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Power Quality Enhancement of Grid Connected Wind Energy System Using Static Synchronous Compensator

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ABSTRACT

Due to increased power demand and environmental concern, wind power generation is rapidly growing and wind plants are being integrated to power networks worldwide in large numbers. Injection of wind power into a utility grid results in violation of power quality due to the fluctuating nature of the wind. According to IEC standard, determination of power quality is from the performance of wind generators. In this work power quality issues such as voltage variations, flickers, harmonics are demonstrated due to installation of wind turbine with the grid. FACTS devices can be used to overcome these power quality problems. This paper proposes the STATCOM control scheme for grid connected wind energy system for power quality enhancement. The simulation has been done in MATLAB/Simulink block set. It is shown that STATCOM enhances the power quality of power grid consisting induction generator based wind plant..

Keywords - FACTS devices, Power quality issues, STATCOM, Wind turbine

1. INTRODUCTION

To have supportable growth and social progress, it is necessary to meet the energy demand by using the renewable energy resources like solar, wind, biomass, hydro, co-generation, etc. in sustainable energy system, energy preservation and the use of renewable source are the vital paradigm. The need to incorporate the renewable energy like wind energy into power system is to make it possible to reduce the environmental impact on conventional power plant. The incorporation of wind energy into existing power system presents a technical challenges and that requires consideration of stability problem, voltage regulation and power quality problems. The power quality is an important consumer focused measure and is significantly affected by the operation of a transmission and distribution network. The issue of power quality is of great significance to the wind turbine [1]. There has been an extensive growth and rapid development in the utilization of wind energy in recent era. The individual generating units can be of large capacity up to 8 MW, feeding into distribution network, mainly with customers connected in close proximity. The main objectives of the paper are to develop a model for STATCOM for the enhancement of power quality in grid connected wind energy generating system. The following objectives are listed for this work.

- Unity Power factor at the grid side (source side).
- Reactive power supply only from STATCOM to wind Generator and nonlinear load.
- Hysteresis current controller for STATCOM to realize fast dynamic response.

2. SYSTEM CONSIDERED FOR STUDY

In this configuration wind generations are based on constant speed topologies with pitch control. The induction generator is used in the proposed scheme because of its easiness, it does not require a separate field circuit for excitation, it can accept constant and variable loads, and it has natural protection against short circuit.

In the fixed-speed wind turbine system operation, all the fluctuation in the wind speed is conveyed as fluctuations in the mechanical torque and electrical power on the grid which leads to large voltage variations. During the normal operation, wind turbine produces continuous output power variations. These power variations are mainly caused by the effect of wind shear, turbulence, and tower-shadow and of control system in the power system. Thus, the network needs to withstand for such fluctuations. The power quality issues can be seen with respect to the generation of wind power, transmission and distribution network, such as harmonics, voltage sag, swells, flickers, etc. However the wind generator presents disturbances into the distribution network. One of the simple methods of operating a wind generating system is to use the induction generator connected directly to the grid system having a non-linear loads as shown in Fig.1. System parameters are tabulated in Table 1.

Table 1 System Parameters of Study System

S.No	Parameters	Ratings
1	Grid Voltage	3-phase,415 V, 50 Hz
2	Induction Generator/Motor	3.35 KVA, 415 V, 50Hz, P=4 Speed=1440rpm, Rs=0.01 Ω Rr=0.015 Ω, Ls=0.06 H, Lr=0.06 H
3	Line series inductance	0.05 mH
4	Load parameters	Non-linear load=25kW

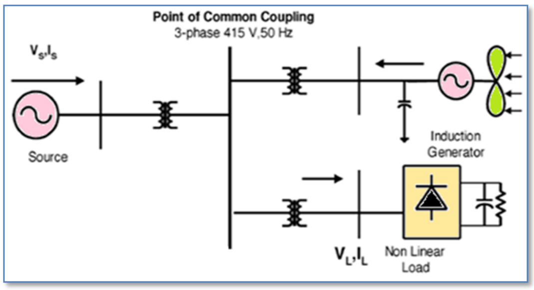

Fig.1 Grid Connected Wind Energy System

The induction generator has essential advantages of cost effectiveness and robustness. However; for magnetization, induction generators absorbs reactive power. When the generated active power of an induction generator is varied due to wind variation, absorbed reactive power and terminal voltage of an induction generator can be affected significantly. A proper control method in wind energy generation system is required under normal operating condition to allow the proper control for the active power production.

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 from inverter will cancel out the reactive part and harmonic part of the non-linear 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.2. The grid connected system in Fig.2 consists of wind energy generation system and battery energy storage system with STATCOM.

The proposed operational and control scheme is simulated using SIMULINK in power system block set. The system parameter for given system is given Table 2.

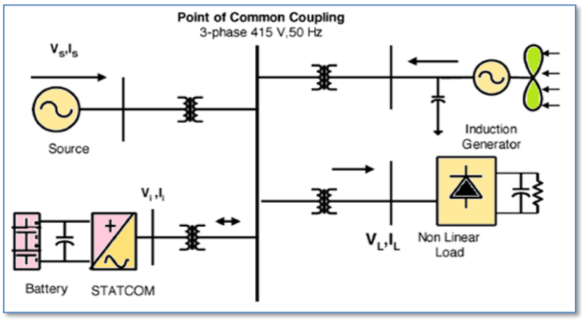

Fig.2 Grid Connected Wind Energy System

Table 2 System Parameters

S.N	Parameters	Ratings
1	Grid Voltage	3-phase,415 V, 50 Hz
2	Induction Generator/Motor	3.35 KVA, 415 V, 50Hz, P=4 Speed=1440 rpm, Rs=0.01 Ω Rr=0.015 Ω, Ls=0.06H, Lr=0.06H
3	Line series inductance	0.05 mH
4	Inverter parameters	DC link voltage=800V DC link capacitance=100μF Switching frequency=2kHz
5	IGBT ratings	Controller voltage=1200V,Forward current=50A Gate voltage=20V,Power dissipation=310 W
6	Load parameters	Non-linear load=25 kW

4. STATCOM (STATIC SYNCHRONOUS COMPENSATOR)

The IEEE definition of a STATCOM [12] is: "A static synchronous generator operated as a shunt connected static Var compensator whose capacitive or inductive output current can be controlled independent of the AC system voltage". Basically STATCOM is a FACTS device which is also known as electronic generator of reactive power. It consists of a VSC, a DC energy storage device (capacitor), and a coupling transformer which connects the VSC in shunt to the power network as shown in Fig.3, SIMULINK model of the STATCOM is shown in Fig.4.

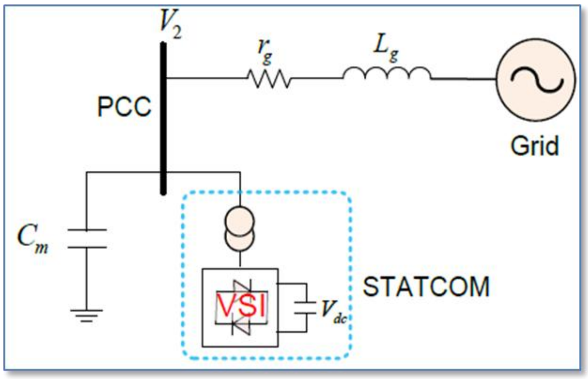

Fig. 3 Single line diagram of the STATCOM connected to power grid

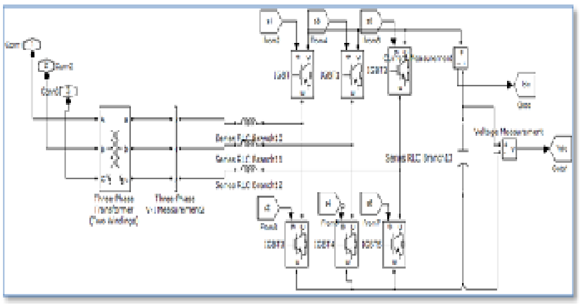

Fig.4 SIMULINK model of the STATCOM

5. 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 compensator 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. 5.

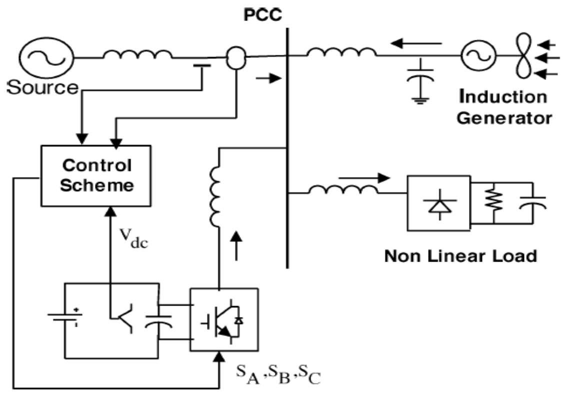

Fig.5 System Operational Scheme

6. 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. 6. The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode

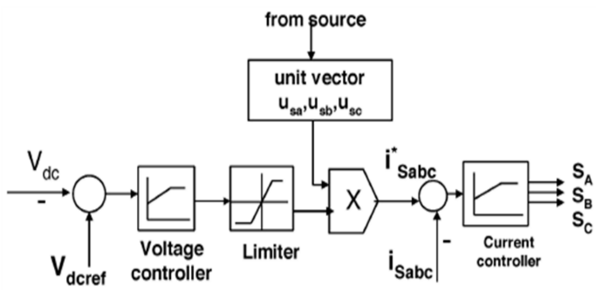

Fig.6 Control system scheme.

6.1 Grid Synchronization

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (Vsabc) and is expressed, as sample template Vsm, sampled peak voltage.

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

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

$$u_{sa} = \frac{V_{sa}}{V_{sm}}, \quad u_{sb} = \frac{V_{sb}}{V_{sm}}, \quad u_{sc} = \frac{V_{sc}}{V_{sm}}$$

The in-phase generated reference currents are derived using in-phase unit voltage template as shown below,

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

6.2 Bang-Bang Current Controller

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated 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 .The switching function 'Sa' for phase 'a' is expressed as below,

$$i_{sa} < (i_{sa}^{*} - HB) \rightarrow S_A = 0$$

$$i_{sa} > (i_{sa}^{*} - HB) \rightarrow S_A = 0$$

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

7. SYSTEM PERFORMANCE

The proposed operational and control scheme is simulated using SIMULINK in power system block set is shown in Fig. 7, Fig.8 respectively. The system parameter for given system is given Table-3.

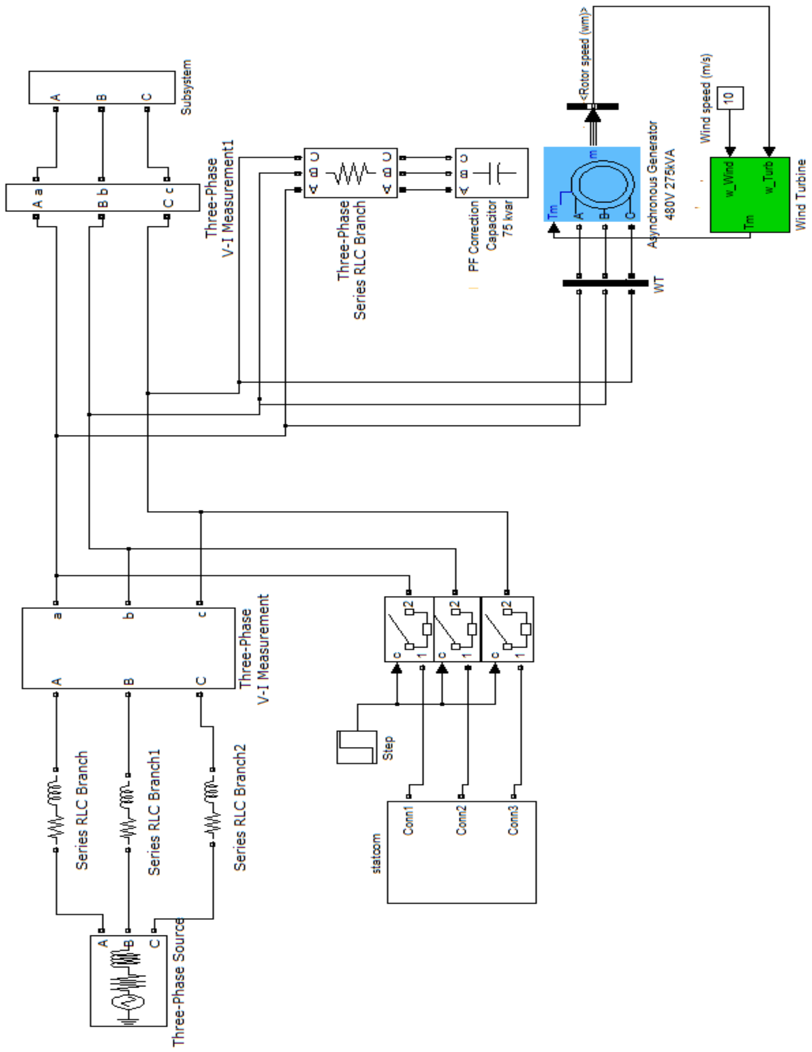

Fig.7 SIMULINK model of the proposed operational scheme.

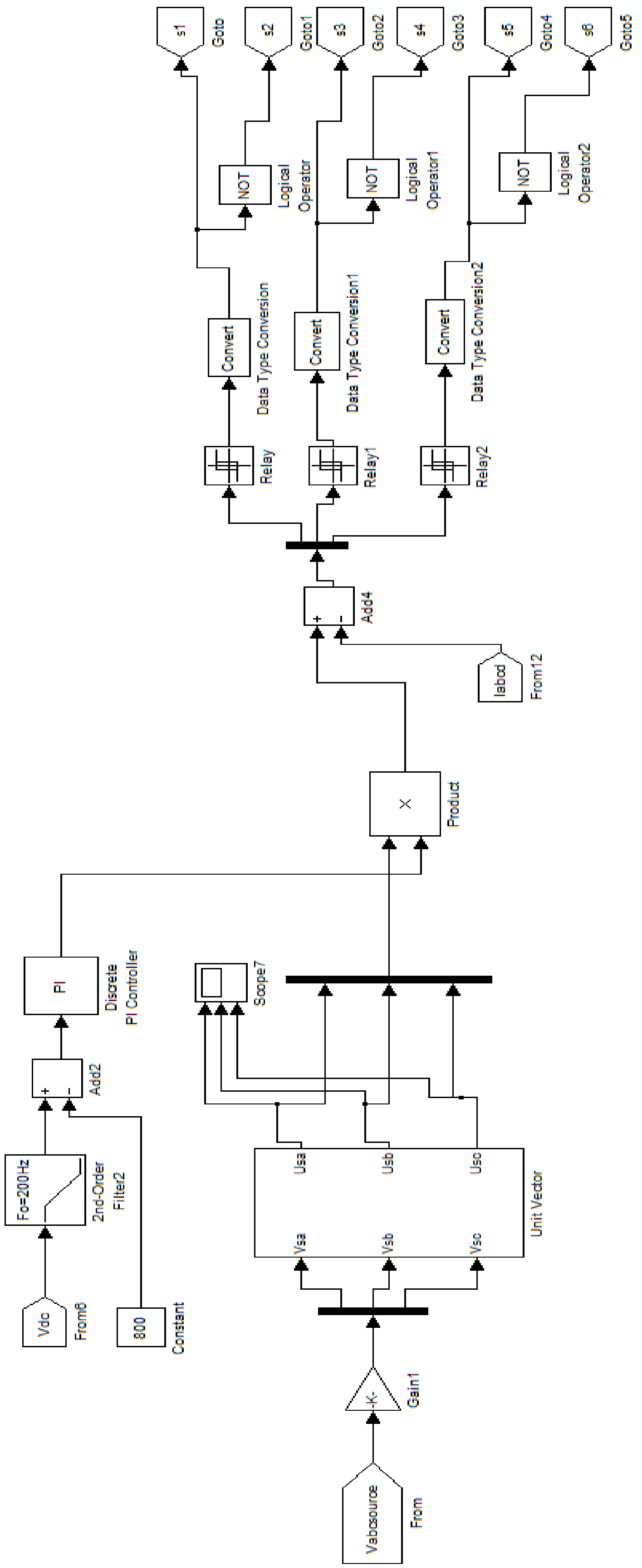

Fig. 8 SIMULINK model of the proposed control scheme.

Table 3 System parameters

S.No	Parameters	Ratings
1	Grid Voltage	3-phase,415 V, 50 Hz
2	Induction Generator/ Motor	3.35 KVA,415 V, 50Hz, P=4 Speed=1440 rpm, Rs=0.01 Ω, Rr=0.015 Ω, Ls=0.06H, Lr=0.06H
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6	Load parameters	Non-linear load=25 kW

7.1 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. The compensated current for the nonlinear load and demanded reactive power is provided by the inverter. The real power transfer from the DC source is also supported by the controller of this inverter. The three phase inverter injected current are shown in Fig 9.

7.2 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 at time s in the system and how the STATCOM responds to the step change command for increase in additional load at 1.0 s is shown in the simulation. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to mitigate for reactive demand as well as harmonic current. The dynamic performance is also carried out by step change in a load, when applied at 1.0 s. This additional demand is fulfil by STATCOM compensator. Thus, STATCOM can regulate the available real power from source. The result of source current, load current are shown in Fig. 10(a) and (b) respectively. While the result of injected current from STATCOM is shown in Fig. 10(c) and the generated current from wind generator at PCC are depicted in Fig. 10(d).

The DC link voltage regulates the source current in the grid system, so the DC link voltage is maintained constant across the capacitor as shown in Fig. 11(a). The current through the dc link capacitor indicating the charging and discharging operation as shown in Fig.11 (b)

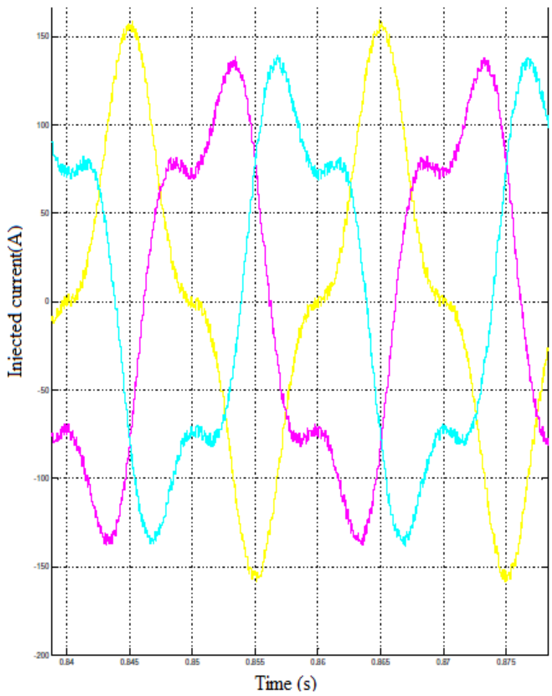

Fig.9 Inverter injected current

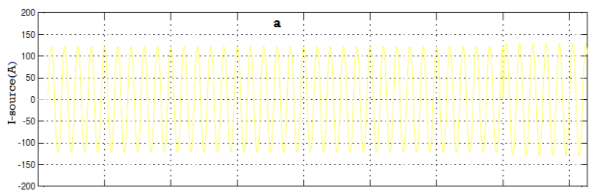

Fig. 10 (a) Source Current.

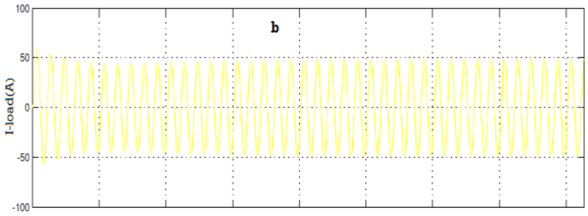

Fig. 10 (b) Load Current.

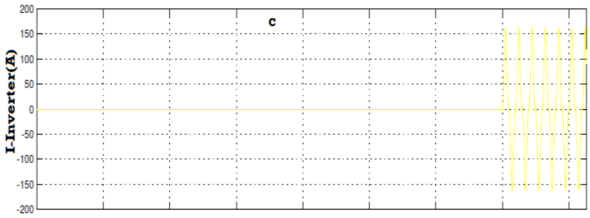

Fig. 10 (c) Inverter Injected Current.

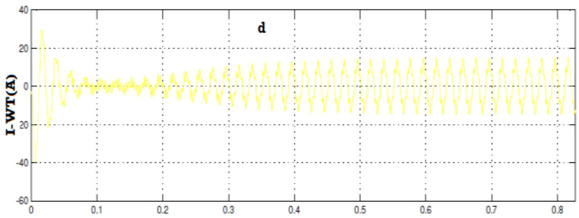

Fig. 10 (d) Wind generator (Induction generator) current.

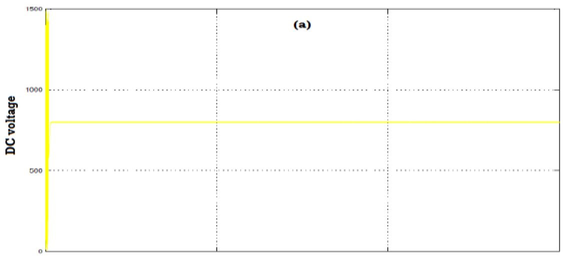

Fig. 11 (a) DC link voltage.

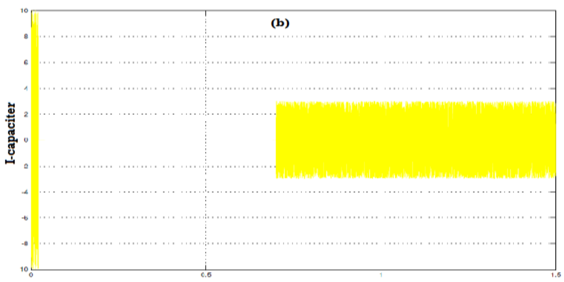

Fig. 11 (b) Current through Capacitor.

7.3 Power Quality Improvement

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 inverter output voltage under STATCOM operation with load variation is shown in Fig. 12. The dynamic load does affect the inverter output voltage. The source current with and without STATCOM operation is shown in Fig. 13. This shows 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 analysed. The Fourier analysis of this waveform is expressed and the THD of this source current at PCC without STATCOM is 4.06%, as shown in Fig. 14. The power quality improvement is observed at point of common coupling, when the controller is in ON condition. The STATCOM is placed in the operation at 0.7 s and source current waveform is shown in Fig. 15 with its FFT. It is shown that the THD has been improved considerably and within the norms of the standard.

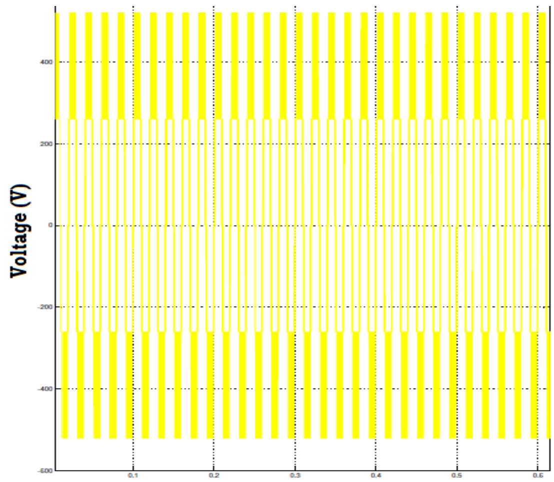

Fig. 12 STATCOM output voltage.

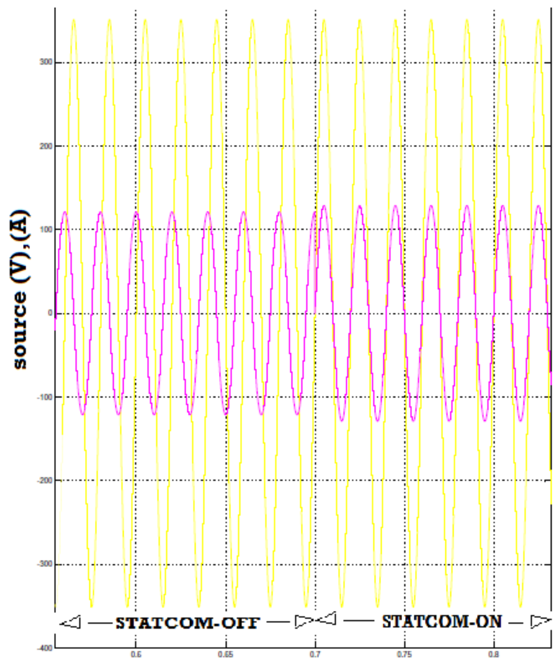

Fig. 13 Supply Voltage and Current at PCC.

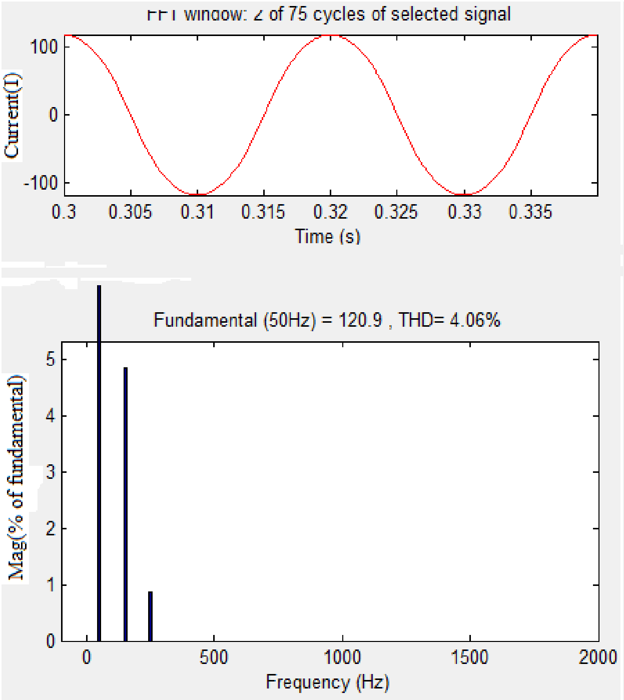

Fig.14 (a) Source current. (b) FFT of source current

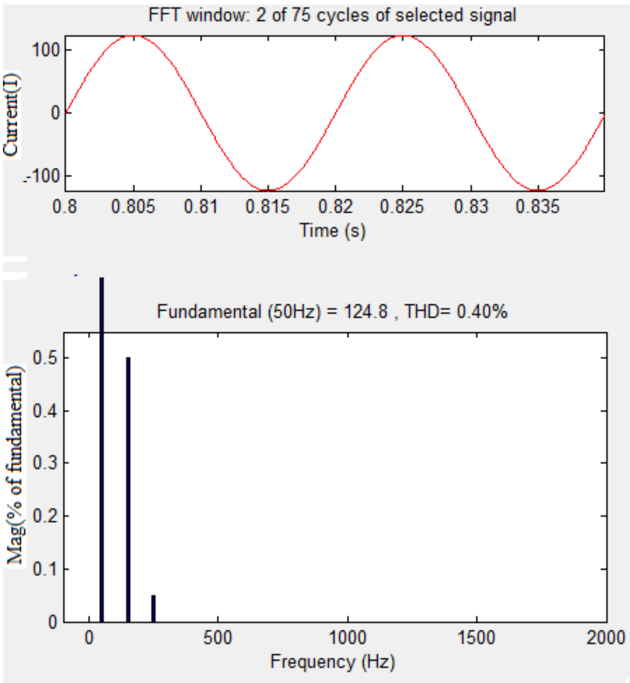

Fig.15 (a) Source current. (b) FFT of source current

8. CONCLUSION

This paper presents the STATCOM-based hysteresis control scheme for power quality enhancement in grid connected fixed speed wind generating system having non- linear load in the point of common coupling(PCC). The power quality issues and its significances on the consumer and electric utility are presented in this study. The operation of the control system developed for the STATCOM in MATLAB/SIMULINK for maintaining the power quality at (PCC) is simulated. Result shows that, it has a capability to cancel out the harmonic parts of the load current. Proposed control system maintains the source voltage and current in-phase and support the reactive power demand for the wind generator and non-linear load at PCC in the grid system. also, it gives an opportunity to enhance the utilization factor of transmission line.

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