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RESEARCH ARTICLE

FUZZY LOGIC BASED POWER QUALITY IMPROVEMENT OF GRID CONNECTED FACTS DEVICE ON INTEGRATION OF WIND ENERGY SYSTEM

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ABSTRACT

Renewable energy sources, which are expected to be a promising alternative energy source, can bring new challenges when connected to the power grid. Like conventional power plants, wind power plants must provide the power quality required to ensure the stability & reliability of the power system. Increasing amount of wind turbine are connected to electrical power system in order to mitigate the negative environmental consequence of conventional electricity generation. While connecting wind turbine to grid it is important to understand source of disturbance that affect the power quality. In general voltage & frequency must be kept as stable as possible. This stability can be obtained by using FACTS devices. Recently voltage-source or current-source inverter based various FACTS devices have been used for flexible power flow control, secure loading and damping of power system oscillation. The power arising out of the wind turbine when connected to a grid system concerning the power quality measurements, are: active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and electrical behavior of switching operation. Fuzzy Logic has two different meanings. In a narrow sense, Fuzzy Logic is a logical system, which is an extension of multivalve logic. However, in a wider sense Fuzzy Logic is almost synonymous with the theory of Fuzzy sets, a theory which relates to classes of objects with un sharp boundaries in which membership is a matter of degree. In this paper fuzzy logic controller is used for controlling the DC capacitor voltage. Simulations using MATLAB / SIMULINK are carried out to verify the performance of the proposed controller.

INTRODUCTION

To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation, etc. In sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional plant [1]. The integration of wind energy into existing power system presents technical challenges and that requires consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network. The issue of power quality is of great importance to the wind turbine [2]. There has been an extensive growth and quick development in the exploitation of wind energy in recent years. The individual units can be of large capacity up to 2 MW, feeding into distribution network, particularly with customers connected in close proximity [3]. Today, more than 28 000 wind generating turbines are successfully operating all over the world.

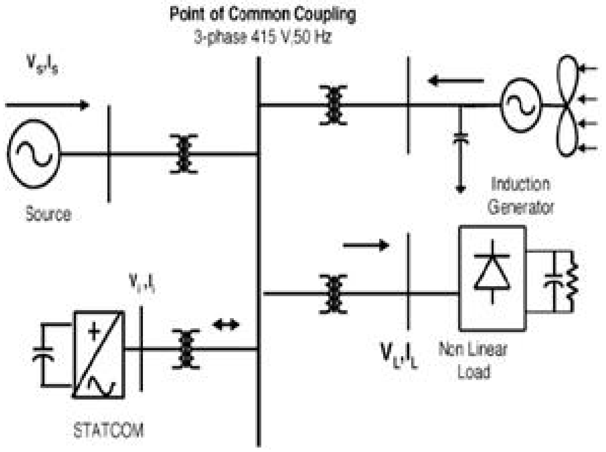

Fig.1 Grid connected system for power quality improvement.

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In the fixed-speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. 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 non-linear load on a power system is typically a rectifier (such as used in a power supply), or some kind of arc discharge device such as a fluorescent lamp, electric welding machine, or arc furnace. Because current in these systems is interrupted by a switching action, the current contains frequency components that are mUltiples of the power system frequency. It changes the shape of the current waveform from a sine wave to some other form and also create harmonic currents in addition to the original (fundamental frequency) AC current. The most used unit to compensate for reactive power in the power systems are either synchronous condensers or shunt capacitors, the latter either with mechanical switches or with thyristor switch, as in Static VAR Compensator (SVC). The disadvantage of using shunt Capacitor is that the reactive power supplied is proportional to the square of the voltage. Consequently, the reactive power supplied from the capacitors decreases rapidly when the voltage decreases [3] .To overcomes the above disadvantages; STATCOM is best suited for reactive power compensation and harmonic reduction. It is based on a controllable voltage source converter (VSC).

Fuzzy logic control theory is a mathematical discipline based on vagueness and uncertainty. It allows one to use non-precise or ill-defined concepts. Fuzzy logic control is also nonlinear and adaptive in nature that gives it robust performance under parameter variation and load disturbances. Many control approaches and applications of fuzzy logic control have appeared in the literature since Mamdani published his experiences using a fuzzy logic controller on a test-bed plant in a laboratory. An extensive introduction to the historical development, current state and concepts involving fuzzy control systems can be found. The fundamental advantage of the fuzzy logic controller over the conventional controller is a less dependence of the mathematical model and system parameters as known widely.

Static Synchronous Compensator (Statcom)

The STATCOM is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM, which is a voltage-source converter which when fed from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor.

A STATCOM based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines. A STATCOM can improve power-system Performance like:

1. The dynamic voltage control in transmission and distribution systems,
2. The power-oscillation damping in power- transmission systems,
3. The transient stability;
4. The voltage flicker control; and
5. The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

A STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both Capacitive and inductive) power.

Wind Driven Induction Generator With Statcom

The STATCOM is a three-phase voltage source inverter having a capacitor connected to its DC link. Fig 2 shows a neutral clamped topology of VSI for STATCOM application.

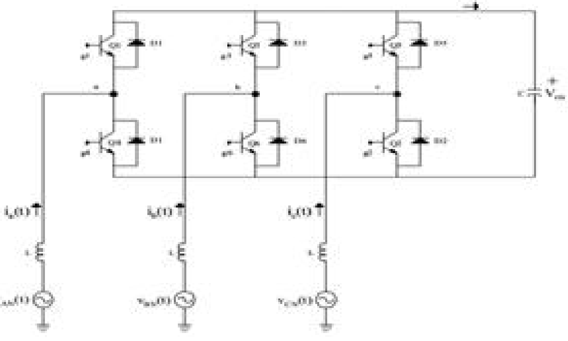

Fig 2 Six Pulse VSI STATCOM

But in the proposed system with STATCOM, reactive power requirement of induction generator and load is supplied by the STATCOM instead of grid. The STATCOM injects a compensating current of variable magnitude and frequency component at the PCC [8]-[10].

The shunt connected ST A TCOM is connected to the PCC through interfacing inductors. The induction generator and load is also connected to the PCC [13]. The STATCOM compensator output is controlled, so as to maintain the power quality norms in the grid system.

Reference Current Generation For Statcom

Reference current for the ST ATCOM is generated based on instantaneous reactive power theory [7]-[l0]. A STATCOM injects the compensation current which is a sum of reactive component current of IG, non-linear load and harmonic component current of non-linear load. Pq theory gives a generalized definition of instantaneous reactive power, which is valid for sinusoidal or non sinusoidal, balanced or unbalanced, three-phase power systems with or without zero sequence currents and/or voltages.

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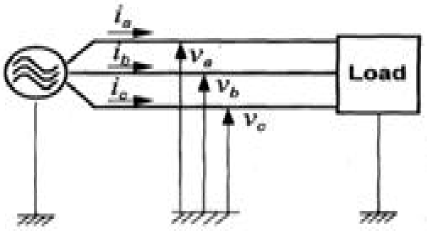


Fig .3 Three phase power system

Fig.3 shows the three phase power system, instantaneous Voltages, va,vb,vc in volts and instantaneous currents, ia, ib, ic in amps of a three phase system are expressed as instantaneous space vectors ' v' and 'i' given by (1)

$$v = \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \qquad i = \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \tag{1}$$

'p' is the instantaneous active power of a three-phase circuitin Watts, given by (2)

P=v. i (2)

Instantaneous active power of a three-phase circuit ' p' is the scalar product of instantaneous voltage and current. It is the product of the sum of three phase voltages and current, given by (3)

P= vaia+vbib+vcic (3)

Instantaneous active power consists of average component and oscillatory component as given by (4)

P = Pdc + Pac (4)

'Pdc' is the average component of instantaneous active power in watts and 'Pac' is the oscillatory component of instantaneousactive power in watts. ' q' is the instantaneous reactive power of a three-phase circuit in VAR, given by (5)

q =IIv x ill (5)

Instantaneous reactive power of a three-phase circuit ' q' is the vector product of instantaneous voltage and current, given by (6)

$$q = \begin{pmatrix} q_a \\ q_b \\ q_c \end{pmatrix} = \begin{pmatrix} \begin{vmatrix} v_b & v_c \\ i_b & i_c \end{vmatrix} \\ \begin{vmatrix} v_c & v_a \\ i_c & i_a \end{vmatrix} \\ \begin{vmatrix} v_a & v_b \\ i_a & i_b \end{vmatrix} \end{pmatrix} \tag{6}$$

Total current is the sum of instantaneous active, reactive and harmonic component of current given by (7)

$$i = i_p + i_q + i_h \tag{7}$$

'ip', 'iq' and 'ih' are of instantaneous active, reactive and harmonic component of current respectively. 'ip' is the instantaneous active component current in amps given by (8)

$$i_p = \frac{P_{dc} \cdot v}{v_a{}^2 + v_b{}^2 + v_c{}^2} \tag{8}$$

Since it is a non linear load reactive component and harmonic component current are used as a reference current for STATCOM. The reference current for the three phases as given by (9),(10),(11).

$$i_{af^*} = i_{ap^*} - i_{as^*} = i_{aq} + i_{ah} \tag{9}$$

$$i_{bf^*} = i_{bp^*} - i_{bs^*} = i_{bq} + i_{bh} \tag{10}$$

$$i_{cf^*} = i_{cp^*} - i_{cs^*} = i_{cq} + i_{ch} \tag{11}$$

'iaf" , 'ibf" and 'ief" are the STATCOM reference current of three phases respectively.' iap*', 'ibp*' and 'iep" are fundamental active component current of three phases respectively. Similarly 'ias"' 'ibs" and 'ies" are the STATCOM source current of three phases respectively. iaq', 'ibq' and 'ieq , are the sum of instantaneous reactive

Component current of induction generator and load of three phases respectively. 'iaq', 'ibq' and 'ieq' are the instantaneous harmonic component current load of three phases respectively

Hysteresis Controller

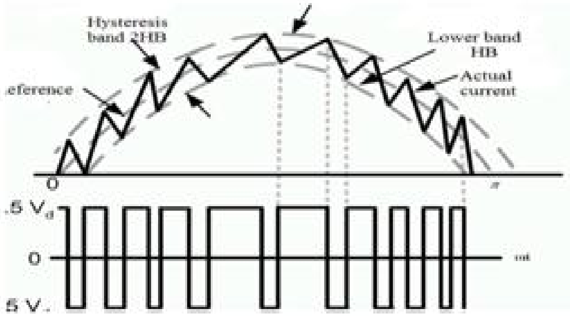


Fig.4 Hysteresis current Modualtion

With the hysteresis control, limit bands are set on either side of a signal representing the desired output waveform [6]. The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal. As the signal exceeds a prescribed hysteresis band, the upper switch in the half bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON. The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.

Construction of Fuzzy Controller

Figure 5 shows the internal structure of the control circuit. The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal.

A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage *Vdc* and the input reference voltage *Vdc-ref* have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current *I*max. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Figure.6.

The fuzzy controller is characterized as follows:

1. Seven fuzzy sets for each input and output;
2. Fuzzification using continuous universe of discourse;
3. Implication using Mamdani's 'min' operator;
4. De-fuzzification using the 'centroid' method.

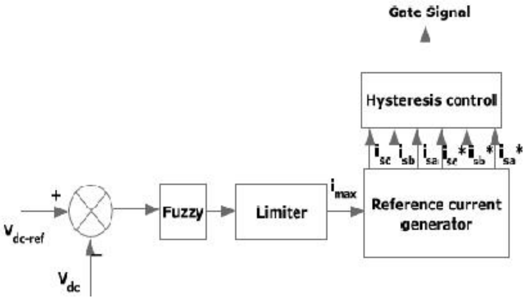
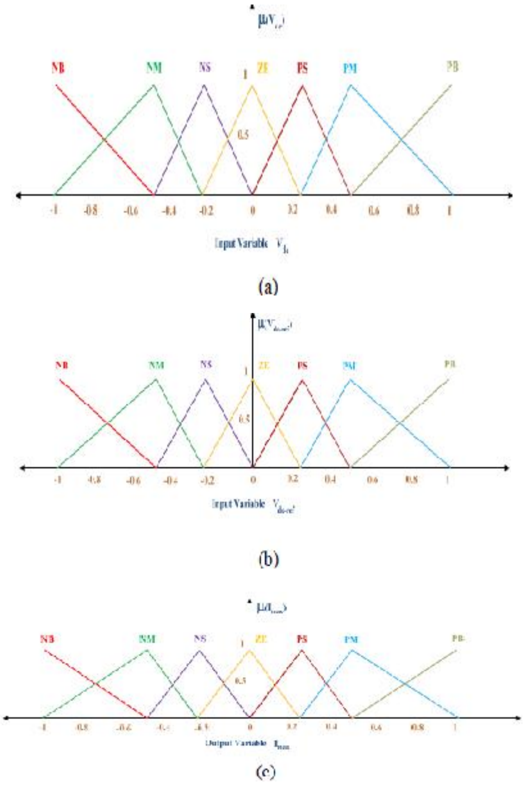


Fig.5 Conventional fuzzy controller



(a)

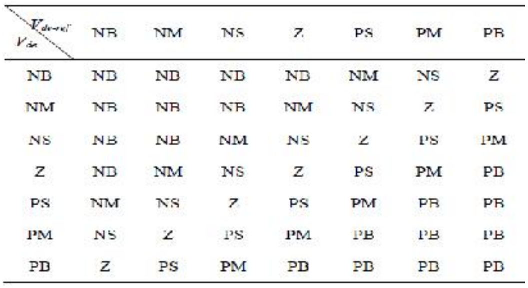
(b)

(c)

Fig.6. (a) Input Vdc normalized membership function; (b) Input Vdc-ref Normalized Membership Function; (c) Output Imax Normalized Membership Function**.**

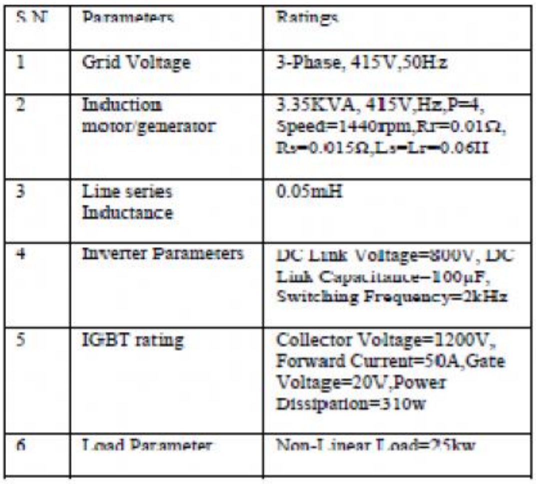
1. ***Fuzzification:*** the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.
2. ***De-fuzzification:*** the rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number).
3. ***Database:*** the Database stores the definition of the membership Function required by fuzzifier and defuzzifier.
4. ***Rule Base:*** the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with '*Vdc*' and '*Vdc-ref*' as inputs.

Table 1. Rule base.



V_{dc-ref} / V_{dc}	NB	NM	NS	Z	PS	PM	PB
ND	ND	ND	ND	ND	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	ND	NM	NS	Z	PS	PM	PD
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PD	Z	PS	PM	PD	PD	PD	PD

System Parameters



S.N	Parameters	Ratings
1	Grid Voltage	3-Phase, 415V,50Hz
2	Induction motor/generator	3.35KVA, 415V,Hz,P=4, Speed=1440rpm,Rr=0.01Ω, Rs=0.015Ω,Ls=Lr=0.06H
3	Line series Inductance	0.05mH
4	Inverter Parameters	DC Link Voltage=800V, DC Link Capacitance=100μF, Switching Frequency=2kHz
5	IGBT rating	Collector Voltage=1200V, Forward Current=50A,Gate Voltage=20V,Power Dissipation=310w
6	Load Parameter	Non-Linear Load=25kw

MATLAB MODELEING & SIMULATION RESULTS

Here the simulation is carried out in two cases

1. Implementation of proposed converter using conventional PI controller.
2. Implementation of proposed converter using fuzzy logic controller

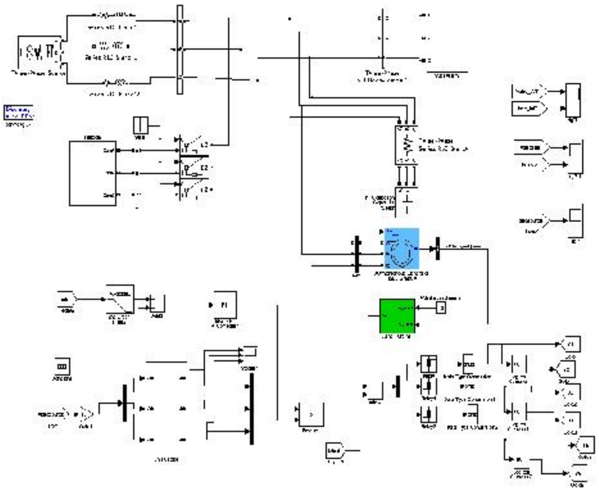


Fig:7 Matlab/Simulink model circuit for control block with PI controller

STATCOM—Performance under Load Variations

The wind energy generating system is connected with grid having the nonlinear load.

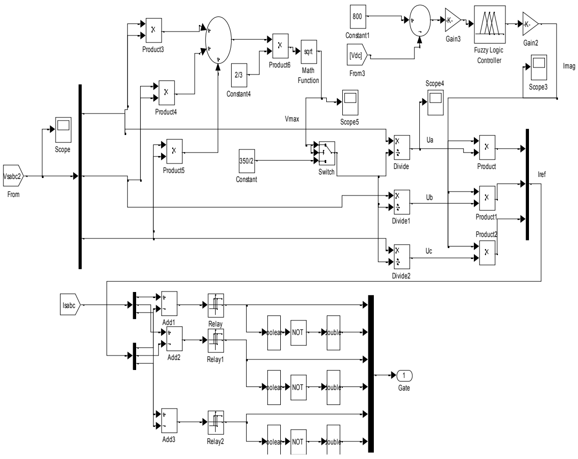


Fig:8 Matlab/Simulink model circuit for control block with fuzzy controller

The performance of the system is measured by switching the STATCOM at time0.7 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 fulfill by STATCOM compensator. Thus, STATCOM can regulate the available real power from source. The result of source current, load current are shown in Fig. 9(a) and (b) respectively. While the result of injected current from STATCOM are shown in Fig. 9(c) and the generated current from wind generator at PCC are depicted in Fig. 9(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. 10(a). The current through the dc link capacitor indicating the charging and discharging operation as shown in Fig. 10(b)

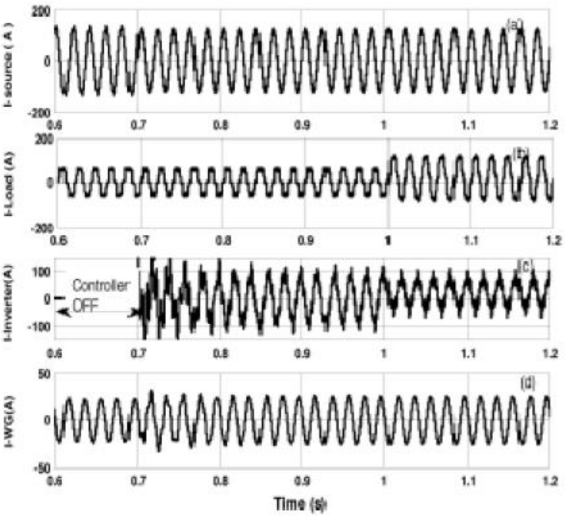


Fig. 9. (a) Source Current. (b) Load Current. (c) Inverter Injected Current.
(d) Wind generator (Induction generator) current.

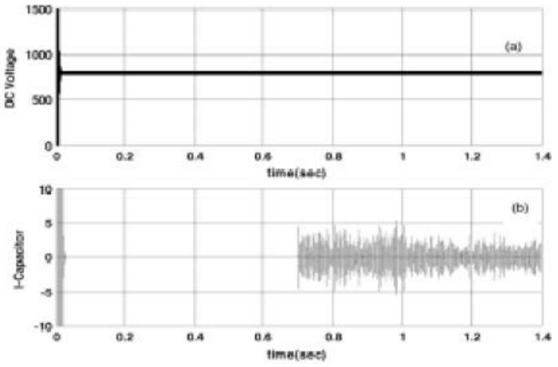


Fig.10.(a) DC link voltage. (b) Current through Capacitor.

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 are analyzed. The Fourier analysis of this waveform is expressed and the THD of this source current at PCC without STATCOM is 4.46%, as shown in Fig. 14.

The power quality improvement is observed at point of common coupling, when the fuzzy 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 that is 0.40%.

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

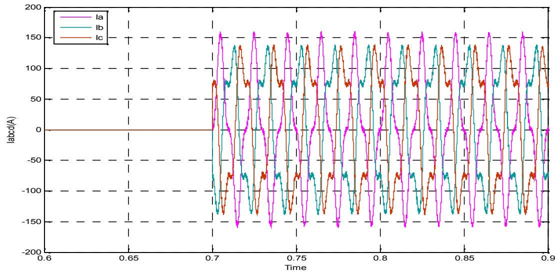


Fig 11STATCOM output current

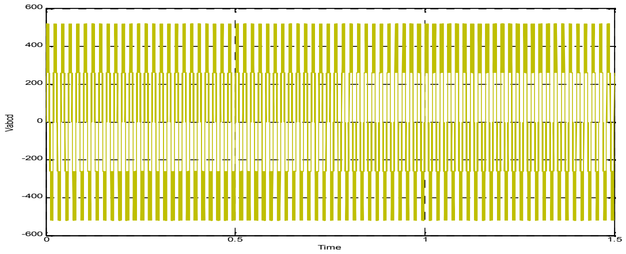


Fig 12 STATCOM output voltage.

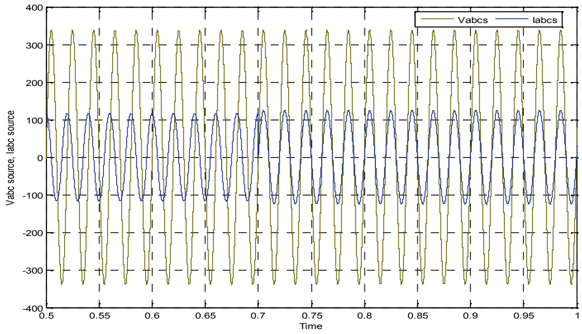


Fig 13 Supply Voltage and Current at PCC.

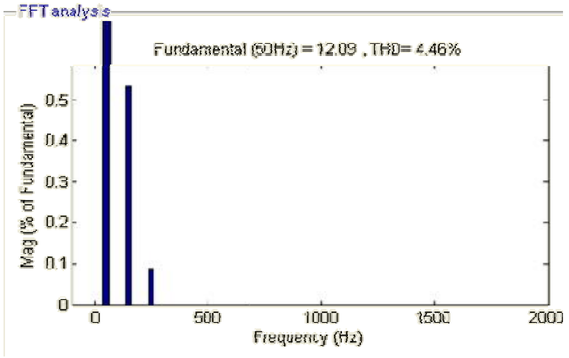


Fig. 14 FFT analysis with PI Controller (THD=4.46%)

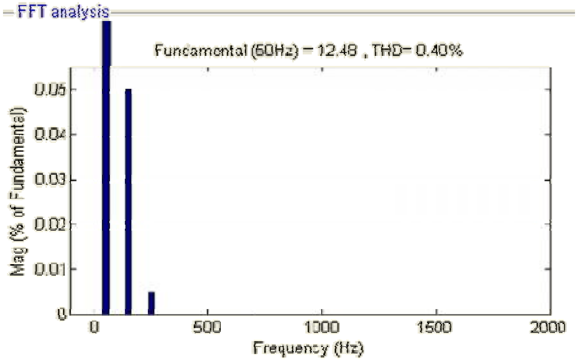


Fig. 15 FFT analysis with Fuzzy Controller (THD=0.40%)

CONCLUSION

In this paper we present the FACTS device (STATCOM) -based control scheme for power quality improvement in grid connected wind generating system and with nonlinear 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 in MATLAB/SIMULINK for maintaining the power quality is to be 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 FACTS device 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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