Power Quality Enhancement in DFIG based Wind Power System using Fuzzy Controlled UPQC

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Abstract- Owing to fuel scarcity and environmental contamination set off by the conventional sources, renewable energy resources rule the world of power generation. Up gradation of energy production through wind farms is being encouraged now-a-days, 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 indeed the starting place of harmonics. As 70% of PQ problems are voltage sag which is one of the most severe disturbances to sensitive loads. As an outcome of the aforementioned issues both consumer sector and production sector gets affected with poor quality of power which urge PQ enhancement at its best level. Among many of custom power devices, Unified Power Quality Conditioner (UPQC) is the only device 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. To improve the performance 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 performance, 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.

Keywords- voltage sag, current harmonics, Doubly Fed Induction Generator (DFIG), Unified Power Quality Conditioner (UPQC), Power Quality (PQ).

1. Introduction
Augmentation of renewable energy sources such as wind, solar, tidal and hydro energies levitate to peak in the present set-up. The cost effectiveness, sustainable and clean nature of wind explains why it’s 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 power development [3][4]. The power efficiency is literally low for most wind speeds as such generators because it always prefers constant speed operation. In order to get improved efficiency, now-a-days, 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 partially rated power converter [5][6]. In order to enlarge 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 PQ in electric power systems [7]. Also the integration of large wind farms to power grid yields PQ problems such as voltage sag, swell, harmonics, flicker etc. Outcome 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 disoperation of drive systems [8]. Most industrial and commercial loads are of non-linear type, which are the origin of harmonics. The utility supplying these nonlinear loads has to deliver large VARs also [9][10]. For the alleviation of both voltage sag and current harmonics, custom power technology comes into picture. The widely exercised custom power device by plentiful researchers for relieving voltage related problems is 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 is the only device widely used for the mitigation of both voltage sag and load current harmonics, thus replacing the functions of two devices DVR and STATCOM [13]-[15]. 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 also requires precise linear mathematical model of the system, which is difficult to obtain under parameter variations and non-linear load disturbances. To overcome this problem the fuzzy logic controller is proposed which is best suited for non linear loads, as it works with linguistic variables and it doesn’t need any mathematical modeling [16]. In the proposed work, the PQ problems voltage sag and current harmonics are simulated and analyzed in the grid connected wind power system. To enhance PQ, the proposed FLC based UPQC is implemented for effective and efficient mitigation of both voltage sag and current harmonics. The performance of the proposed system is validated by comparing the simulation results with conventional PI controlled UPQC.

II. GRID INTEGRATED DFIG BASED WIND POWERSYSTEM - 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](image-url)

Wind power is fast becoming 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 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.
- 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 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 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.

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.

V. 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 Kp=0.1 and Ki=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 generator, 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.

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.
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 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.
- 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.

TABLE.I. FUZZY RULE REPRESENTATION

<table>
<thead>
<tr>
<th>Rule Base</th>
<th>NB</th>
<th>PB</th>
<th>PS</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>e&lt;0</td>
<td>NB</td>
<td>PB</td>
<td>PS</td>
<td>NS</td>
<td>NS</td>
<td>PS</td>
<td>PB</td>
</tr>
<tr>
<td>e&gt;0</td>
<td>NB</td>
<td>NS</td>
<td>PB</td>
<td>PS</td>
<td>NS</td>
<td>PB</td>
<td>PS</td>
</tr>
<tr>
<td></td>
<td>PS</td>
<td>NS</td>
<td>PB</td>
<td>PS</td>
<td>NS</td>
<td>PB</td>
<td>PS</td>
</tr>
</tbody>
</table>

VLSIMULATION 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.9. The non linear load is connected which makes load current harmonics in a grid connected wind power system and is shown Fig.10. The Total Harmonic Distortion (THD) in the load current of an uncompensated system is shown by the FFT analysis in Fig.11.
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.12 and Fig.13. The THD spectrum for load current is also shown in Fig.14.

Case 3: UPQC with Fuzzy Logic Controller

The detailed Simulation of the Proposed UPQC with Fuzzy Logic Controller is shown in Fig.15 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.16 and Fig.17. The THD for load current is also shown in Fig.18.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values used in the Simulation model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Transformer Turns ratio</td>
<td>1:1</td>
</tr>
<tr>
<td>Shunt APF</td>
<td>Filter Inductance L= 6mH Filter Capacitance C=20μF</td>
</tr>
<tr>
<td>DC Link Capacitor</td>
<td>2200 μF</td>
</tr>
<tr>
<td>Inverter</td>
<td>IGBT based, 3 arms, 6 pulse Carrier frequency = 10000 Hz</td>
</tr>
</tbody>
</table>

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 III.
TABLE III. PERFORMANCE COMPARISION

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>LOAD CURRENT THD IN%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncompensated system</td>
<td>43.24</td>
</tr>
<tr>
<td>UPQC with PI Controller</td>
<td>8.82</td>
</tr>
<tr>
<td>UPQC with Fuzzy Logic Controller</td>
<td>2.30</td>
</tr>
</tbody>
</table>

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.

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. In addition, the load current harmonics are mitigated in a superior way by keeping THD level of load current within acceptable bounds as per IEC 2015 International Conference on Circuit, Power and Computing Technologies [ICCPCT] norms. Thus the proposed Fuzzy controlled UPQC is successfully proven as efficient device through its outstanding performance for improving PQ in a grid connected wind power system.

REFERENCES

[14] G. Siva Kumar, Kalyan Kumar, and Mahesh K. Mishra, “Mitigation of Voltage Sags With Phase Jumps