POWER QUALITY ENHANCEMENT IN GRID CONNECTED WIND POWER SYSTEM BASED ON DFIG USING FUZZY CONTROLLED UPQC

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Abstract—**The renewable energy resources rule the world of power generation. Now-a-days wind farms are encouraged for up gradation of energy production, as the wind power is dirt free, readily available renewable alternative. The integration of wind farms with power grid leads to Power Quality (PQ) issues such as voltage sag, swell, flicker, harmonics etc. Most of the industrial and commercial loads are of non-linear type which produce the starting place of harmonics. As 70% of PQ problems are voltage sag which is one of the most severe disturbances to sensitive loads. The outcome issues are pronounced at both sides consumer sector as well as production sector which get affected with poor quality of power. Among many of custom power devices, Unified Power Quality Conditioner (UPQC) is the only device which can be used to diminish both voltage sag and current harmonics. This paper analyzes PQ problems, voltage sag and current harmonics due to the interconnection of grid connected wind turbine and also provides PQ enhancement by introducing UPQC. For the performance improvement of UPQC, a novel control strategy using Fuzzy Logic Controller (FLC) is proposed which eliminates the drawback of using fixed gains in conventional PI controller. From the simulation results, by comparing controller performances, the proposed fuzzy controlled UPQC provides effective and efficient mitigation of both voltage sag and current harmonics than the conventional PI controlled UPQC , thus making the grid connected wind power system more reliable by providing good quality of power.**

I. INTRODUCTION

The renewable energy sources such as wind, solar, tidal and hydro energies are peak in the present set-up. The cost effectiveness, sustainable and clean nature of wind explains the fast growing energy source in the world [1][2]. Wind farms were built with fixed speed wind turbines and induction generators in the old era of wind development [3][4]. The power efficiency is literally low for most wind speeds as such generators always prefers constant speed operation. Now-a-days for improving efficiency, the development of ample modern wind generators with variable speed operation has been increased. In that sense, Doubly Fed Induction Generator (DFIG) is widely used due to its variable-speed action ,independent control of active and reactive power and employing partially rated power converter [5] [6]. To increase the power production, wind farm is made to interlock with power grid. While interconnecting wind farm with power grid, the wind farm emits fluctuating electric power because of the arbitrary nature of wind resources. These fluctuations have a pessimistic impact on stability and Power Quality in electric power systems [7]. Also the integration of large wind farms to power grid yields PQ problems such as voltage sag, voltage swell, harmonics, flicker etc. The outcomes of PQ problems are data errors, automatic resets, equipment failure. Voltage sag is considered to be one of the most severe disturbance which is triggered due to three phase to ground fault or starting of large motors since it may cause equipment tripping, shutdown for domestic and industrial equipment and mal-operation of drive systems [8]. Most of the industrial and commercial loads are of non-linear type, which are the origin of harmonics and as a result the utilities supplying these nonlinear loads has to deliver large VARs also [9] [10]. For reducing the intensity of both voltage sag and current harmonics, custom power technology comes into picture. The Dynamic Voltage Restorer (DVR), Due to its excellent dynamic capabilities, DVR is well suited to protect sensitive loads from short duration voltage dips or swells [11]. But DVR doesn't take care of load current harmonics, which when untreated, results in low power factor, leads to voltage notch and reduced consumption of the distribution system. The device STATCOM is widely used for the eradication of load current harmonics in addition to the contribution of reactive power control [12], but it doesn't take care of voltage related problems. UPQC replaces the functions of both devices by mitigating both voltage sag and load current harmonics, thus replacing the functions of two devices DVR and STATCOM.

The choice of suitable controller plays a vital role to improve the performance of UPQC. In conventional PI controller, proportional and integral gains are chosen heuristically and requires precise linear mathematical model of the system which makes it difficult to obtain under parameter variations and non-linear load disturbances. The fuzzy logic controller is proposed works with linguistic variables and it doesn't need any mathematical modeling which is best suited for non linear loads [16]. In the proposed work, the Power Quality problems namely voltage sag and current harmonics are simulated and analyzed in the grid connected wind power system. The FLC based UPQC is implemented for effective and efficient mitigation of both voltage sag and current harmonics and its performance is validated by comparing the simulation results with conventional PI controlled UPQC.

II. GRID INTEGRATED DFIG BASED WIND POWER SYSTEM - POWER QUALITY ISSUES AND THEIR IMPACTS

Power Quality (PQ) is used to describe electric power that drives an electrical load and the load's ability to function properly. Power Quality determines the fitness of electric power to consumer devices.

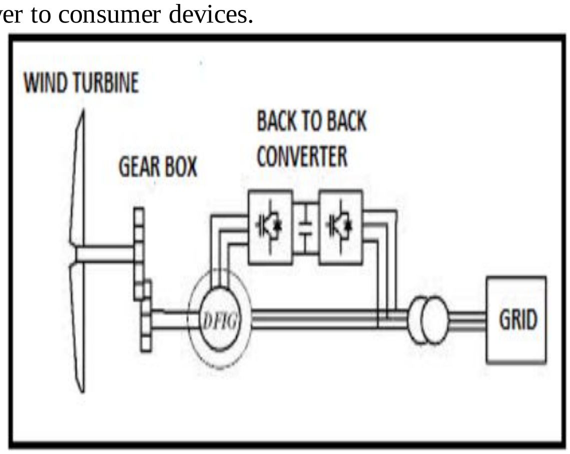

Fig.1. Grid connected DFIG based wind power system

Wind power is one of the leading renewable energy sources worldwide. Most of the wind farms uses fixed speed wind turbine, its performance relies on the characteristics of mechanical sub circuits, every time a gust of wind strikes the turbine, a fast and strong variation of electrical output power can be observed, as the response time of mechanical sub-circuits is in the range of 10 milliseconds. These load variations necessitates a stiff power grid and sturdy mechanical design to absorb high mechanical stresses. This approach leads to expensive mechanical construction, so that in order to overcome the above issues, now-a-days DFIG based variable speed wind turbine comes into picture which is more benefit by following

- Power Quality Improvement
- Simple pitch control mechanism
- Provides Cost effective solution
- Reduced mechanical stresses
- Reduced acoustic noise

The schematic diagram of interconnection of Grid with DFIG based wind power system is shown in Fig.1. The stator of DFIG is used to supply power directly to the grid, while the rotor supplies power to the grid via power electronic converter. As the back to back converter is connected only to the rotor, the cost of converter is only 25% of the total system power which improves entire system efficiency to a greater extent. While integrating electric grid with wind power system, the quality of power from the generator output gets affected. If a huge proportion of the grid load is supplied by wind turbines, the output deviations owing to wind speed alternations incorporate voltage variations, harmonics and flicker. Due to variations in the wind velocity voltage sag and voltage swell will be developed. Harmonics is one of the severe problems in grid connected wind power system. As the consequences faced by voltage sag and harmonics are dominant, this leads to degradation of PQ at the consumer's terminal.

The foremost impacts of the PQ problems are

- Malfunction of equipments such as adjustable speed drives, microprocessor based control system and Programmable Logic Controller.
- Unwanted tripping of protection devices.
- Stoppage and damage of sensitive equipments like personal computers, industrial drives etc.,

The Standards provided by IEEE for individual customers and utilities for improving PQ is shown below:

- IEEE Standard 519 issued in 1981, suggests voltage distortion < 5% on power lines below 69 kV.
- ANSI/IEEE Standard C57.12.00 and C57.12.01 confines the current distortion to 5% at full load in supply transformer.

In order to keep PQ within bounds, there is a need for PQ Enhancement. For this custom power devices plays a vital role for the purpose of supplying required level of PQ thus make the grid connected wind power system free from PQ problems.

III. UNIFIED POWER QUALITY CONDITIONER

UPQC is a custom power device responsible for the alleviation of PQ disturbances in both supply and load side. The schematic diagram of UPQC is shown in Fig.2. It consists of two Voltage Source Inverters (VSI) series and shunt, tied back to back with each other sharing a common dc link.

The shunt inverter is controlled in current control mode such that it delivers a current which is equal to the set value of the reference current as governed by the UPQC control algorithm and also to maintain the dc bus voltage at a set reference value.

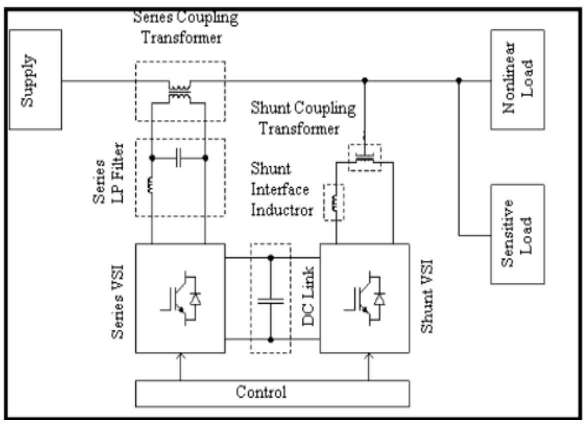

Fig.2. Schematic diagram of Unified Power Quality Conditioner

The mitigated harmonics introduced by nonlinear load ,the shunt inverter injects a current as governed by following equation:

$$I_{sh}\ (\omega t) = i_s^*\ (\omega t) - i_L\ (\omega t) \qquad (1)$$

where Ish (ωt) , is* (ωt) and iL(ωt) represents the shunt VSI current, reference supply current, and load current respectively.

The series inverter of UPQC is employed in voltage control mode as it supplies and injects voltage in series with line to realize a sinusoidal, distortion free voltage at the load terminal. The voltage injected by series VSI is depicted by the following equation :where Ish (ωt) , is* (ωt) and iL (ωt) represents the shunt VSI current, reference supply current, and load current respectively.

$$V_{Sr}\ (\omega t) = V_L^*\ (\omega t) - V_S\ (\omega t) \qquad (2)$$

where Vsr(ωt), VL*(ωt) and Vs(ωt) represents the series inverter injected voltage, reference load voltage, and actual supply voltage respectively.

UPQC is responsible for mitigating both current and voltage related issues and also has the subsequent facilities:

- It eradicates the harmonics in the supply current, thus enlarging utility current quality for nonlinear loads.
- It supports VAR requirement of the load, so the supply voltage and current are in phase and so any additional power factor correction equipment is not essential.
- The load end voltage is maintained at the rated value even in the existence of supply side disturbances.
- The voltage injected by UPQC to keep the load voltage at the desired value is taken from the same dc link, thus no extra dc link voltage support is involved for the series compensator.

IV. PROPOSED METHODOLOGY

TABLE I. DESIGN VALUES

PARAMETERS	SIMULATION VALUES
Main Supply voltage	120kV
Line frequency	50Hz
Source Impedance	L_s = 16.58 mH; R_s = 0.8929 Ω
Non linear load Bridge Rectifier	R=500Ω ; L=1mH
Doubly Fed Induction Generator (DFIG)	Nominal power = 1MW ; Voltage = 120 kV ; Frequency =50HZ

The simulation model of the proposed work is shown in Fig.3. In this model, the power grid is interconnected with Doubly Fed Induction Generator (DFIG) based wind Turbine and it will be synchronized in terms of voltage and frequency.

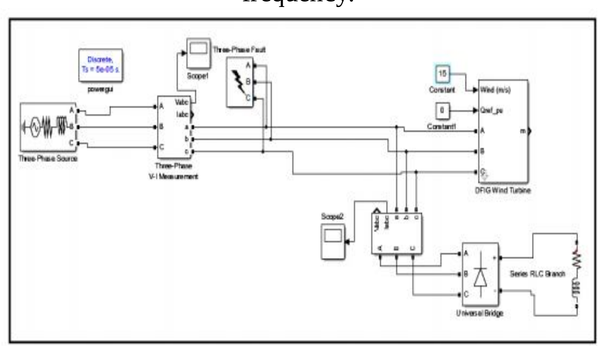

Fig.3.Simulation of PQ Problems

controller. Its output is converted to three phase and it is fed wind speed is kept as 15m/s which is regarded as nominal value which may vary from 8 to 15 m/s owing to fluctuations. The PQ problems voltage sag is simulated by creating three phase to ground fault and load current harmonics are simulated by connecting Diode bridge rectifier load in the proposed grid connected wind power system. The design values of the simulation model are shown in Table. I. For PQ enhancement, UPQC is designed for the above mentioned problems and the proposed control strategy using Fuzzy Logic Controller is implemented for the generation of reference voltage for series inverter and the reference current for shunt inverter which provides an effective mitigation of both supply side and also loads side disturbances, thus keeps the PQ in a grid connected wind power system as per IEEE norms. The effectiveness of the proposed FLC based UPQC by comparing the simulation results with the conventional PI controller based UPQC.

V. CONTROL STRATEGY

The performance of UPQC is enhanced by developing a novel control strategy using FLC. The benefits of FLC over the conventional controller are that FLC even works without a perfect mathematical model and is capable of handling nonlinearity .The FLC is more robust compared to conventional PI controller which also improves the performance of UPQC. The control strategy used in this work is described below.

A) Conventional PI Control strategy

In this control strategy, both shunt and series APF in UPQC is controlled with conventional PI controller as shown in fig.4. and fig.5. Using trial and error method the gain values P and I are chosen as Kp=0.1 and Ki=2. In series APF, the faulted sag voltage is compared with the reference voltage. The error voltage is processed through PI controller and its output is converted to three phase through unit vector generation, then it is fed into Pulse Width Modulation (PWM) generator to provide gate pulses to Series APF so as to inject the required voltage for the mitigation of voltage sag.

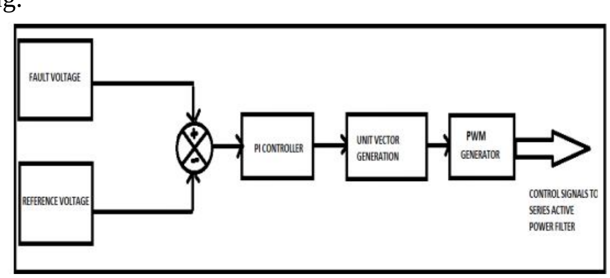

Fig.4. Control strategy for Series APF of UPQC

In Shunt APF, the harmonic load current is compared with the reference current and the error is processed through PI into PWM generator for providing gate pulses to Shunt APF so as to inject the required current for mitigating load current harmonics.

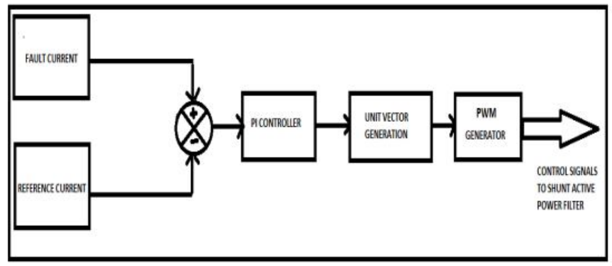

Fig.5. Control strategy for Shunt APF of UPQC

B) FUZZY LOGIC CONTROLLER

FLC is one of the most successful operations of fuzzy set theory. Its chief aspects are the exploitation of linguistic variables rather than numerical variables. FL control technique relies on human potential to figure out the system behavior and is constructed on quality control rules.. The basic structure of an FLC is represented in Fig.6.

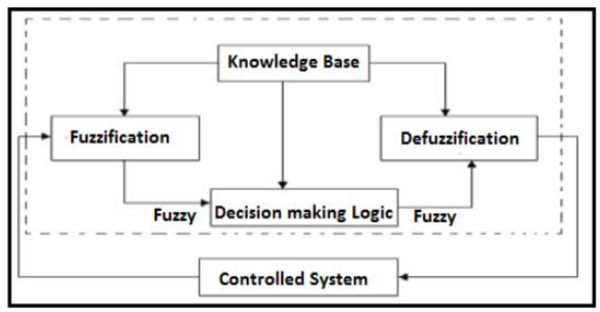

Fig.6. Basic structure of Fuzzy Logic controller

- A Fuzzification interface alters input data into suitable linguistic values.
- A Knowledge Base which comprises of a data base along with the essential linguistic definitions and control rule set.
- A Decision Making Logic which collects the fuzzy control action from the information of the control rules and the linguistic variable descriptions
- A Defuzzification interface which surrenders a non fuzzy control action from an inferred fuzzy control action.

In this paper, an advanced control strategy, FLC is implemented along with UPQC for voltage correction through Series APF and for current regulation through Shunt APF.

Error and Change in Error are the inputs and Duty cycle is the output to the Fuzzy Logic Controller as shown in Fig. 7-Fig.9

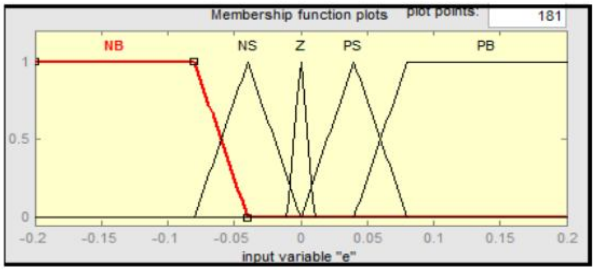

Fig.7. Error as input

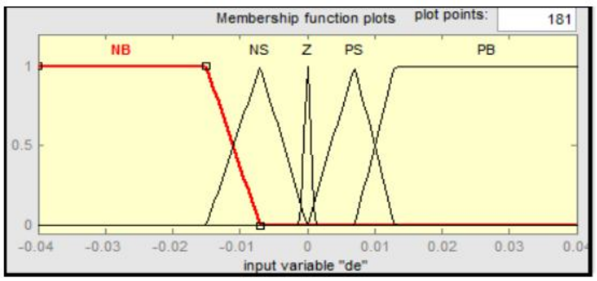

Fig.8 Change in Error as input

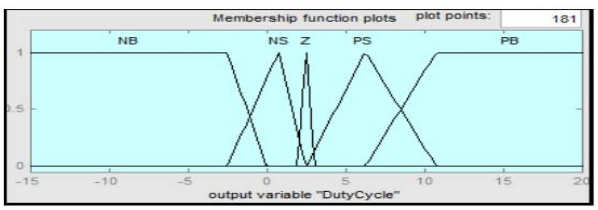

Fig.9 Output variables to defuzzification process

In the decision-making process, there is rule base that links between input (error signal) and output signal. Table II shows the rule base exercised in this proposed Fuzzy Logic Controller.

TABLE II. fuzzy rule representation

e \ de	NB	NS	Z	PS	PB
NB	PB	PS	NS	NS	NB
NS	PS	PS	NS	PB	NB
Z	NB	NB	NS	PS	PB
PS	NS	NS	PB	NB	PS
PB	NS	NS	PB	PB	PB

VI.SIMULATION RESULTS

The proposed system is implemented by integrating 120 kV power grid with 1 MW, 120 KV DFIG based wind turbine and also synchronized with respect to voltage and frequency using MATLAB Simulink. The effectiveness of the proposed system is validated by considering three different cases. The simulation of PQ problems and the implementation of UPQC along with proposed FLC and conventional PI controller are shown by the subsequent cases.

CASE 1: UNCOMPENSATED SYSTEM

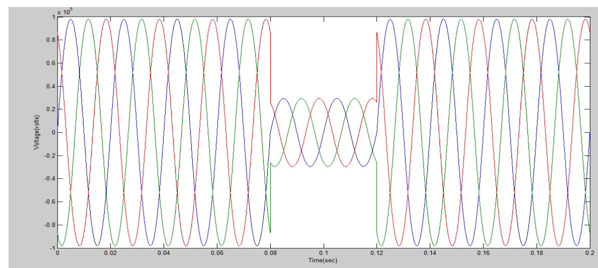

Fig.10.Voltage sag due to three phase to ground fault

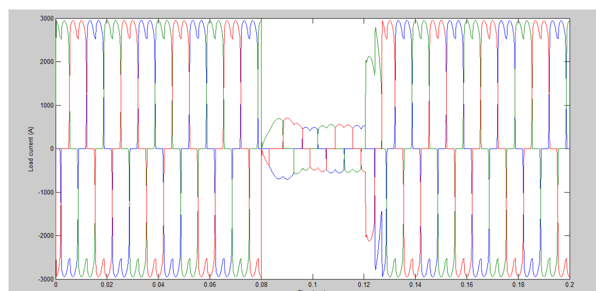

Fig.11. Load current due to non linear load

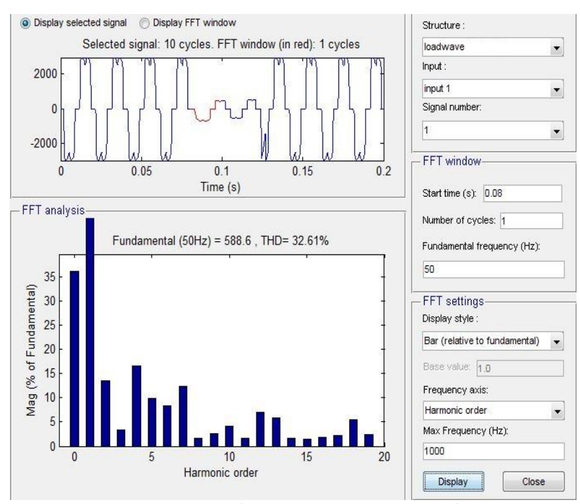

Fig.12. THD of Load current waveform

Case 2: UPQC with PI Controller

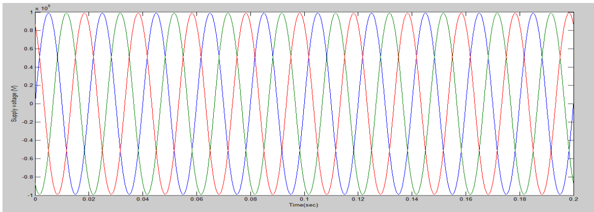

Fig.13.Source Voltage

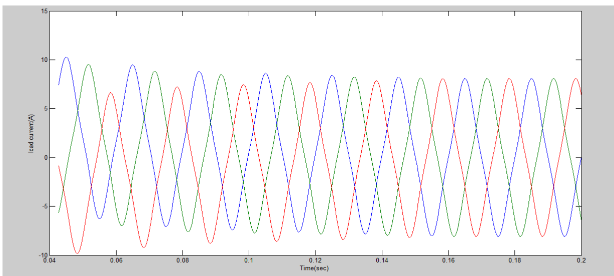

Fig. 14.Load current

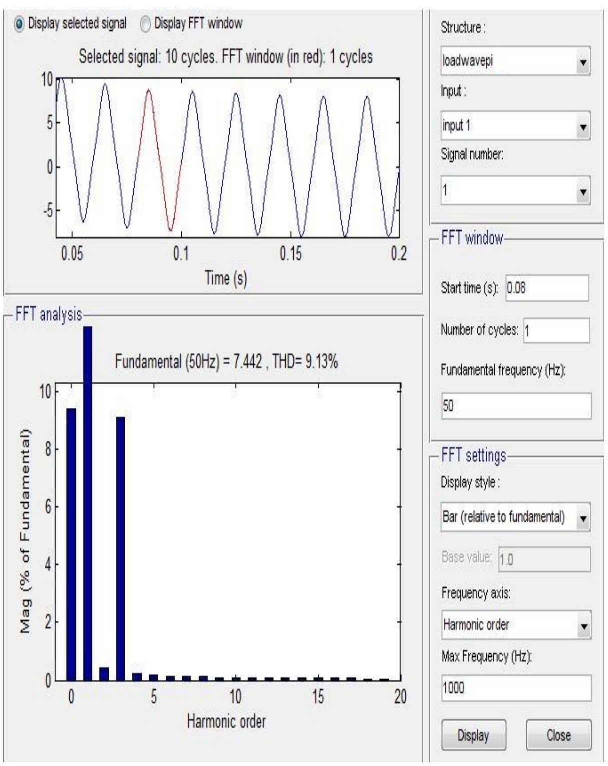

Fig.15. THD level of Load current

Case 3: UPQC with Fuzzy Logic Controller

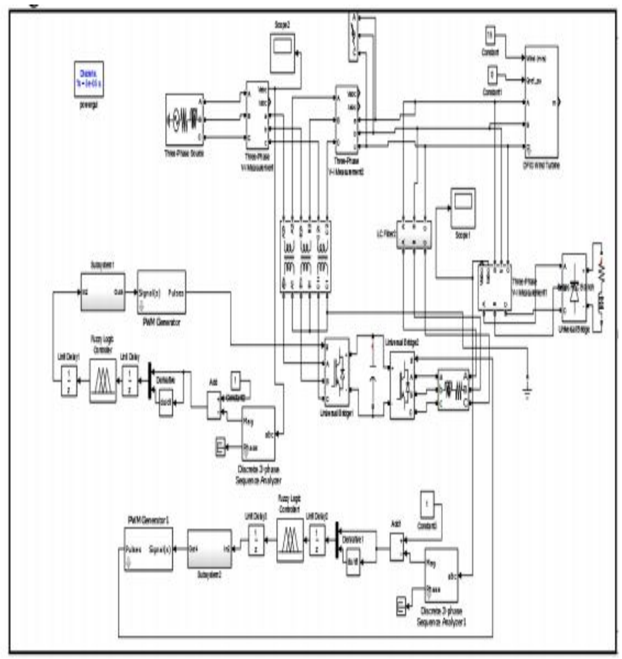

Fig.16. Proposed System

TABLE III . Design Values

PARAMETERS	VALUES USED IN THE SIMULATION MODEL
Injection Transformer Turns ratio for Series APF	1:1
Shunt APF	Filter Inductance L=6mH Filter Capacitance C= 20µF
DC Link Capacitor	2200µF
Inverter	IGBT based, 3 arms 6 pulse Carrier frequency = 10000 Hz

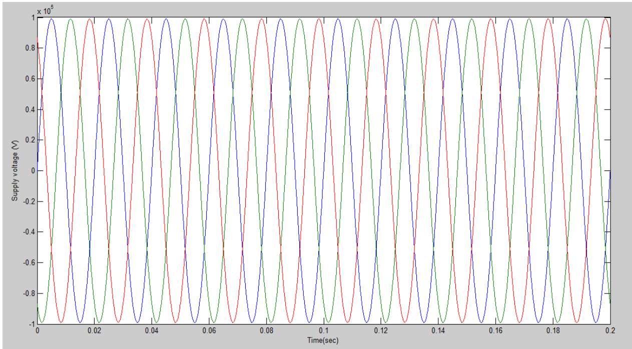

Fig.17. Source Voltage

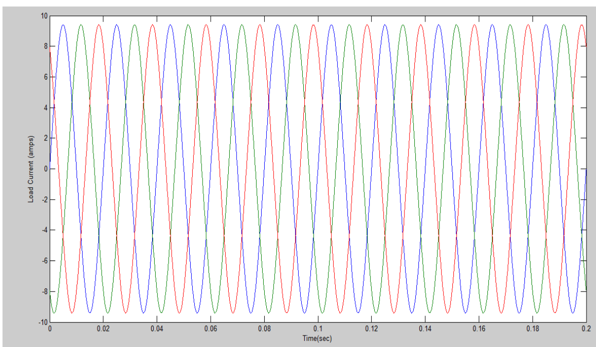

Fig.18.Load Current

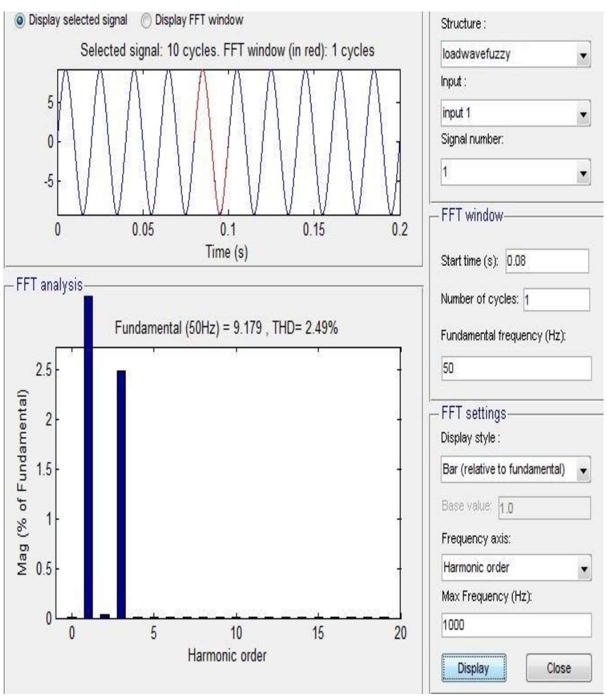

Fig.19.THD level of Load current

V.PERFORMANCE COMPARISON OF UPQC

TABLE IV . Performance Comparison

SYSTEM	LOAD CURRENT THD IN %
Uncompensated System	32.61
UPQC with PI controller	9.13
UPQC with Fuzzy Logic Controller	2.49

VI. CONCLUSION

This paper spotlights both Voltage and Current quality improvement in a Grid connected DFIG based wind power system. The PQ problems -Voltage sag and Current harmonics are simulated using MATLAB in a Grid connected wind power system. The fuzzy controlled UPQC is implemented for PQ enhancement to diminish both voltage sag and current harmonics and the simulation results are also compared with conventional PI controller. From the simulation results, the PI controlled UPQC completely mitigates voltage sag but the load current harmonics obtained is not within the acceptable bounds. The proposed Fuzzy Logic Controlled UPQC completely mitigates voltage sag and in addition to it, the load current harmonics are mitigated in a superior way by keeping THD level of load current within acceptable bounds as per IEC norms. Thus the proposed Fuzzy controlled UPQC is successfully proved efficient through its outstanding performance for improving PQ in a grid connected wind power system.

REFERENCES

[1] Frede Blaabjerg and Ke Ma, "Future on Power Electronics for Wind Turbine Systems," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, no. 3, pp. 139- 152, September 2013.

[2] Zheng Wang, Bo Yuwen, Yongqiang Lang and Ming Cheng, "Improvement of Operating Performance for the Wind Farm With a Novel CSC-Type Wind Turbine-SMES Hybrid System," IEEE Transactions on Power Delivery, vol. 28, no. 2, pp. 693-703, April 2013.

[3] M. Jahangir Hossain, Hemanshu R. Pota, Valeri A. Ugrinovskii and Rodrigo A. Ramos, "Simultaneous STATCOM and Pitch Angle Control for Improved LVRT

Capability of Fixed-speed Wind Turbines," IEEE Transactions on Sustainable Energy, vol. 1, no.3, pp. 142-150, October 2011.

[4] Christian Wessels, Nils Hoffmann, Marta Molinas, Friedrich Wilhelm Fuchs, "Statcom Control at Wind farms with FixedSpeed Induction Generators Under Asymmetrical Grid Faults," IEEE Transactions on Industrial Electronics, vol. 60, no. 7, pp. 2864-2873, July 2013.

[5] Mahmoud M. Amin and Osama A. Mohammed, "Development of High-Performance Grid-Connected Wind Energy Conversion System for Optimum Utilization of Variable Speed Wind Turbines," IEEE Transactions on Sustainable Energy, vol. 2, no. 3, pp. 235-245, July 2011.

[6] Yazhou Lei, Alan Mullane, Gordon Lightbody, and Robert Yacamini, "Modeling of the Wind Turbine With a Doubly Fed Induction Generator for Grid Integration Studies," IEEE Transactions on Energy Conversion, vol. 21, no.1, pp. 257-264, March 2006.

[7] S. Khalid and Bharti Dwivedi, "Power Quality Issues, problems, Standards and their Effects in Industry with Corrective Means," International Journal of Advances in Engineering and Technology, vol. 1, no.2, pp. 1-11, May 2011.

[8] P.Karuppanan and Kamala Kanta Mahapatra, "Active Harmonic Current Compensation To Enhance Power Quality," Electrical Power And Energy Systems, vol. 62, pp. 144-151, 2014.

[9] M. Shiddiq Yunus, Mohammad A. S. Masoum, and A. AbuSiada, "Application of SMES to Enhance the Dynamic Performance of DFIG during Voltage Sag and Swell," IEEE Transactions on Applied Superconductivity, vol. 22, no, 4, August 2012

[10] P. Karuppanan and Kamala Kanta Mahapatra, "PI and Fuzzy Logic Controllers for Shunt Active Power Filter," ISA Transactions, vol. 51, pp. 163-169, 2012.