POWER QUALITY IMPROVEMENT IN DFIG BASED WINDSYSTEM USING FUZZY CONTROLLED UPQC

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ABSTRACT- Inferable from fuel shortage and ecological sullying set off by the conventional sources, renewable energy resources rule the universe of power generation. Up degree of energy creation through wind ranches is being supported now-a-days, as the wind power is without earth, promptly accessible renewable option. The integration of wind ranches with power grid prompts Power Quality (PQ) issues, for example, voltage sag, swell, flicker, harmonics and so forth. A large portion of the industrial and business loads are of non-linear compose which surely the beginning spot of harmonics. As 70% of PQ issues are voltage sag which is a standout amongst the most serious unsettling influences to touchy loads. As a result of the previously mentioned issues both buyer division and creation part gets influenced with low quality of power which encourage PQ improvement taking care of business level. Among a large number of custom power devices, Unified Power Quality Conditioner (UPQC) is the main gadget used to reduce both voltage sag and current harmonics. This paper dissects PQ issues, voltage sag and current harmonics because of the interconnection of grid associated wind turbine and furthermore gives PQ upgrade by presenting UPQC. To enhance the execution of UPQC, a novel control procedure utilizing Fuzzy Logic Controller (FLC) is proposed which dispenses with the disadvantage of utilizing settled picks up in conventional PI controller. From the simulation results, by looking at controller execution, the proposed fuzzy controlled UPQC gives compelling and proficient moderation of both voltage sag and current harmonics than the conventional PI controlled UPQC , in this manner making the grid associated wind power system more dependable by giving great quality of power.

INTRODUCTION

With growing concerns about environmental pollution and a possible energy shortage, great efforts have been taken by the governments around the world to implement renewable energy programs, based mainly on wind power, solar energy, small hydro-electric power, etc. Ever since the first large grid connected wind farm appeared in California (U.S.) in the 1980s, wind power generation has been undergoing a significant development. With improving techniques, reducing costs and low environmental impact, wind energy seems certain to play a major part in the world's energy future. As the wind power penetration continually increases, power utilities concerns are shifting focus from the power quality issue to the stability problem caused by the wind power connection. In such cases, it becomes important to consider the wind power impact properly in the power system planning and operation.

Amongst many variable speed concepts, the DFIG equipped wind turbine has many advantages over others For example, the power converter in such wind turbines only deals with rotor power, therefore the converter rating can be kept fairly low, approximately 20% of the total machine power. This configuration allows for variable speed operation while remaining more economical than a series configuration with a fully rated converter. Other features such as the controllability of reactive power help DFIG equipped wind turbines play a similar role to that of synchronous generators. Whilst the simulation of the DFIG wind turbine has been dealt with in many publications, most of them were electromagnetic models suitable for the detailed study of the power converter and its control strategy. The unified power quality conditioner (UPQC) aims at integrating both shunt and series APFs through a common DC link capacitor. The UPQC is similar in construction to a unified power flow controller (UPFC). The UPFC is employed in power transmission system, where as the UPQC is employed in a power distribution system. The primary objective of UPFC is to control the flow of power at fundamental frequency. On the other hand the UPQC controls distortion due to harmonics and unbalance in voltage in addition to control of flow of power at the fundamental frequency.

In the normal operation of UPQC, the control circuitry of shunt APF calculates the compensating current for the current harmonics and the reactive power compensation. In the conventional methods, the DC link capacitor voltage is sensed and is compared with a reference value. The error signal thus derived is processed in a controller. A suitable sinusoidal reference signal in-phase with the supply voltage is multiplied with the output of the PI controller to generate the reference current. Hysteresis band is normally (most often but not always) is imposed on top and bottom of this reference current. The width of the hysteresis band is so adjusted such that the supply current total harmonic distortion (THD) remains within the international standards. The function of the series APF in UPQC is to compensate the voltage. The control circuitry of the series APF calculates the reference voltage to be injected by the series APF by comparing the terminal voltage with a reference value of voltage.

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 Wind power is fast becoming one of the leading renewable energy sources worldwide.

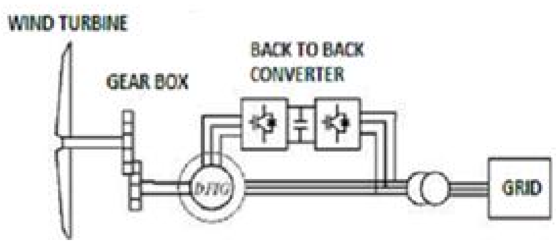

Fig.1. Grid connected DFIG based wind power system

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 benefitted with the following pros:

- ❖ Cost effective
- ❖ Simple means of pitch control
- ❖ Reduced mechanical stresses
- ❖ Dynamic compensation of torque pulsations
- ❖ Improved Quality of Power
- ❖ 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 converter costs only 25% of the total system power which improves entire system efficiency to a greater extent. While integrating electric grid with wind power system, owing to the stochastic nature of the wind, 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. The origin of voltage variations such as voltage sag and swell is due to wind velocity, generator torque and switching of wind turbine generator. Harmonics is one of the severe problems in grid connected wind power system. As the consequences faced by voltage sag and harmonics are dominant and leads to degradation of PQ at the consumer's terminal, this paper concentrates on alleviating these two PQ problems. The foremost impacts of the PQ problems are

- ❖ Malfunction of equipments such as adjustable speed drives, microprocessor based control system and Programmable Logic Controller, 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.

UNIFIED POWER QUALITY CONDITIONER

UPQC is a custom power device which is responsible for the alleviation PQ disturbances in both supply and load side. The schematic diagram of UPQC is shown in Fig.2. UPQC 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.

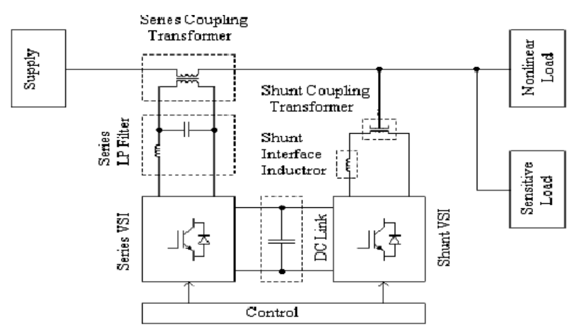

Fig.2. Schematic diagram of Unified Power Quality Conditioner

In order to mitigate harmonics commenced by nonlinear load, the shunt inverter injects a current as governed by following equation:

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

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:

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

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.
- UPQC also supports VAR requirement of the load, so that the supply voltage and current are forever in phase. As a consequence no additional power factor correction equipment is essential.
- UPQC maintains load end voltage 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.

PROPOSED METHODOLOGY

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

TABLE I.
DESIGN VALUES

PARAMETERS	SIMULATION VALUES
Main Supply voltage	120 kV
Line frequency	50 HZ
Source Impedance	Ls=16.58 mH; Rs= 0.8929 Ω
Non linear load Bridge Rectifier	R=5 Ω; L=1mH
Doubly Fed Induction Generator (DFIG)	Nominal power = 1MW Voltage = 120 kV Frequency = 50 HZ

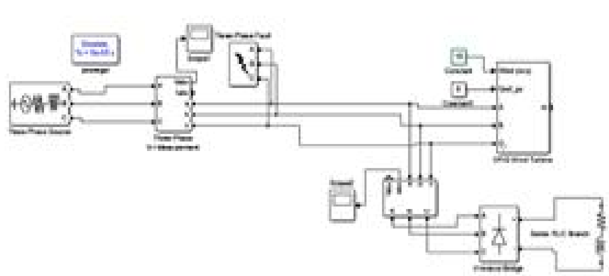

Fig.3.Simulation of PQ Problems

The wind speed is kept as 15m/s which are regarded as nominal value which may diverge from 8 to 15 m/s owing to fluctuations. The PQ problems voltage sag is simulated by creating three phase to ground fault and the 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 FLC is implemented for the generation of both 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.

CONTROL STRATEGY

In this work 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. Also FLC is capable of handling nonlinearity and 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. The gain values P and I are chosen as K_p=0.1 and K_i=2 using trial and error method. 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 such that this can be able to inject the required voltage for the mitigation of voltage sag.

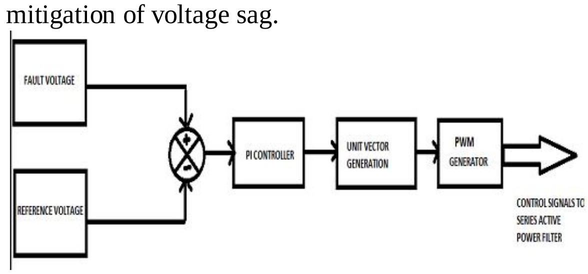

Fig.4. Control strategy for Series APF of UPQC

In Shunt APF, the harmonic load current is compared with the reference current and the error is processed through PI controller. Its output is converted to three phase and it is fed into PWM generator for providing gate pulses to Shunt APF which is capable of mitigating load current harmonics.

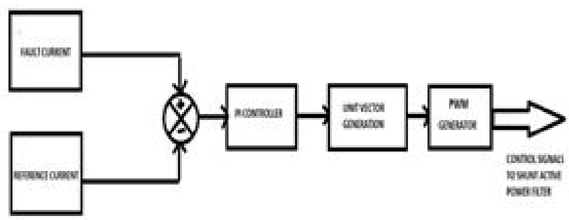

Fig.5. Control strategy for Shunt APF of UPQC

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. FLC Technique relies on human potential to figure out the systems behavior and is constructed on quality control rules. FL affords a simple way to arrive at a definite conclusion based upon blurred, ambiguous, imprecise, noisy, or missing input data. The basic structure of an FLC is represented in Fig.6.

- 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.

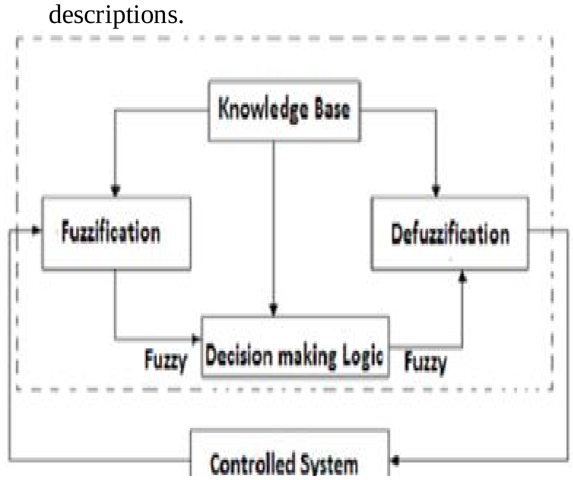

Fig.6. Basic structure of Fuzzy Logic controller

- A Defuzzification interface which surrenders a non fuzzy control action from an inferred fuzzy controlaction.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.

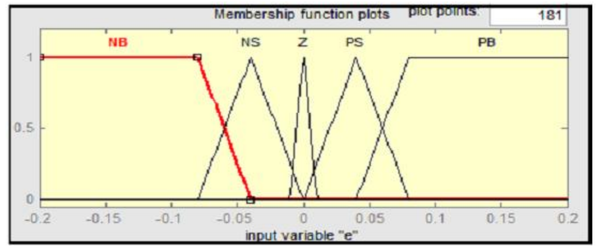

Fig.7. Error as input

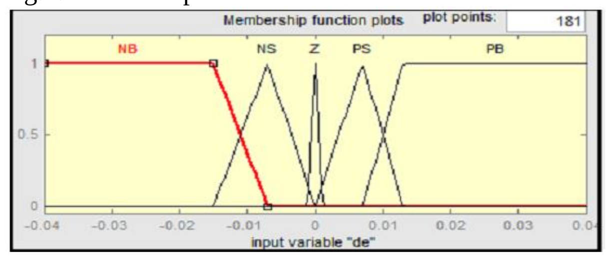

Fig.8 Change in Error as input

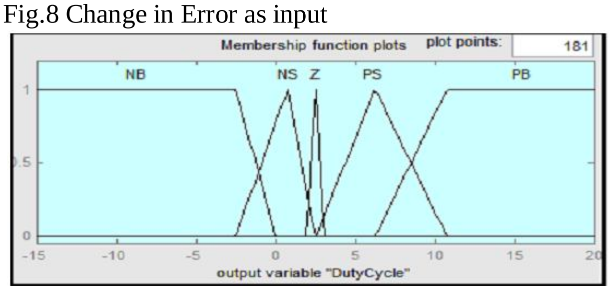

Fig.9 Output variables to defuzzification process

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

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.

A .Case 1: Uncompensated System

In the proposed system, the voltage sag is simulated by creating three phase to ground fault in the time interval of 0.08s to 0.12s and is shown in Fig.10. The non linear load is connected which makes load current harmonics in a grid connected wind power system and is shown Fig.11. The Total Harmonic Distortion (THD) in the load current of an uncompensated system is shown by the FFT analysis in Fig.12.

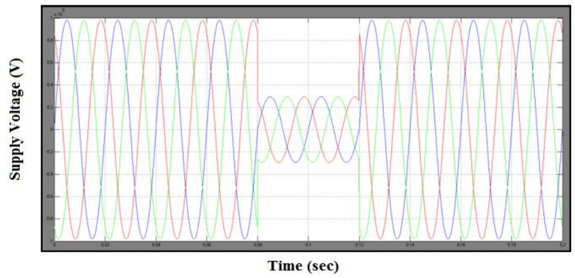

Fig.10.Voltage sag due to three phase to ground fault

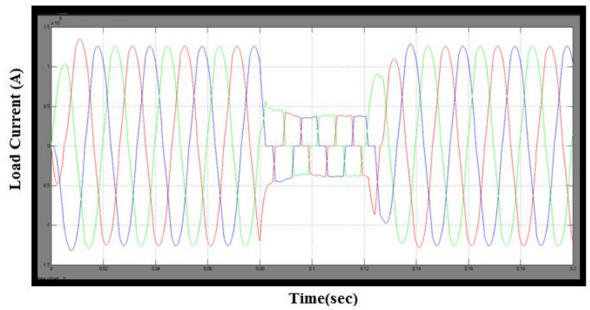

Fig.11. Load current due to non linear load

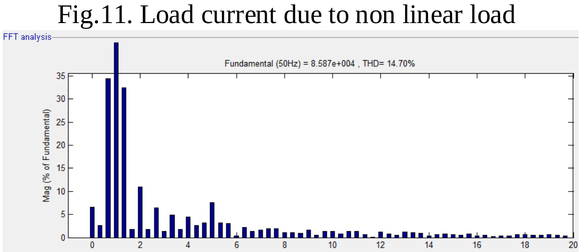

Fig.12. THD of Load current waveform

B. Case 2: UPQC with PI Controller

The custom power device UPQC is implemented with conventional PI controller to compensate both voltage sag and load current harmonics in the proposed system. The values of P and I are chosen by trial and error method appropriate for compensation. The simulation results for both source voltage and load current is shown in Fig.13 and Fig.14.The THD spectrum for load current is also shown in Fig.15.

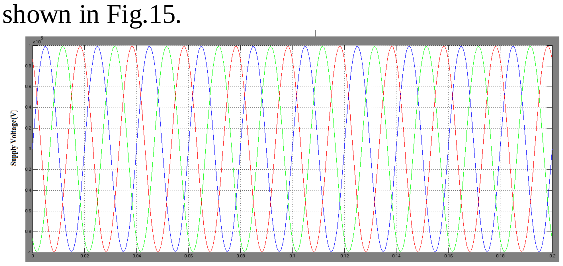

Fig.13. Source Voltage

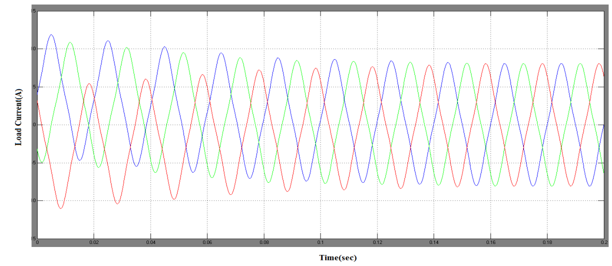

Fig.14. Load current

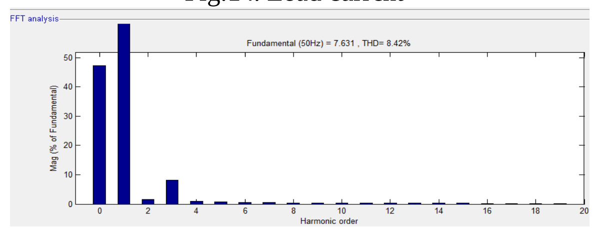

Fig.15. THD level of Load current

Case 3: UPQC with Fuzzy Logic Controller

The detailed Simulation of the Proposed UPQC with Fuzzy Logic Controller is shown in Fig.16 and the design values are also shown in Table III. The proposed Fuzzy Logic controller based UPQC is put into service to compensate both voltage sag and load current harmonics. The simulation end results for both source voltage and load current is shown in Fig.17. and Fig.18. The THD for load current is also shown in Fig.19.

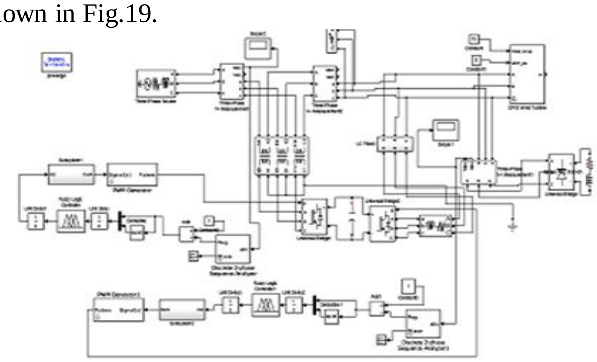

Fig.16. Proposed System

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	2200 µF
Inverter	IGBT based, 3 arms, 6 pulse Carrier frequency = 10000 Hz

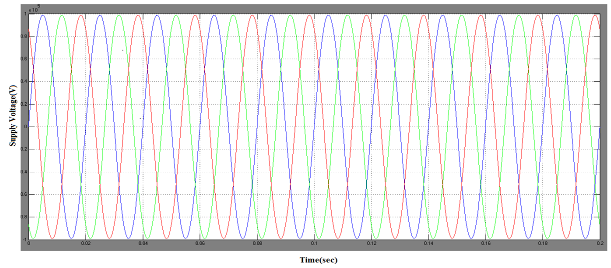

Fig.17. Source Voltage

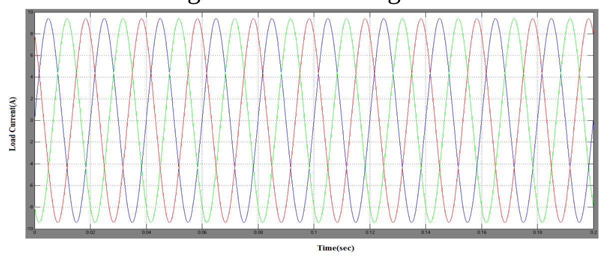

Fig.18. Load current

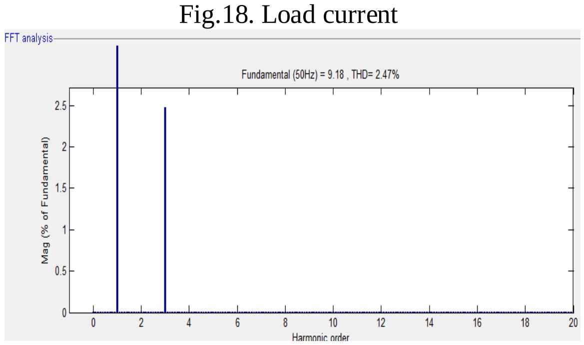

Fig.19.THD level of Load current

V.PERFORMANCE COMPARISON OF UPQC

The proposed Fuzzy controlled UPQC for alleviating both voltage sag and load current harmonics is implemented in a grid connected wind power system. The success of the proposed system is proven by comparing the proposed control strategy with conventional PI controller. The performance comparison results of UPQC with PI and Fuzzy logic controller is shown in Table IV.

TABLE IV.
PERFORMANCE COMPARISION

SYSTEM	LOAD CURRENT THD IN %
Uncompensated system	14.70
UPQC with PI Controller	8.42
UPQC with Fuzzy Logic Controller	2.47

By comparing the THD of load current, UPQC with PI Controller the load current harmonics achieved is 8.82% and the UPQC with Fuzzy Logic Controller the load current harmonics achieved is 2.30%., which shows the proposed FLC based UPQC offers effective and proficient compensation for both voltage sag and current harmonics. Thus the performance of UPQC is greatly improved by completely mitigating voltage sag and also the THD of load current is drastically diminished and is kept within acceptable IEEE norms.

CONCLUSION

This paper spotlights both Voltage and Current quality improvement in a Grid associated DFIG based wind power system. The PQ issues - voltage sag and current harmonics are recreated utilizing MATLAB in a grid associated wind power system. The fuzzy controlled UPQC is actualized for PQ upgrade to decrease both voltage sag and current harmonics and the simulation results are likewise contrasted and conventional PI controller. From the simulation results, the PI controlled UPQC totally mitigates voltage sag however the load current harmonics acquired isn't inside the worthy limits. The proposed Fuzzy Logic Controlled UPQC totally mitigates voltage sag. What's more, the load current harmonics are moderated superiorly by keeping THD level of load current inside adequate limits according to IEC standards. Therefore the proposed Fuzzy controlled UPQC is successfully demonstrated as proficient gadget through its remarkable execution for enhancing PQ in a grid associated wind power system.

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