Power quality improvement in grid connected wind energy conversion systems by using custom power device

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Abstract -*Renewable energy sources like solar, wind, tidal and hybrid each contribute major amount of power to generate electricity. Earlier days fossil fuels are used largely to extract electricity. Today due to shortage of fuels and environmental pollution caused by greenhouse gases, renewable energy has come to an effect. So, wind power penetration is increased worldwide in present days.* Due to the combination of penetration level of wind generation in to existing power grid has important impact on the ability system operation.*The connection of large wind farms to power grid may result in power quality problems. Power quality problems such as current and voltage harmonics, voltage sag / swell, voltage unbalance etc. have become the major reasons causing the malfunction of the electrical equipment. Poor power quality may cause various serious impacts on electrical loads and ultimately results in huge economic losses. Mitigation of voltage dips and swells and harmonics in a grid-connected wind energy conversion systems (WECS) employing multipole permanent magnet synchronous generator (PMSG) will be investigated (unified power quality conditioner) UPQC. So UPQC plays a major role to overcome the power quality problems. The performance of the designed custom power devices like DVR, STATCOM, UPQC etc. in the grid to which the wind energy systems are connected and evaluated using the MAT LAB /SIMULINK software. Power quality problems such as voltage dip, voltage swell and harmonic contents are mitigated in a grid to which a WECS is connected. The results shows that the quality of power is increased with CPD.*

Key Words: **Power quality, CPD, DVR, STATCOM, UPQC, WECS**

I. INTRODUCTION

Fossil fuelsare (coal, crude oil, natural gas and uranium) are primarily created of carbon. Air, water and land pollution are all consequences of using fossil fuels. So, this can be the most reason for changing from non-renewable to renewable energy resources. Wind energy is one of the most promising renewable energy resources for generating electricity due to its cost competitiveness compared to other conventional types of energy resources [1].The wind is a free, clean and inexhaustible energy source. Wind energy conversion is the fastest-growing source of new electric generation in the world. There are many challenges regarding the integration of wind energy in to the power systems. The connection of large wind farms to power grid may result in power quality problems. Power quality problems such as current and voltage harmonics, voltage sag, voltage unbalance etc. have become the major reasons causing the degradation or malfunction of the electrical equipment.

This paper is organized as follows: In Section II, grid connected wind energy system are presented. Section III describes the power quality problems and there causes. Techniques for power quality improvement are discussed in Section IV. Control methods for UPQC are discussed in Section V. Simulation results are discussed in Section VI. Finally, conclusions and future work are addressed in Section VII.

II GRID CONNECTED WIND ENERGY SYSTEM

The interaction between the wind energy conversion systems (WECS) and therefore the grid are a very important aspect within the designing of WECS. The most important problem faced throughout integration of the alternative energy production systems into existing power production systems is that the quality of power. Different wind tribune types have varied power quality characteristics. The power quality disturbances are power variances, vibrations, and harmonics [2].
Basically, a wind turbine can be equipped with any type of three-phase generator. Today, the demand for grid-compatible current are typically met by connecting frequency converters, although the generator provides alternating current (AC) of variable frequency or direct current (DC).

In the synchronous generator is much more expensive and mechanically more complicated than an induction generator of a similar size [3]. However, it has one clear advantage compared with the induction generator specifically, that it doesn't want a reactive magnetizing current. The flux within the synchronous generator may be created by using permanent magnets or with a traditional coil. If the synchronous generator has a suitable number of poles (a multi pole WRSG or a multi pole PMSG) [4], it can be used for direct-drive applications without any gearbox. As a synchronous machine, it is probably most suited for full power control as it is connected to the grid through a power electronic converter.

Mathematical Formulation of wind Turbine Model is presented as follows:

Under constant acceleration a, the kinetic energy (E) of an object having mass (m) and velocity (v)is equal to the work done (W) sin displacing that object from rest to a distances under a Force F, i.e. [5].

E = W = Fs. (1)

According to Newton's second law of motion [6],

F = ma (2)

Assuming the initial velocity of the object is zero, we have that a =$\frac{v^2}{2s}$. Hence from equation (2) we have that

$E = \frac{1}{2}\, m\, v^2$(3)

This kinetic energy formulation is based on the fact that the mass of the solid is a constant. However, if we consider wind (air in motion) as a fluid, both density and velocity can change and hence no constant mass.

The power P in the wind is given by the rate of change of kinetic energy, i.e.

$$P = \frac{dE}{dt} = \frac{1}{2}\frac{dm}{dt} v_m^2 \quad (4)$$

But mass flow rate dm/ dt is given by dm/ dt = ρ Av_m where, A is the area through which the wind in this case is flowing and ρ is the density of air. With this expression, equation (4) becomes

$P = \frac{1}{2}\rho.\ A.\ V_W^3$(5)

$P_w = \frac{1}{2}\rho.\ A\ .V_W^3\ .c_p$

$c_{\ p} = 0.5\,[\gamma\ - 0.022\beta^2\text{-}5.6]e^{-0.17\gamma}$(6)

Where $'c_p'$ is a power coefficient of the rotor and it varies with tip speed ratio.

β = Blade pitch angle.

III. POWER QUALITY

Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment. Set of parameters process the properties of the ability supply as delivered to the user in traditional operative conditions in terms of continuity of supply and characteristics of voltage (frequency, magnitude and waveform). The aim of the power system has always been to supply electrical energy to the customers.

3.1 Power Quality Problems

Sags (Dips): A sag is an decrease to between 0.1 and 0.9 p.u in rms voltage or current at power frequency for durations from 0.5 cycle to at least one min. Examples include system faults, energization of heavy loads, starting of big motors etc.

*Swells:*A swell is an increase to between 1.1 and 1.8 p.u in rms voltage or current at power frequency for durations from 0.5 cycle to one min. Sometimes the term momentary over voltage is used as a synonym for the term swell. Examples includesystem faults, switching off heavy loads, energizing a large capacitor bank etc.

Harmonics: Harmonic distortion originates within the nonlinear characteristics of devices and loads on the power system. Examples embrace computers; fax machines, UPS systems, variable frequency drives (VFDs) etc.

3.2 Options to Mitigate Harmonics

A number of options that work to minimize actual harmonic loads are presently available, but should be carefully considered because of the added expense and because they utilize more copper, which is becoming increasingly scarce.

1. *K-factor transformers*

Standard transformers will overheat and fail untimely owing to the high currents made by non-linear loads. K-rated transformers are designed to handle the heat generated by harmonic currents. Standard transformers have a K-factor rating of one. The higher the K-rating, the lot of harmonic-generated heat the transformer will accommodate and minimize. K-factor transformers should be properly chosen so as to balance cost, efficiency and safety.

2. *Phase shifting transformers*

These transformers will facilitate cancel harmonics once many several non-linear loads of equal ratings share a power system. Loads are phased-shifted opposite of every alternative (E.g., -20° phase shift and +20° phase shift) so once combined, the harmonics from both phases create a clean sine wave. This selection adds another expense to the information center and isn't continually fully effective because the loads need to be exactly the same on each transformer.

3. *Harmonics filters*

Harmonic filters remove harmonics and correct the phase of the fundamental current, thus converting non-linear loads into linear loads.

IV TECHNIQUES FOR POWER QUALITY IMPROVEMENT

Resistors, capacitors and inductors all consume power once a current passes through them, and incapable of power gain. Therefore, any RLC filter may be a passive filter, particularly with the inductors enclosed. Another major characteristic of the passive filters is that the filters don't would like associate external power supply for operation. Passive filters also create a little amount of noise, due to the thermal noise in the elements. Some drawbacks for passive filters are can filter only the frequencies Resonances will occur attributable to the interaction between the passive filters and other loads, with unpredictable results [7]. To come out of these disadvantages recent efforts are concentrated in the development of active filters.

Filters with parts like operational amplifiers, transistors, or alternative active parts are referred to as active filters. They use capacitors and resistors, however not inductors. Active filters need an external power source to operate because of the power consuming active elements in the design [8]. Since no inductors are used, the circuit is more compact and less heavy. Active power filters are relatively costlier than passive filters.

Now a day's power electronics based appliances are wide utilized in industries and in distribution system that creates a lot of power quality problems. The ability of power electronics based power conditioning devices are often an effective solution to enhance power quality in power system. Now, more advanced technology is used for reliable and operation of distribution in power system. To achieve both reliable and benefit economically. Custom power devices (CPD) are effective and capable of increasing the power transfer capability of a line and support the power system to work with comfortable margins of stability. The technology of the application of power electronics to power distribution system for the benefit of a customer or group of customers is called custom power devices (CPD) [6].

CUSTOM POWER DEVICES (CPD)

The compensating custom power devices are used for active filtering, load balancing, power factor improvement and voltage regulating (sag/swell).There are three types of custom power devices: distribution static compensator (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC).

A. *Distribution Static Compensator (DSTATCOM)/Shunt Active Power Filter:*

Distribution static compensator (DSTATCOM) [6], it is a shunt connected device. This can perform load compensation, i.e., power factor correction, harmonic filtering, load balancing etc. when connected at the load terminals. The main aim of SAPF are to compensate for distortions and harmonics which are produced due to current [6].

B. *Dynamic Voltage Restorer (DVR)/Series Active Power Filters:*

Dynamic voltage restorer (DVR), it is a series connected device. The most purpose of this device is to protect sensitive loads from sag/swell, interruptions within the supply side. Series active power filters are used to maintain the load voltage at a desired magnitude and part by compensating the voltage sag/swell, voltage unbalance and voltage harmonics presented at the supply side [9]. So as to mitigate voltage disturbances, DVR injects voltagesof appropriate magnitude and introduce in series with the supply voltage.

C. *Unified Power Quality Conditioner (UPQC):*

UPQC which can solve voltage and current related problem simultaneously [10]. This is connected before load to make load voltage distortion free and at the same time reactive current drawnfrom source should becompensated in such a way that the currents at source side would be in phase with supply voltage [10]. The UPQC with [11] distribution generation (DG) help to compensate voltage and current power quality problems and have given additional bene-fit by providing the power to load whenever voltage interruption occur with source side.

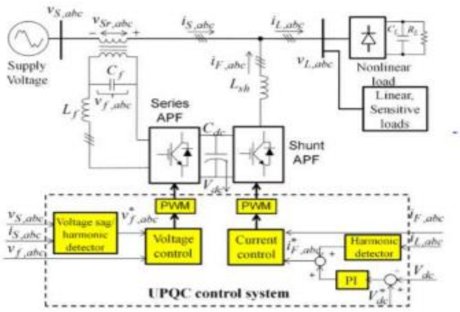

Fig. 1 Configuration of UPQC

UPQC has two voltage-source inverters which are connected back to back by common DC bus. A series electrical converter is connected through transformer between supply and point of common coupling (PCC) and a shunt electrical converter is connected across load. Series inverter is responsible for mitigation of supply side disturbances such as voltage sag/swell, flickers and voltage unbalance and its main problem is the poor voltage regulation at the point of common coupling (PCC) [12]. The shunt inverter is responsible for mitigating the current related problems caused by consumers such as poor power factor, load harmonic currents and load unbalance etc. It injects current in system in such some way that supply current become balanced, sinusoids and in phase with the supply voltage [11].

V. CONTROL METHODS FOR UPQC

They are different control techniques used for controlling the switches of VSI. The controlling techniques are used to improve the performances of the filters.

A. EXISITING METHOD

A proportional integral controller (PI controller) could be a generic control loop feedback mechanism (controller) wide utilized in industrial control systems. This controller is most ordinarily used feedback controller. PI controller calculates associate "error" value because the difference between a measured process variable and a desired point. The controller makes an attempt to attenuate the error by adjusting the method control inputs [13].

Disadvantages:

PI Current Control does not react fast enough to deliver current to load, which results distortions of current and PI controllers designed based on the equivalent linear model and also it is a manual tuning.

B. PROPOSED CONTROL METHOD

Due to these drawbacks for PI controller, the performance is poor. So in this paper consider a Adaptive Neuro-Fuzzy Inference Systems (ANFIS) control method is applied in the WECS.

Adaptive Neuro-Fuzzy Inference Systems (ANFIS) are a class of adaptive networks that are functionally equivalent to fuzzy inference systems. ANFIS represents Sugenoe fuzzy models. It uses a hybrid learning algorithm. A good performance is achieved with ANFIS controller by the fusion of fuzzy and Neural Network (NN). The fuzzy logic and neural networks can be integrated to form a connective adaptive network based fuzzy logic controller. The ANFIS controller is gives better results compared to the PI controller.

ADVANTAGES OF ANFIS:

Faster convergence than typical feed forward NN, numbers of training sets are less and the system can be modelled with small set of rules and it is an auto tuning.

IV. MATLAB SIMULATION RESULTS

A. Test System without Compensation

The test system consists of PMSG, circuit breaker, RLC load and supply which is shown in Fig. 2.

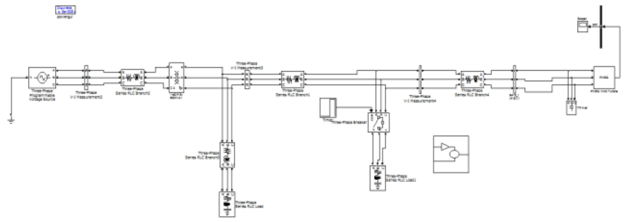

Fig.2 Simulink diagram for grid connected wind energy conversion systems without UPQC

A. Results Without Compensation For Voltage Sag /Swell

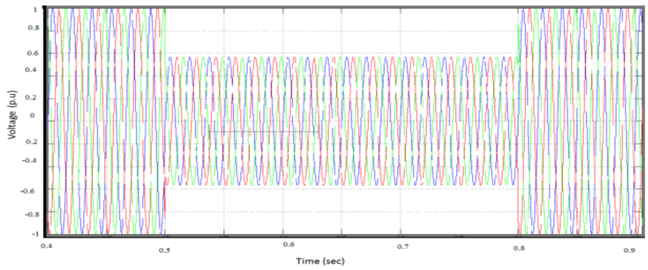

Fig. 3 Voltage waveform with sag at load bus

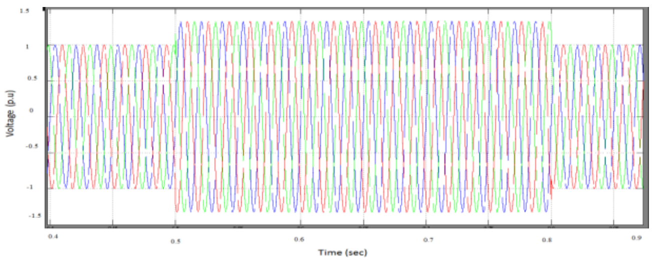

Fig. 4 Voltage waveform with swell at load bus

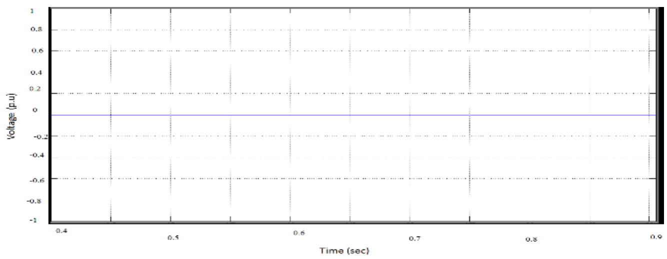

Fig. 5 Voltage Injection / absorption waveform during voltage sag / swell at Loadbus

A. Test System With Compensation

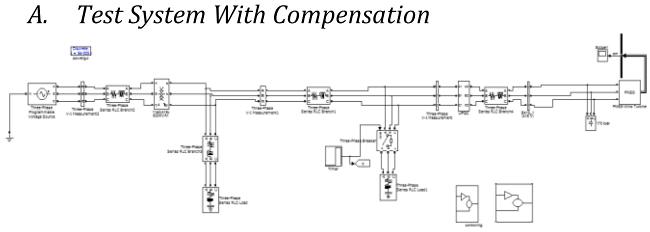

Fig. 5 Simulink diagram for grid connected wind energy conversion systems with UPQC

A. Results With Compensation For Voltage Sag /Swell

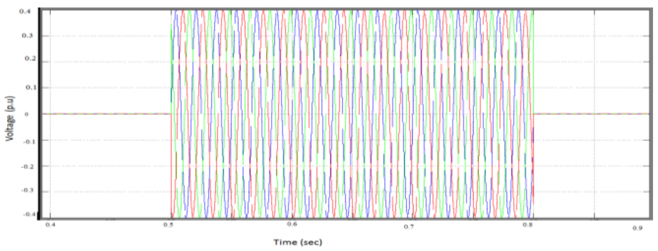

Fig. 6 Voltage injection at load bus when sag / swell occurs.

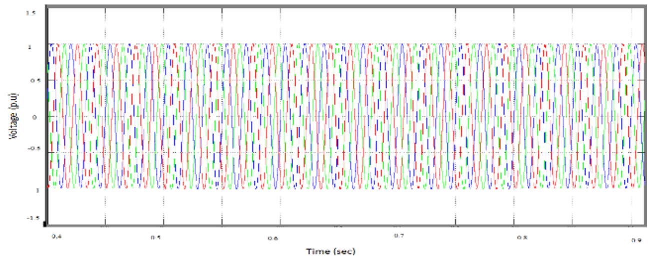

Fig. 7 Voltage at Load bus without sag / swell

Table 1: Comparison for THD and Voltage sag /swell without and with UPQC using PI and ANFIS controller

Causes	Without UPQC	With UPQC Using PI Controller	With UPQC Using ANFIS Controller
THD	14.14%(V) 11.88% (I)	2.24% (V) 1.75% (I)	1.13% (V) 1.32% (I)
Voltage Sag/Swell	Duration Time (0.5 - 0.8)	Duration Time (0.5 - 0.8)	

The above table shows that comparison for all THD values with UPQC and without UPQC. The THD values are decreasing from 14.14 to 1.13 % (source voltage) and THD values are decreasing from 11.88% to 1.32 % (source current).

V. CONCLUSION

Nonlinear loads/ switching devices produce harmonic currents that can propagate to other locations in the power system and eventually return back to the source. Therefore, harmonic current propagation produces harmonic voltages throughout the power systems. Power quality problems (voltage sag/swells, harmonics etc.) creates malfunction in customer equipment's. Integration of high penetration level of wind power in to existing power systems, creates stability problems, possible blackouts and also reduces overall efficiency and power quality. Mitigation of power quality problems investigated in a grid-connected wind energy conversion systems (WECS) employing multipole permanent magnet synchronous generator (PMSG) Using WECS electricity can be produced locally and also to transpose to grid. Installation of PMSG topologies is easy and has high efficiency compare to other topology. Mitigation techniques have been proposed and implemented to maintain the harmonic voltages and currents within recommended levels are harmonic filters (passive, active and hybrid) and custom power devices such as DVR, DSTATCOM and UPQC .The power electronic based power conditioning devices can be an effective solution to improve power quality in power system. Custom power devices are used to mitigate the power quality problems in a grid to which a WECS is connected. FFT analysis shows that there is a significant decrease in %THD values both for current and voltages waveforms with UPQC compared with UPQC is not used.

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