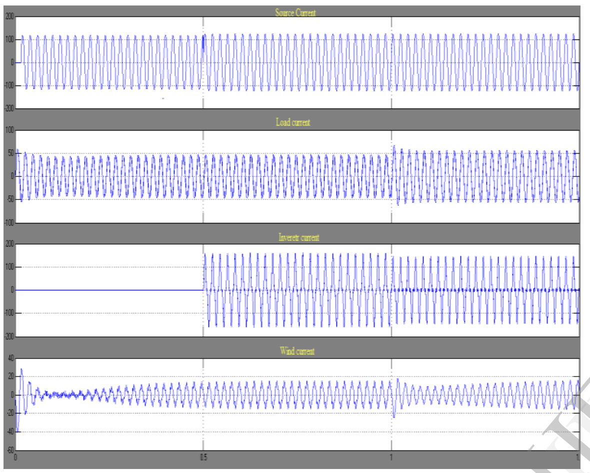

Fig.12 Currents at Sourec, Load, Inverter, Wind

Fig. 9 shows the inverter output waveform of the test system with fuzzy controller based STATCOM and the Fig. 10 shows the corresponding FFT analysis waveform. From FFT analysis, it is observed that the THD of the inverter voltage waveform of the test system with fuzzy controller based STATCOM is 0.32 %. 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 as shown in fig.11, thus it gives an opportunity to enhance the utilization factor of transmission line. The performance of the wind generating system when connected to grid having non linear load is measured by switching STATCOM at t=0.5sec and how the STATCOM respond when an increase of additional load at 1.0sec is shown in the simulation. When STATCOM made to ON, then it mitigate the reactive power demand. When additional load is applied, STATCOM compensates the demand required is shown in above Fig.12, it can be observed different types of currents with and without STATCOM.

6. CONCLUSION

In this paper fuzzy logic controller based STATCOM is presented for grid connected Wind Energy Generating System. The proposed FLC based STATCOM have improved the power quality of system significantly by reducing the THD from 2.33% to 0.32 %. It is clearly presented that STATCOM with FLC gives better performance than STATCOM with conventional PI controller. It has a capability to cancel out the harmonic parts of the inverter 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 maintain the unity power factor. The effectiveness of the proposed scheme relives the main supply source from the reactive power demand of the load and the induction generator. The development of the grid co-ordination rule and the scheme for improvement in power quality norms as per IEC-standard on the grid has been presented. The integrated wind generation and STATCOM with BESS have shown the outstanding performance.

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[8] MATLAB software designed by MATLAB team in the version of *7.8.0.347(R2011b)* and online documents in the website www.mathwork.in .