DESIGN OF STATCOM CONTROL SCHEME TO MITIGATE THE POWER QUALITY PROBLEMS

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Abstract— Power quality can be defined as any power quality problems manifested in voltage, current and frequency those results in failure or mal-operation of customer equipment. Injection of wind power into an electric grid affects the power quality. The work analyses the performance of Static Compensator (STATCOM) with a wind energy generating system at the point of common coupling to mitigate the power quality issues. During the Normal Operation, wind turbine produces a continuous variable output power. The main Power quality issues are voltage sag, swell, flickers, harmonics etc. The design of a Fuzzy logic controller using voltage as feedback for significantly improving the dynamic performance of converter. The performance is analysed with the help of PI controller and Fuzzy logic technique. The simulation studies have demonstrated the effective influence of the STATCOM on the improvement of the voltage using MATLAB/Simulink and make the wind turbine generator to be in service even under fault conditions. It also shows that fuzzy logic controller gives better result as compared to PI controller.

Index terms- Fuzzy logic controller (FLC), Point of common coupling , PI Controller, Power Quality,, STATCOM, Total harmonic Distortion (THD), Wind Generating System .

I. INTRODUCTION

The power quality of power supply of an ideal power system means to supply electric energy with perfect sinusoidal waveform at a constant frequency of a specified voltage with least amount of disturbances. Power quality is an issue that is becoming increasingly important to electricity consumers at all level of usage. Power quality is the combination of voltage quality and current quality, thus power quality is concerned with deviation of voltage and current from ideal. Power quality (PQ) related issues are of most concern nowadays. The widespread use of electronic equipment and electrical equipment susceptible to power quality or more appropriately lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electrical motor, a transformer, a generator, a computer, a printer, communication equipment, or household appliances.

Here proposing a STATCOM based control technology for mitigating the power quality issues when we are integrating wind farms to the grid. In the event of increasing grid disturbances, a battery energy storage system is required to compensate the fluctuation generated by wind turbine. Here two control schemes for STATCOM is designed and compared: Bang-Bang Current controller and fuzzy logic controller. PI controller plays an important role in reducing fluctuating voltage error signal efficiently. Simulation result shows that the proposed SVC and STATCOM with PI controller is efficient in mitigating voltage sags and thus improving the power quality of the power grid. Fuzzy logic technique has been used as it has advantage of robustness, easily adaptive fast technology is also used and best results are achieved when compared to conventional PI technique.

II. POWER QUALITY CONSTRAINTS AND PROBLEMS

Power system constraints are:

1. Random external factors
    - Whether
    - Human activities
    - Animals
    - Vegetation
2. Increasing share of Non-linear loads
3. Increasing demand of High PQ

The various power quality problems are:

- Harmonic distortion
- Voltage spikes
- Voltage swells
- Voltage fluctuations
- Voltage unbalance
- Voltage sags
- Micro-interruptions
- Long interruptions
- Noise

III. 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.1.

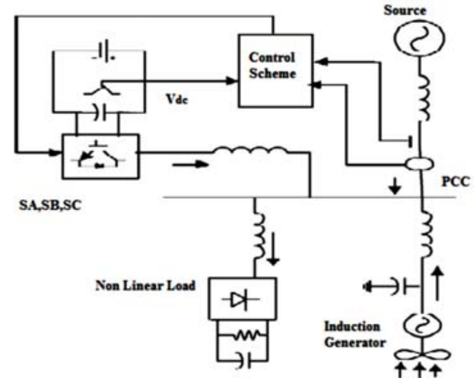

Fig.1.System operational schemes in grid system.

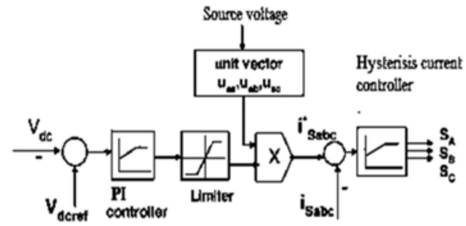

Fig.2. Control system scheme

IV. STATCOM- PERFORMANCE UNDER VARIOUS 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 t= 0.3 s in the system. 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. This additional demand is fulfil by STATCOM compensator. Thus, STATCOM can regulate the available real power from source. The results of source current are shown in Fig. and respectively. While the result of injected current from STATCOM are shown in fig.3.

1. PI CONTROLLER

The PI controller is traditionally suitable for second and lower order system. It can also be used for higher order plants with dominant second order behaviour. The Ziegler-Nichols (Z-N) methods rely on open-loop step response or closed loop frequency tests, are usually used to determine the values of PI controller. In our case, the values of tuning parameters obtained are Kp= 350 , Ki= 85. Usually, these obtained values are only initial values of PI controller and need to be adjusted repeatedly through computer simulation until the closed loop system performs or compromises are satisfied.

The STATCOM control block diagram is shown in Fig.2. The voltage regulator is of proportional plus integral type.

The integral term in a PI controller causes the steady 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 the 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 the noisy data. PI controller to eliminate offset, a major weakness of a P-only controller. It is shown in fig.3 as below.

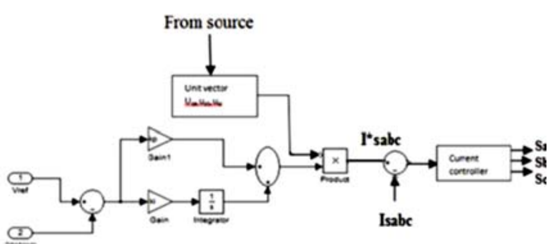

Fig.3 STATCOM model with PI – Voltage Regulator block diagram

2. FUZZY LOGIC CONTROLLER

The disadvantage of PI controller is its inability to react to abrupt changes in error signal ε , because it is only capable of determining the instantaneous value of the error signal without considering the change of the rise and fall of the error, Which in mathematical terms is derivative of the error signal, denoted as Δε. To solve this problem, Fuzzy logic control as it is shown in fig. 4 is proposed. The determination of the output control signal, is done in an interference engine with a rule base having if-then rules in the form of

If ε is ………… And Δε is …………, then output is ………..

With the rule base, the value of the output is changed according to the value of the error signal ε, and the rate of error Δε. The structure and determination of the rule base is done using trial and error method and is also done through experimentation.

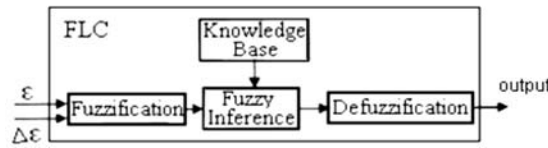

Fig.4 Basic representation of the Fuzzy logic controller (FLC).

The MATLAB/SIMULINK implementation of the fuzzy controller for one phase is shown in fig.4.

All the variables fuzzy subsets for the inputs ε and Δε are defined as (NB, NM, NS, Z, PS, PM, PB). Taking into account of the coverage, sensitivity, robustness of universe, the fuzzy subsets of the membership functions use "Z" shaped membership function in the left, triangular membership function in the middle, and "S" shaped membership function curve in the right. The FLC with STATCOM input is shown in fig.5.

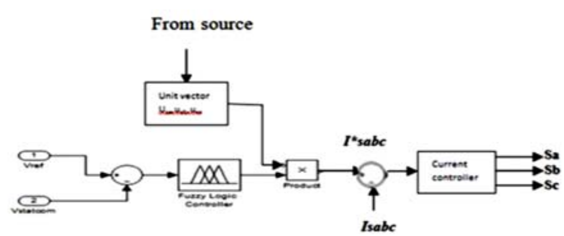

Fig.5 STATCOM model with FLC- Voltage Regulator block diagram

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The objectives include excellent rejection of input supply variations both in utility and in wind generating system and load transients. Expert knowledge can also be participated with ease that is significant when the rules developed are intuitively inappropriate. The rule base developed is reliable since it is complete and generated sophistically without using extrapolation. In this paper, fuzzy control is used to control the firing angle for the switches of the VSI of STATCOM. In this design, the fuzzy logic based STATCOM has two inputs 'change in voltage(ΔV)' and 'change in current(ΔI)' and one control output(ΔU). Firstly the input values will be converting to fuzzy variables. This is called fuzzification. After this, fuzzy inputs enter to rule base or interface engine and the outputs are sent to defuzzification to calculate the final outputs. These processes are demonstrated in Fig.6. Here seven fuzzy subsets have been used for two inputs. These are: PB (positive big), PM (positive medium), PS (positive small), ZE (zero), NS (negative small), NM (negative medium) and NB (negative big). We use Gaussian membership functions and 49 control rules are developed, which are shown in Table.I.

Fuzzification: It is the process of representing the inputs as suitable linguistic variables .It is first block of controller and it converts each piece of input data to a degree of membership function. It matches the input data with conditions of rules and determines how well the particular input matches the conditions of each rule.

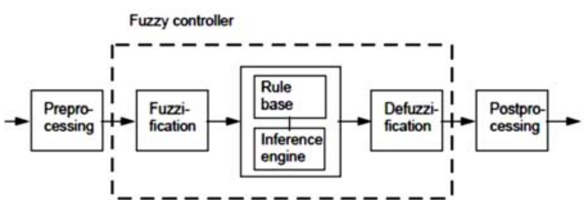

Fig.6 Fuzzy control block diagram

TABLE. I Control Rules

ΔI/ΔV	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NB	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PM	ZE	PS	PM	PB	PB	PB	PB

The membership functions for the inputs (for ΔV and ΔI) are shown in Fig.7 and Fig.8 The number of fuzzy levels is not fixed and it depends on the input resolution needed in an application. The larger the number of fuzzy levels, the higher is the input resolution. The fuzzy control implemented here uses sinusoidal fuzzy-set values.

Decision making: The control rules that associate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behaviour. However, some of the control actions in the rule table.1 are also developed using "trial and error" and from an "intuitive" feel of the process to be controlled. In this effort, the control rules for the STATCOM in Table1.resulted from the understanding of STATCOM's behaviour and experimental tests of its VSI's performance.

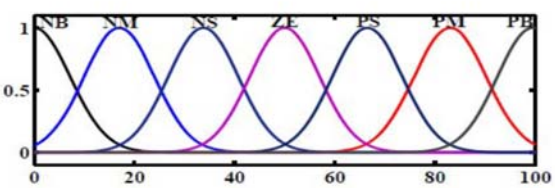

Fig.7 Membership function for ΔI

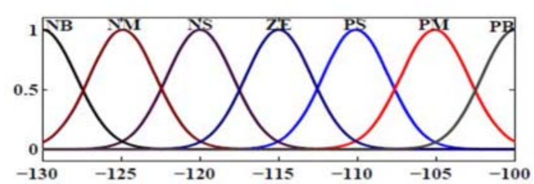

Fig.8 Membership function for ΔV

Defuzzification: It is the Process of converting fuzzified output into a crisp value. In the defuzzification operation a logical sum of the results from each of the rules performed. This logical sum is the fuzzy representation of the change in firing angle (output). A crisp value for the change in firing angle is calculated.

Correspondingly the grid current changes and improves the power quality.

V. POWER QUALITY IMPROVEMENT FORMULATION MODEL

The wind energy generating system is connected with grid having the non-linear 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 non-linear load and wind generator. The source current with and without STATCOM operation is shown in Fig. and . 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 is expressed and the THD of this source voltage at PCC with and without STATCOM Using Fuzzy logic Controller is 15.74% and 3.92% respectively, as shown in Fig. and respectively.

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.

The proposed control scheme is simulated using MATLAB/SIMULINK in power system block set. The simulation parameters used for the system is given Table II.

TABLE II
System Parameters

Sr. No .	Parameter	Rating
1	Grid voltage	3phase ,415 volt 50Hz
2	Induction Motor/Generato r	3.35 KVA , 415 volt 50 Hz speed 1440 rpm P=4, Rs=0.01Ω, Rr=0.015 Ω, Ls=0.06H,Lr=0.06H .
3	Line Series inductance	0.05 mH
4	Inverter parameter	DC link voltage =800V, Switching frequency =2KHz, DC Link Capacitance= 100 µf.
5	Load Parameter	Non Linear Load 25kW
6	IGBT Rating	Collector Voltage= 1200 V, Forward Current=50A, Gate Voltage=20V, Power Dissipation= 310W.

1. MATLAB SIMULINK MODEL:

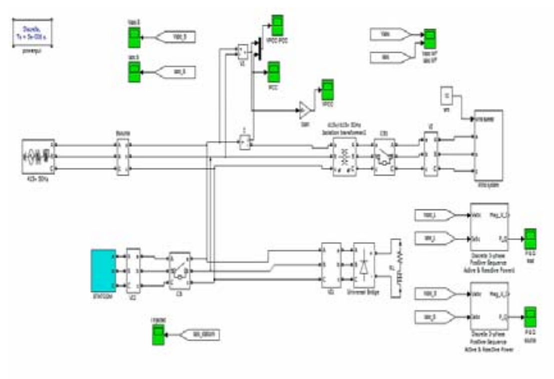

Fig.9 STATCOM Connected Wind Energy System for Power Quality Improvement Using Fuzzy Logic Controller

2. WIND ENERGY GENERATING SYSTEM MODELLING:

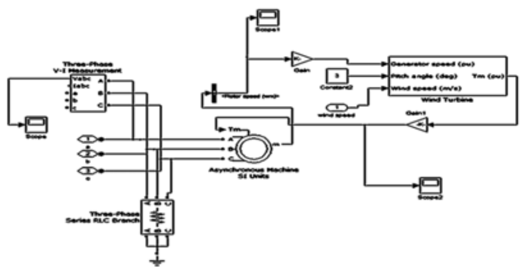

Fig.10 Wind Energy Generating System Model

The performance of the system is measured by switching ON the STATCOM at time T=0.3 s and an increase in additional load is given at time T=0.2s. The load current and source currents are shown in fig and fig. respectively. While the injected current from STATCOM is shown in fig.11.

The STATCOM controller is made ON, it starts to mitigate the reactive demand as well as harmonic current. The additional demand is fulfil by STATCOM compensator with the help of BESS. This can be easily seen in the source current (grid current). Because whatever changes occurs in the load or induction generator occurs it can't be seen in the source current and it is free from harmonics also.

3. STATCOM SIMULINK MODEL OF SYSTEM:

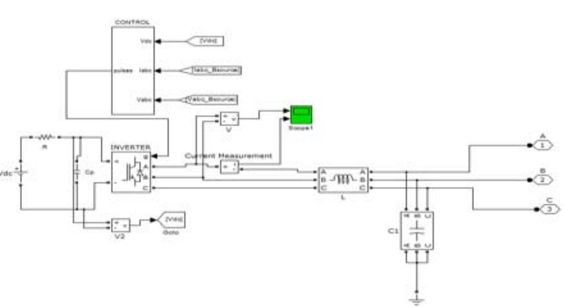

Fig.11 STATCOM Model with Control Scheme of System

The DC link voltage regulates the source current in the grid system, so the DC link voltage is maintained constant across the capacitor as in fig.10 System is analysed and performance of the system is evaluated. One of the easiest measurements of harmonic is the total harmonic distortion (THD) measurement through FFT analysis.

The Fourier analysis of waveform with and without using PI controller is performed and the THD obtained for the source current without STATCOM is 2.30% and the THD of source current (grid current) is only 1.19% as shown in Table III. The injected currents also have harmonic and it cancel out reactive and harmonic part produced by the induction generator and the non-linear load. Thus it improves power quality.

4. CONTROL SCHEME USING PI CONTROLLER:

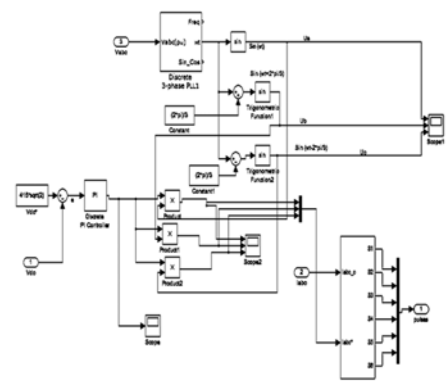

Fig.12 Control scheme of STATCOM Using PI Controller

5. CONTROL SCHEMES USING FUZZY LOGIC CONTROLLER:

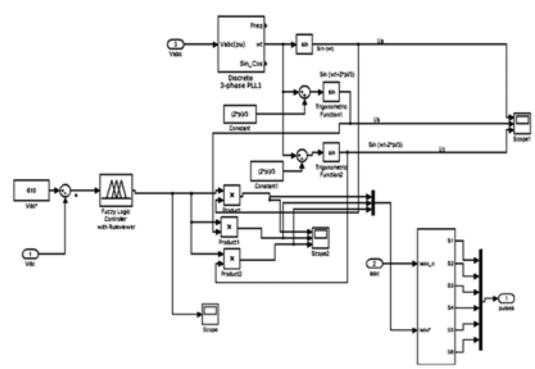

Fig.13. STATCOM Control Scheme Using FUZZY Logic Controller

VI. SIMULATION WAVEFORM

The current waveform before and after the STATCOM operation is analyzes. Without using fuzzy controller for STATCOM the source THD is 1.23% and using fuzzy controller the source current (grid current) THD is reduced to 0.81% as shown in Table. It indicates that when we are using fuzzy controller the harmonics are reduced more as compared to PI controller.

A) SIMULATION WAVEFORM USING PI CONTROLLER

All the below figure shows the Source Current, Wind generating Current, load current , source voltage , load voltage, real power and reactive power with conventional PI controller. Here compensator is tuned on at 0.3 seconds, before we get some harmonics coming from non-linear load, then distorts our parameter and get sinusoidal when compensator is in ON.

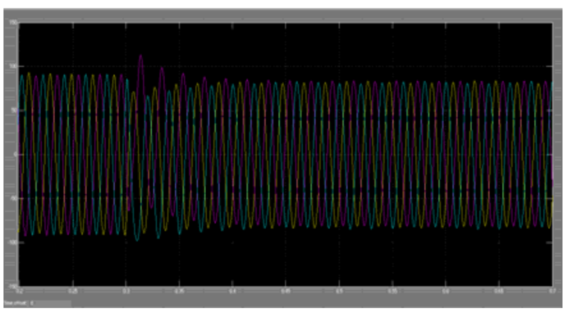

Fig.14 Source Current with and without STATCOM using PI Controller

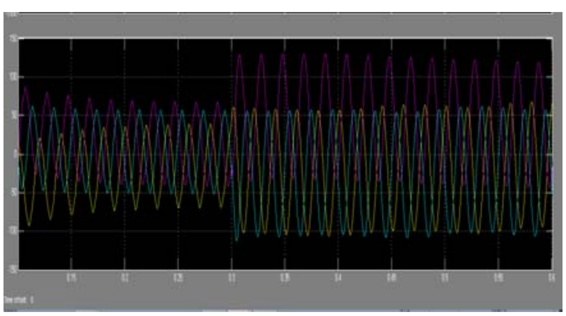

Fig.15 Current after connecting wind system with and without STATCOM using PI controller

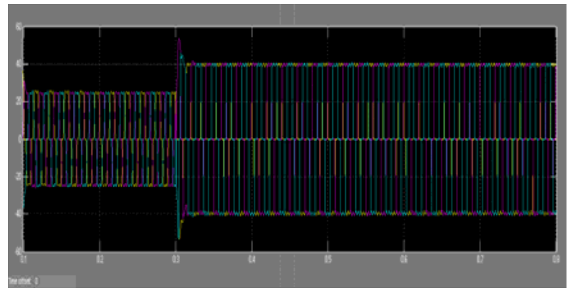

Fig.16 Load current with and without STATCOM using PI controller

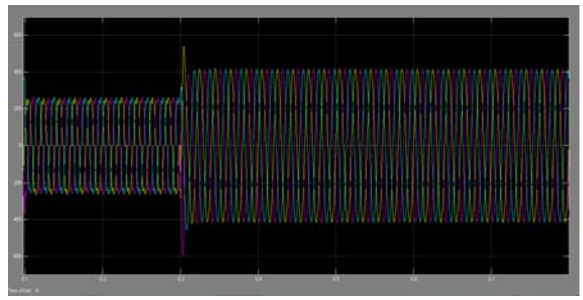

Fig.17 Source Voltage with and without STATCOM using PI Controller

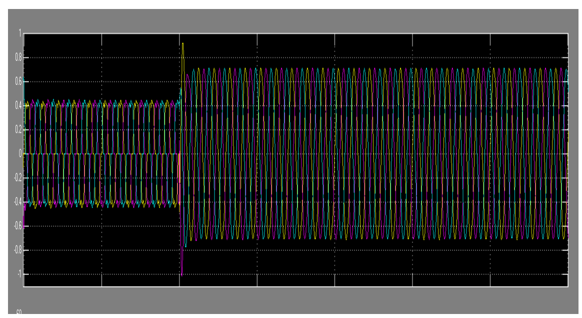

Fig.18 Load voltage with and without STATCOM using PI controller

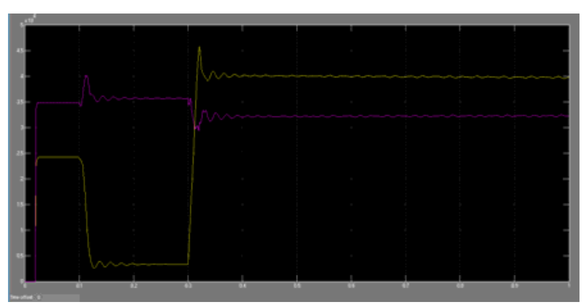

Fig.19 Real and Reactive Power at Source Side before and after STATCOM using PI Controller

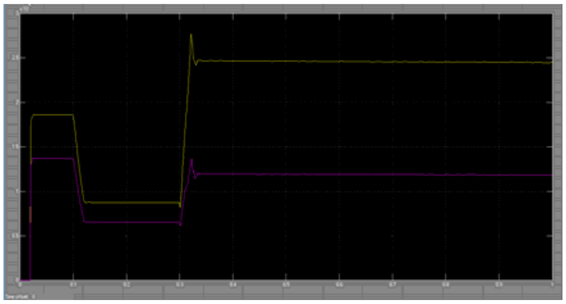

Fig.20 Real and Reactive Power at Load Side before and after STATCOM using PI Controller

B) USING FUZZY LOGIC CONTROLLER

All the below figure shows the Current at PCC, Source Current, Wind generating Current, load current and Inverter injected Current with Fuzzy Logic controller. Here compensator is tuned on at 0.3 seconds, before we get some harmonics coming from non-linear load, then distorts our parameter and get sinusoidal when compensator is in ON. It is compared with PI controller and shows better results.

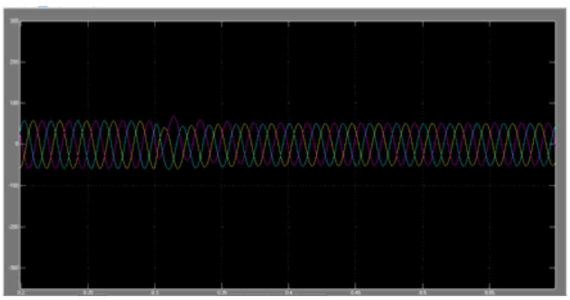

Fig.21 Source Current with and without STATCOM using Fuzzy logic Controller

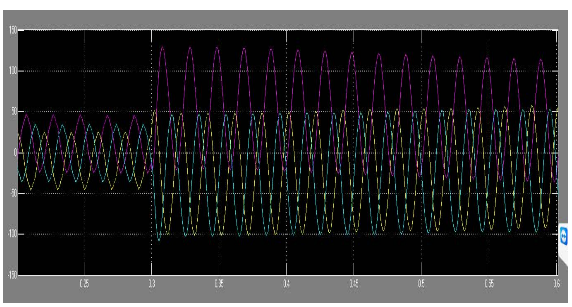

Fig.22 Current after connecting wind system with and without STATCOM using Fuzzy logic Controller

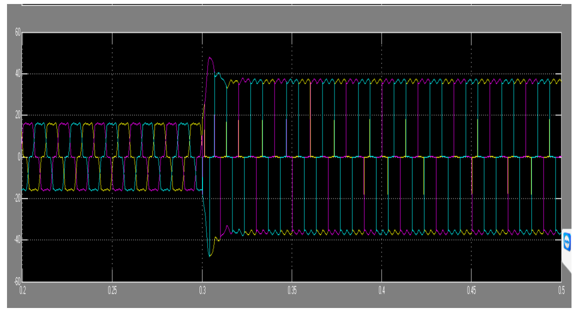

Fig.23 Load current with and without STATCOM using Fuzzy logic Controller

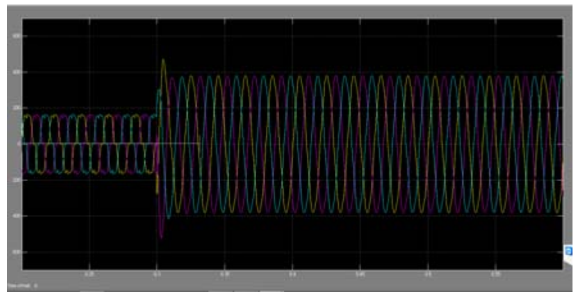

Fig.24 Source Voltage with and without STATCOM using Fuzzy Logic Controller

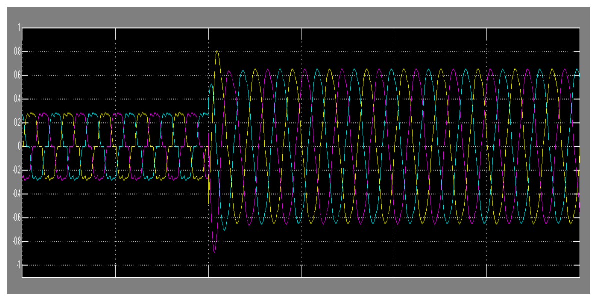

Fig.25 Load Voltage with and without STATCOM using Fuzzy logic controller

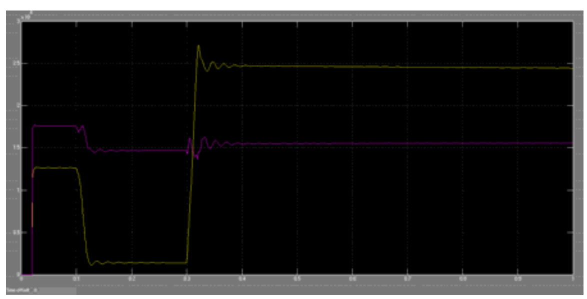

Fig.26 Real and Reactive Power at Source Side before and after STATCOM using Fuzzy Logic Controller

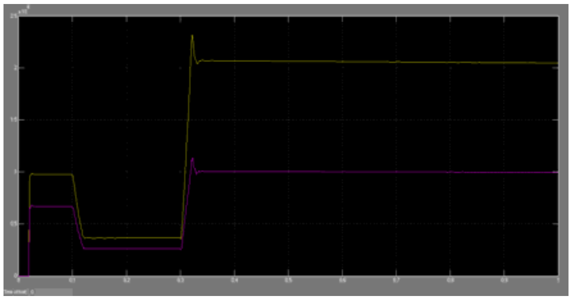

Fig.27 Real and Reactive Power at Load Side before and after STATCOM using Fuzzy Logic Controller

C) COMPARATIVE ANALYSIS OF TWO CONTROL SCHEME FOR STATCOM

Result of two control schemes are summarized in the table below. From this table we can conclude that the % THD reduces more with Fuzzy logic controller. Without load variations, by using PI controller the THD in the source current reduced to 1.19% and using Fuzzy logic controller the THD is reduced to 0.81%.

a) THD analysis of System using PI controller.

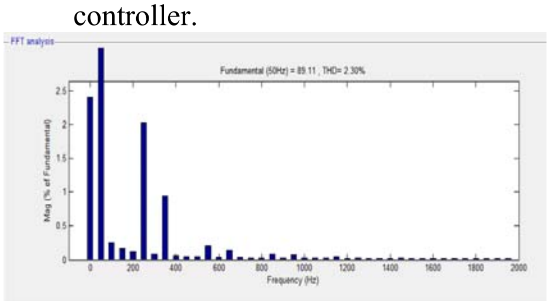

Fig.28 Source current without STATCOM using PI controller

Fig.28 shows FFT analysis of Source Current for balanced Non-linear load without any compensation, here we get 2.30%.

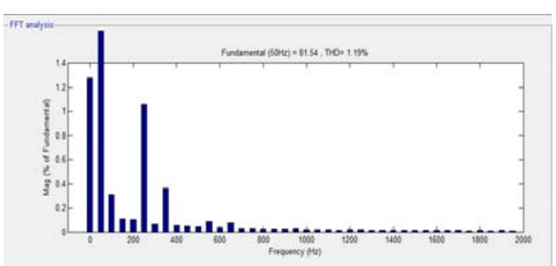

Fig.29 Source current with STATCOM using PI controller

Fig.29 shows FFT analysis of Source Current for balanced Non-linear load, here we get 1.19%.

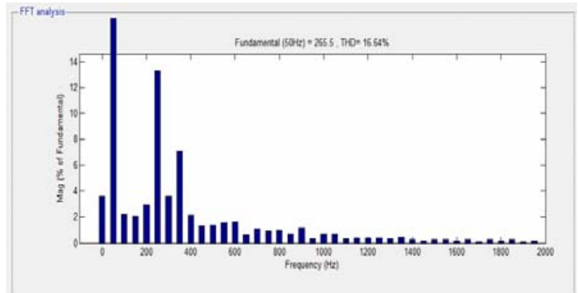

Fig.30 Source voltage without STATCOM using PI controller

Fig.30 shows FFT analysis of Source Voltage for balanced Non-linear lad without any compensation, here we get 16.64%.

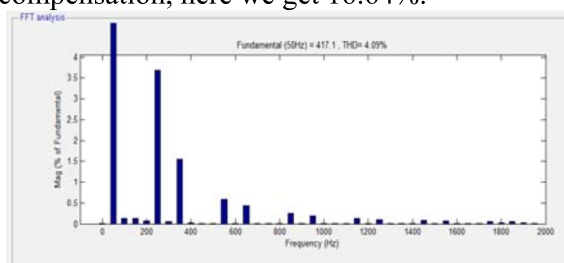

Fig.31 Source voltage with STATCOM using PI controller

Fig.31 shows FFT analysis of Source Voltage for balanced Non-linear load, here we get 4.09%.

Table.III % THD content in Source Current, Source voltage

Total Harmonic Distortion % THD		
	Without STATCOM	With STATCOM
Source Current	2.30%	1.19%
Source Voltage	16.64%	4.09%

Table.III shows % THD content in Source Current and Source voltage without STATCOM and with STATCOM. It is observed from the Table 7.1 source current THD in phases are improved from 2.30%to 1.19%.Similarlly for the source voltage THD improved from 16.64% to 4.09%.

b) THD analysis of System using Fuzzy Logic Controller.

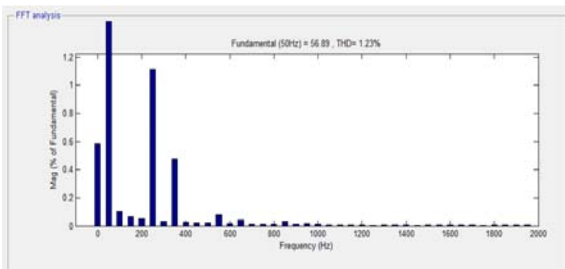

Fig.32 Source Current without STATCOM using Fuzzy Logic controller.

Fig.32 shows FFT analysis of Source Current for balanced Non-linear load without any compensation, here we get 1.23%.

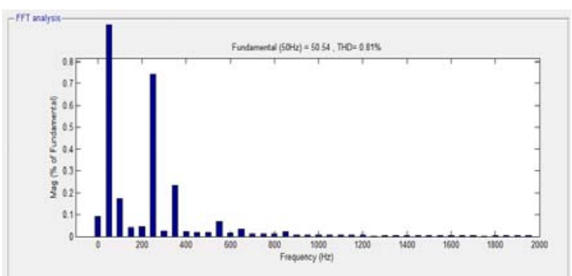

Fig.33 Source Current with STATCOM using Fuzzy Logic controller.

Fig.33 shows FFT analysis of Source Current for balanced Non-linear load, here we get 0.81%.

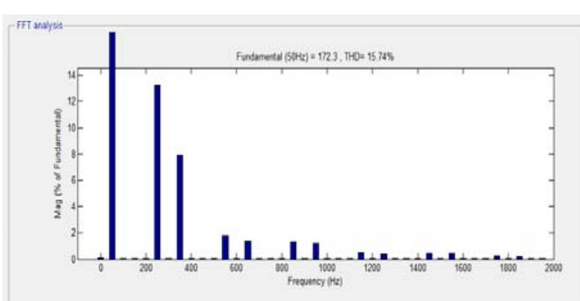

Fig.34 Source Voltage without STATCOM Using Fuzzy Logic Controller

Fig.34 shows FFT analysis of Source Voltage for balanced Non-linear load without any compensation, here we get 15.74%.

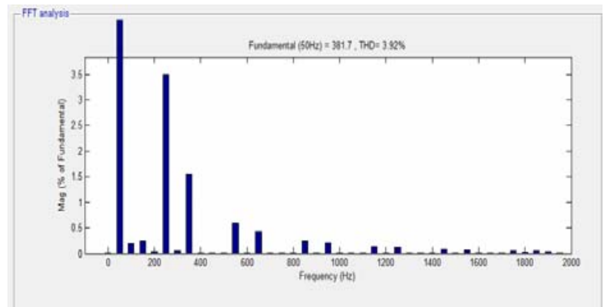

Fig.35 Source Voltage with STATCOM Using Fuzzy Logic Controller

Fig.35 shows FFT analysis of Source Voltage for balanced Non-linear load without any compensation, here we get 3.92%.

Table.IV % THD content in Source Current, Source voltage

Total Harmonic Distortion % THD		
	Without STATCOM	With STATCOM
Source Current	1.23%	0.81%
Source Voltage	15.74%	3.92%

Table.IV shows % THD content in Source Current, Source voltage without STATCOM and with STATCOM. It is observed from the Table shows that source current THD in phases are improved from 1.23% to 0.81%.Similarlly for the source voltage THD improved from 15.74% to 3.92%.

CONCLUSION

In this Project we present the STATCOM based control scheme for power quality improvement in wind generating system on integration to the grid and with nonlinear load. The power quality its effects on consumer utility are shown. The operation of the control system developed for the STATCOM in MATLAB/SIMULINK for maintaining the power quality is to be simulated. It has potentially to cancel out the harmonic parts of the load end current. It maintains the source voltage and current in phase and support the reactive power during demand for the wind generator and load at PCC in the wind grid system, thus it enhance the utilization factor of transmission line also. The operation of the STATCOM is simulated using two controllers: Bang-Bang current controller and Fuzzy controller. The proposed FLC based STATCOM have improved the power quality of source current significantly by reducing the THD from 1.19% to 0.81%. It is clearly presented that STATCOM with FLC gives better performance than STATCOM with conventional PI controller. For better voltage regulation Fuzzy-PI control technique showed better performance than the conventional controller. One of the major advantages of the proposed FLC is being less sensitive to the system parameter variation; in addition, it is characterized by a negligible response time. Simulation result analysis has shown that the proposed controller has fast dynamic response, high accuracy of tracking the DC-voltage reference, and strong robustness to load sudden variations compared to the conventional PI controller.

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