International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 2, Volume 2 (February 2015) www.ijirae.com

INVESTIGATION OF UPQC FOR POWER QUALITY DISTORTIONS IN WIND ELECTRIC SYSTEMS

Anisha Asmy N.R. [1], Aparna M Nambiar[2], P. Deebikha[3], Deepthi.S [4], S.Lavanya[5]
[1]Assistant Professor, [2,3,4,5]UG Scholars
Department of Electrical and Electronics Engineering

***Abstract*--The power quality problems like voltage sag, voltage swell, harmonics etc can be compensated through a three phase four wire unified power quality conditioner (UPQC) under unbalanced and distorted load condition. UPQC is a device which is used to share the active power between shunt and series converters through DC link. This reduces the use of power source installed in DC bus by maintaining series voltage injection with any phase angle. The SRF based control method for UPQC have been used and simulated using MATLAB/SIMULINK.**

***Keywords*—UPQC, Voltage sag, Voltage swell, SRF**

I. INTRODUCTION

In the last years, the wind power generation incorporated into standard grids has been increased significantly. This situation forced the revision of grid connection code requirements, to guarantee the reliability in systems with high wind power penetration. In case of three phase short circuit, voltage sags are observed near the point of failure, and characterized by a sudden voltage reduction and lagging phase jump. For induction generator based wind farms connected to weak grids, such sag may lead to wind farm outage, due to limited low voltage ride through capability of induction generators.

A robust multivariable controller with the objective of enhancing the low-voltage ride-through (LVRT) capability of wind farms with fixed-speed induction generators has been proposed in [1]. The designed robust controller provides acceptable post fault performance for both small and large perturbations. Under unbalanced grid voltage dips, the negative sequence voltage causes heavy generator torque oscillations that reduce the lifetime of the drive train. Investigations on an FSIG-based wind farm in combination with a STATCOM under unbalanced grid voltage fault are carried out by means of theory, simulations, and measurements and discussed in [2]. The results clarify the effect of the positive- and the negative-sequence voltage compensation by a STATCOM on the operation of the FSIG-based wind farm. A new concept of optimal utilization of a unified power quality conditioner (UPQC) is introduced in [3]. The active power control approach compensates the voltage sag/swell and is integrated with theory of power angle control (PAC) of UPQC to coordinate the load reactive power between the two inverters. Since the series inverter simultaneously delivers active and reactive powers, this concept is named as UPQC-S (S for complex power). A detailed mathematical analysis, to extend the PAC approach for UPQC-S, is presented.

UPQC is a device that is used to eliminate the disturbances in the power system. It controls the power flow and the voltage stability and it can compensate the voltage sag, swell, harmonic current and voltage interruption. UPQC is the combination of a series active power filter (APF) and a shunt APF which compensates the voltage interruption if it has some energy storage or battery in the dc link.

Shunt APF compensates current related problems such as reactive power compensation, power factor improvement and load unbalance compensation. Shunt APF is connected across the load and series APF is connected in series with the line through a series transformer. Series APF compensate all voltage related problems such as voltage harmonics, voltage sag, voltage swell, flicker and it can control the voltage source.

In this work a voltage sag compensation strategy is proposed for amplitude and phase jump restoration. These strategies were implemented using Unified Power Quality Compensator (UPQC). Unlike other Custom Power Devices like DVR and D–STATCOM, the UPQC has the feature of active power sharing between shunt and series converters through DC–link; thus, series voltage injection with any phase angle may be maintained without the need of power source installed in DC bus. The system performance is improved by optimising UPQC system with SRF based control. Results show a better wind farm performance with proposed strategy. Thus, considering the improvement in performance, the proposed strategy is recommended in retrofitting the existing installed fixed speed induction generators based wind farms.

II. PROPOSED SYSTEM

The proposed SRF-based control method is one of the most conventional and the most practical methods. It uses a-b-c to d-q-0 transformation equations, filters and the modified PLL algorithm. Fig.1 shows the UPQC general block diagram. Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. The shunt converter is connected in parallel to the load. It provides VAR support to the load and supply harmonic currents. Whenever the supply voltage undergoes sag/swell then series converter injects suitable voltage with supply. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor.

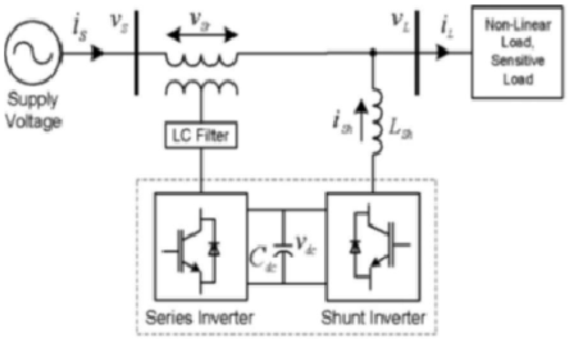

Figure 1: UPQC general block diagram

III. SRF

The conventional SRF method can be used to extract the harmonics contained in the supply voltages or currents. For current harmonic compensation, the distorted currents are first transferred into two-phase stationary coordinates using α−β transformation. After that, the stationary frame quantities are transferred into synchronous rotating frames using cosine and sine functions from the phase-locked loop (PLL). The conventional SRF algorithm is also known as d−q method, and it is based on park transformation.

In 3P4W systems, since the i_d component of the current in the "d" coordinate is in phase with voltage, it corresponds to the positive-sequence current. However, the i_q component of the current in the "q" coordinate is orthogonal to the i_d component of the current, and it corresponds to the negative sequence reactive current. The i_0 component of the current, which is orthogonal to i_d and i_q, corresponds to the zero sequence component of the current. If the i_q component of the current is negative, the load has inductive reactive power. If it is positive, the load has capacitive reactive power.

The oscillating components (i_d and i_q of the current) correspond to harmonic currents, and the average components of the current correspond to the active (i_d) and reactive (i_q) currents. In the balanced and linear three-phase systems, the load voltage and current signals generally consist of fundamental positive-sequence components. However, in unbalanced and nonlinear load conditions, they include fundamental positive-, negative-, and zero-sequence components. In APF applications, the fundamental positive-sequence components of the signals should be separated in order to compensate the harmonics.

IV. PROPOSED SRF-BASED CONTROL ALGORITHM

The proposed SRF control method uses a−b−c to d−q−0 transformation equations, filters, and the modified PLL algorithm. The proposed method is simple and easy to implement and offers reduced current measurement. Therefore, it can run efficiently in DSP platforms. Hence, the proposed modified PLL algorithm efficiently improves the performance of the UPQC under unbalanced and distorted load conditions.

In the proposed method shown in Fig.3, sensing three phase source current and voltages and load voltages along with a dc-link voltage are adequate to compute the reference switching signals in the UPQC. Generally, for SRF-based controllers, either source currents or shunt active filter and load currents are used for reference-current signal generation. The proposed SRF-based control method presents some advantages, compared with other methods. The overall control system can be easily applied since it has less current measurement requirements. The proposed method has an effective response under distorted and unbalanced load conditions. The proposed control strategy is capable of extracting most of the load-current and source-voltage distortions successfully.

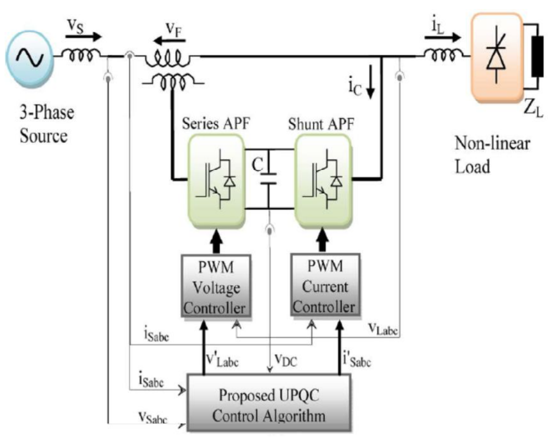

Figure 2: Proposed UPQC control block diagram.

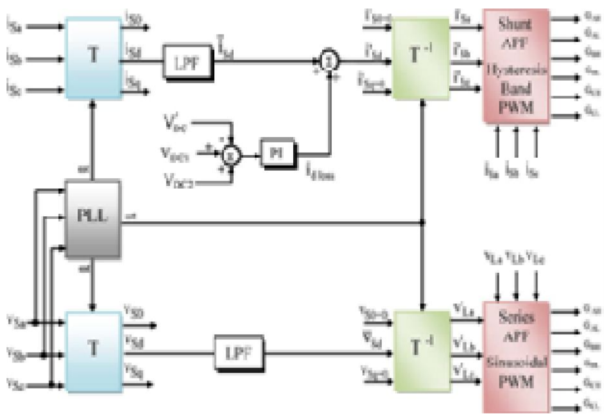

Figure 3: SRF-based UPQC control algorithm

The proposed SRF-based UPQC control algorithm can be used to solve the PQ problems related with source-voltage harmonics, unbalanced voltages, and voltage sag and swell at the same time for series APFs. In the proposed method, the series APF controller calculates the reference value to be injected by the STs, comparing the positive-sequence component of the source voltages with load-side line voltages.

The source-voltage positive-sequence average value in the d-axis is calculated by LPF. Zero and negative sequences of source voltage are set to zero in order to compensate load voltage harmonics, unbalance, and distortion.The produced load reference voltages and load voltages (V_{La} , V_{Lb}, and V_{Lc}) are compared in the sinusoidal pulse width modulation controller to produce insulated-gate bipolar transistor (IGBT) switching signals and to compensate all voltage-related problems, such as voltage harmonics, sag, swell, voltage unbalance, etc., at the PCC.

The proposed SRF-based shunt APF reference source-current signal-generation algorithm uses only source voltages, source currents, and dc-link voltages. The source currents are transformed to d−q−0 coordinates and coming from the modified PLL. In 3P4W systems and nonlinear load conditions, the instantaneous source currents (i_{Sd} and i_{Sq}) include both oscillating components and average components.

The proposed SRF-based method employs the positive-sequence average component in the d-axis and the zero- and negative-sequence component in the 0- and q-axes of the source currents, in order to compensate harmonics and unbalances in the load. The active power is injected to the power system by the series APF in order to compensate the active power losses of the UPQC power circuit, which causes dc-link voltage reduction. For this purpose, the dc-link voltage is compared with its reference value, and the required active current is obtained by a PI controller. The source current fundamental reference component is calculated by adding to the required active current and source current average component (i_{Sd}), which is obtained by an LPF.

In the proposed method $i'_{Sd} = i_{dloss} + i_{Sd}$, the zero- and negative-sequence components of the source current reference (i'_{so} and i'_{sq}) in the 0- and q-axes are set to zero in order to compensate the harmonics, unbalance, distortion, and reactive power in the source current. The produced reference-source currents and measured source currents (i_{sa}, i_{sb}, and i_{sc}) are compared by a hysteresis band current controller for producing IGBT switching signals to compensate all current-related problems, such as the reactive power, current harmonic, neutral current, dc-link voltage regulation, and load current unbalance.

V. RESULTS

The simulation of the proposed system has been done using MATLAB/SIMULINK for series compensation alone. A 415V, 50Hz, Programmable voltage source has been used as a grid and is connected to the fixed speed squirrel cage induction generator.

A load of 8kW has been connected and the effect of sag and swell has been analysed for three phase to ground fault. 20% of voltage sag and swell has been applied for a period of 1 to 2s for all the three phases in the grid side. The grid and wind generator voltage for voltage sag and swell has been shown in Fig.4 and Fig.7 respectively. It can be seen that without UPQC the voltage sag and swell in the grid side has affected the wind electric generator voltage. The rotor speed of wind electric generator without UPQC has been shown in the Fig.5 and 6. It can be seen that on connecting UPQC, the voltage and speed of the wind electric generator drastically changes to the pre-fault value as shown in Fig.8-11.

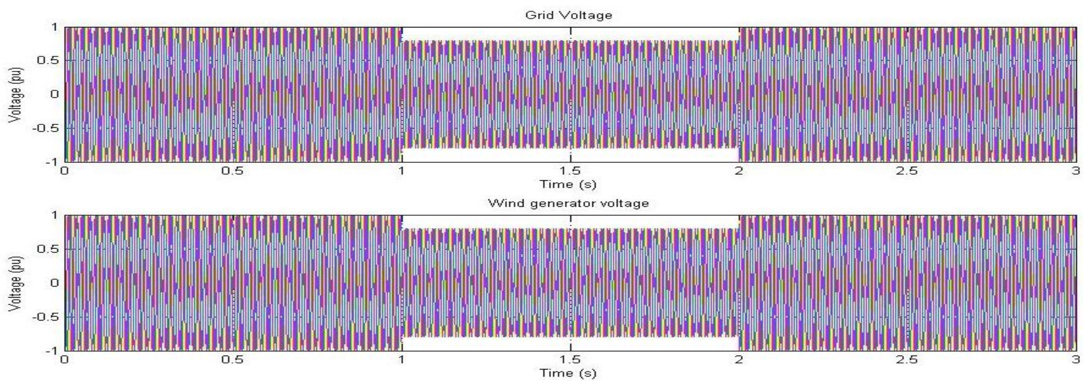

Figure 4: Voltage sag-Grid and wind generator voltage without UPQC for three phase to ground fault.

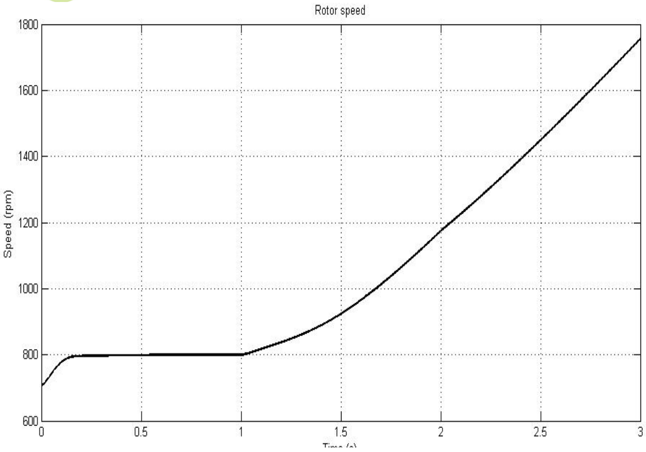

Figure 5: Voltage sag-Rotor speed of wind electric generator without UPQC.

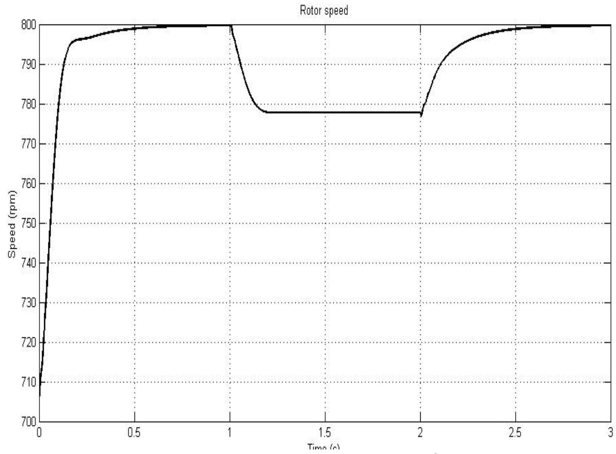

Figure 6: Voltage swell-Rotor speed of wind electric generator without UPQC.

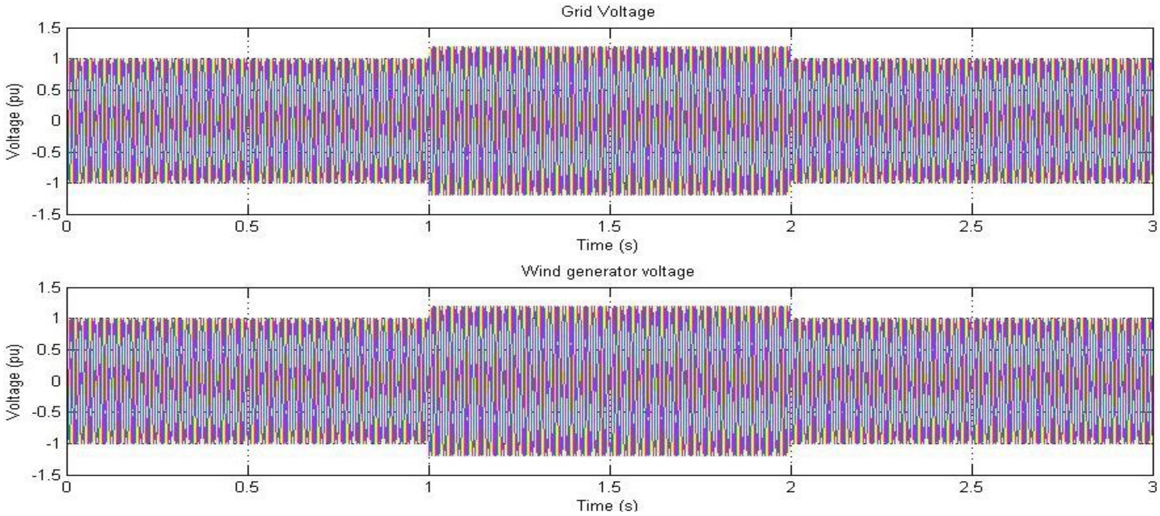

Figure 7: Voltage swell-Grid and wind generator voltage without UPQC for three phase to ground fault.

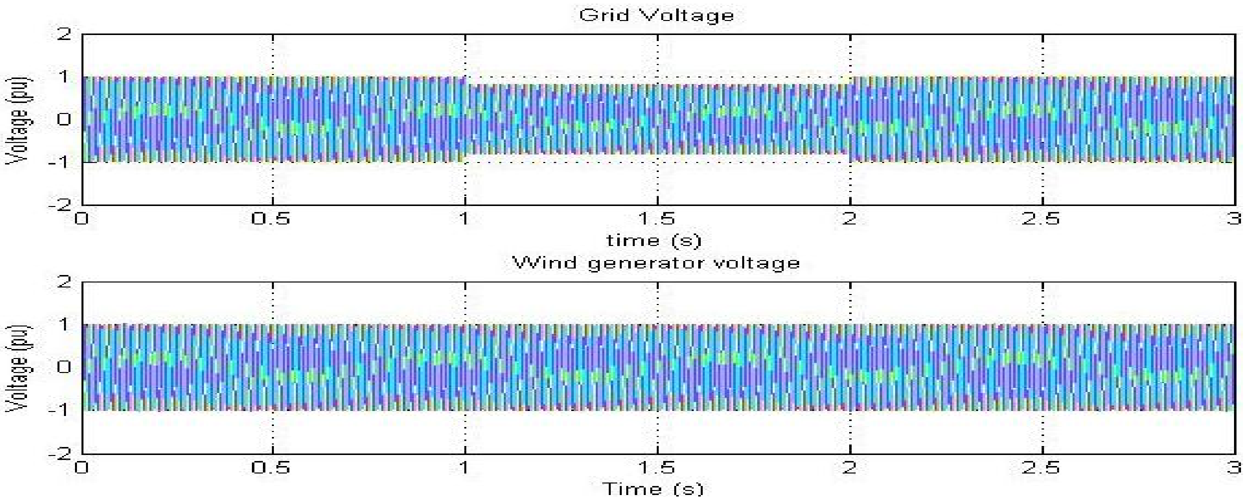

Figure 8: Voltage sag-Grid and wind electric generator voltage with UPQC

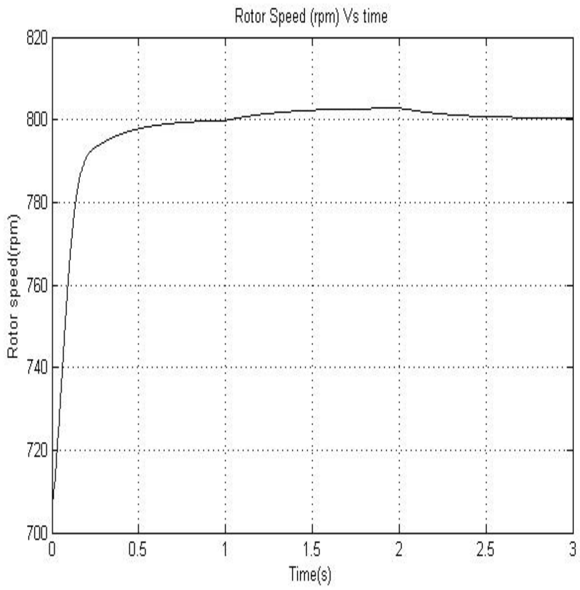

Figure 9: Voltage sag-Rotor speed of wind electric generator with UPQC.

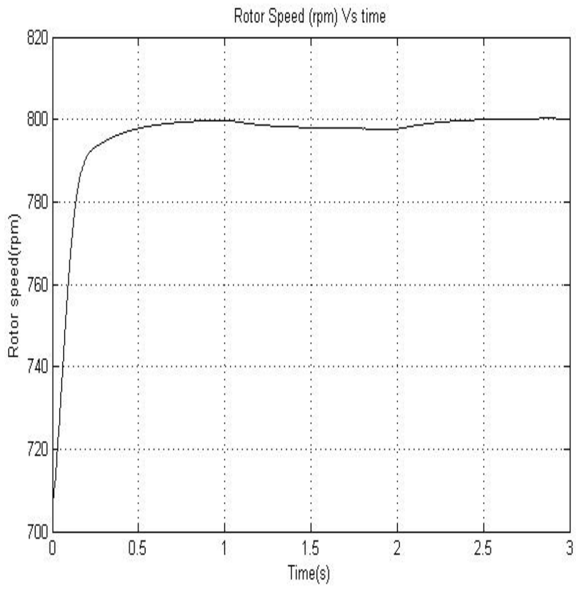

Figure 10: Voltage swell-Rotor speed of wind electric generator with UPQC.

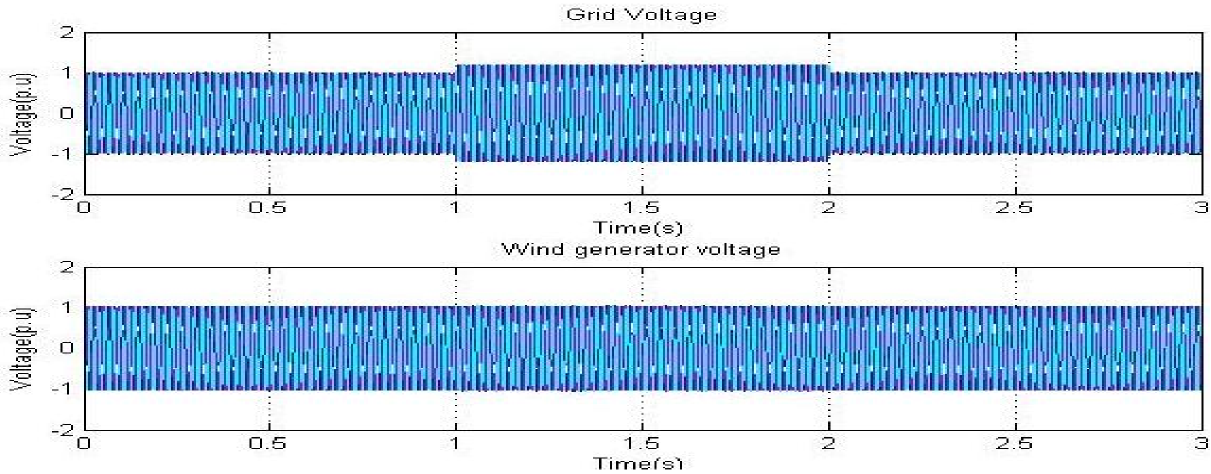

Figure 11: Voltage swell-Grid and wind electric generator with UPQC

CONCLUSION

The SRF-based control strategy used in the UPQC uses only loads and mains voltage measurements for the series APF. The conventional methods require the measurements of load, source, and filter currents for the shunt APF and source and injection transformer voltage for the series APF. The simulation results show that, when under unbalanced voltage conditions, the control algorithm eliminates the impact of rotor speed instability and series APF compensates the loads voltage. Recent rapid interest in renewable energy generation, especially front-end inverter-based large-scale photovoltaic and wind system, is imposing new challenges to accommodate these sources into existing transmission/distribution system while keeping the power quality indices within acceptable limits. Thus UPQC compensates both voltage- and current-related power quality problems simultaneously.

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