

Active Control for Power Quality Improvement Using Unified Power Quality Conditioner (UPQC) in Hybrid Power Systems

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ABSTRACT: Renewable energy has made a stunning entrance to the market. The integration of these systems (wind energy, hydro energy, solar power etc.) created different kinds of problems in the grid. Whether system stability problems or Power Quality issues, these issues need solving. Classically passive filters were used but nowadays active filters such as Static Var Compensator (SVC), Dynamic Static Compensator (DSTATCOM), Dynamic Voltage Regulator (DVR), Unified Series-Shunt Compensator (USSC) and Unified Power Quality Conditioner (UPQC). The UPQC is a relatively new member of the custom power device family. This paper presents a 3-phase unified power quality conditioner (UPQC) to compensate voltage fluctuation and current distortion in the power utility side. The UPQC compensates for any unbalanced or distorted three-phase supply voltages and load currents in a power distribution network. In this paper, UPQC and its control strategies are described. Hysteresis current controller is used for obtaining the gate pulses from the reference current and voltage signal. The simulation has been done by MATLAB/SIMULINK and shows the work of the UPQC.

KEYWORDS: Wind Turbine, UPQC, Active Filters, Hysteresis Current Controller, Harmonics, Voltage Sag, Power Quality.

I. INTRODUCTION

In the last couple of decades, the creation, implementation and perfection of renewable energy has occurred. It has progressed through time with increasing reliability. The integration of renewable energy such as wind, photovoltaic, fuel cell, and tidal to the grid solved many problems and replenished the exceeding and ascending need for electrical energy but created plenty more. This leads to a more complex electrical network or "Grid". This enlargement and enrichment in equipment has caused problems such as stability, reliability and power quality. The issue of power quality is of great importance to the wind turbine. There's a need to find solutions to these problems, using different technologies such as smart meters, monitoring system, controllers, remote ability. The integration of wind energy into a weak system is a challenge; voltage fluctuation, voltage dips, swells and swags are created due to the uncontrollable resource and the nature of the DWIG (Distributed Wind Induction Generators) on the already weak system. This causes stability issues, reliability and power quality issues which need to be solved.

A. Power Quality

1. Voltage Variation

Wind speed and induction generator torque are the main cause of voltage variations. These voltage variations are directly related to real and reactive power variations. Voltage Sag/Swell, Short Interruptions and Long duration variation are common voltage variation issues. The amplitude of voltage fluctuation depends on grid strength, network impedance, phase-angle and power factor of the wind turbines.

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2. Harmonics

Harmonics are created due to power electronic switching devices in the system. The harmonic content in a voltage or current should be under the limit at the Point of Common Coupling (PCC). The filtering by rapid switching largely reduces the lower order harmonic current, but the remaining current will have higher order frequency content which can be easily filtered-out.

3. Consequences of the Issues

The power quality issues damage equipment such as Microprocessors, Programmable Logic Controllers (PLC's), Variable Speed Drives (VSD's) and delicate control systems. It may cause the tripping of Contactors and protection devices. It can lead to stopping sensitive equipment such as PC's, and even stop the process of plants.

B. Wind Turbine Induction Generator

The wind turbine needs a relatively large amount of reactive power to operate. This power must be fed externally whether from a capacitor bank, or a controlled inverter, or from the electrical synchronous grid. The reactive power absorbed by the WTIG causes the voltage on the bus where the generator is connected to drop, and the system build up will raise the voltage again to the nominal voltage of the grid.

Power electronics based FACTS devices are used in distribution system to improve the quality and reliability of power supplied. These devices include Static Var Compensator (SVC), Dynamic Static Compensator (DSTATCOM), Dynamic Voltage Regulator (DVR) Unified Series-Shunt Compensator (USSC) and Unified Power Quality Conditioner (UPQC).

The UPQC is a relatively new member of the custom power device family. It contains both shunt and series compensators. Thus, it can handle any supply voltage and load current problems when installed in a power distribution network. Since PQ (power quality) problem arises either because of supply voltage distortion or because of load current distortion, any PQ issues can be tackled by UPQC.

II. RELATED WORK

Previously this paper integrates the STATCOM and the DVR for harmonics filtering and voltage control. STATCOM is a device that compensates the harmonics or the reactive power in the system. It is used to maintain power quality, enlargement of critical clearing time. DVR is a voltage restorer that can solve the voltage power quality issues.

- The STATCOM is shunt connected and uses in this paper a Hysteresis current control method to inject a current in the system to counter the harmonics created by the non-linear load and the WTIG. Because the hysteresis current controller takes measurements of the current signal and compares it to a reference sinusoidal signal coming from the voltage of the grid, it is blind to the load changes and thinks that the load increase is a Power Quality fault. The STATCOM works to correct that work and in return injects higher current to render the current at a 1 p.u. reference. This means that the STATCOM is supplying the load increase instead of the grid. To solve this issue a load tracking technique is required. That method makes the STATCOM correct the Power quality issue alone without supplying any real power to the load.
- The DVR is used to protect critical or sensitive loads by mitigating the effects of voltage sags or swells on the distribution feeder due to faults and huge reactive loads in the system by maintaining constant voltage magnitude. It is basically a BESS connected to an inverter which itself is connected to an injection transformer that is mounted in series with the 3 phase sensitive load. The DVR can compensate voltage sags by injecting reactive power or real and reactive power. This depends on the depth and width of the sag or swell.

In order to avoid the load tracking system for STATCOM and reduce the no. of FACTS devices are being used for the compensation of harmonics and voltage imbalances we are moving for UPQC. It contains both shunt and series compensators. Thus, it can handle any supply voltage and load current problems when installed in a power distribution network.

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III. CONFIGURATION OF PROPOSED UPQC

The UPQC is a power electronics based compensator which works on active filtering technique. The UPQC is used for simultaneous voltage fluctuation, harmonic distortion and power quality disturbance mitigation. In this paper, we have emphasized mainly on elimination of voltage fluctuation and harmonic distortion of voltage and current in the utility side. Though the active filters used in UPQC can be either voltage-source converters or current source converters, but the voltage-source converters are commonly used. It is a combination of Shunt (SHUC) and Series (SERC) Compensators, joined together back to back with the help of a DC link capacitor as shown in Fig.1. The SERC operates as a controlled voltage source and compensates for any voltage disturbance in the network. The SHUC works as a controlled current source and compensates for reactive or harmonic elements in the load.

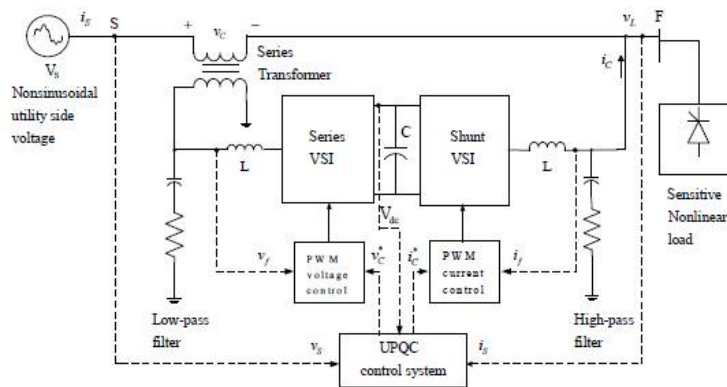


Fig. 1. Schematic diagram of UPQC

A. Series Control Block

The SERC of the UPQC acts as a controlled voltage source. The voltage at the point of common coupling (PCC) is always regulated at a predetermined value.

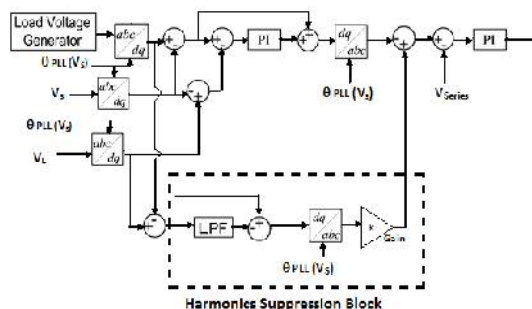


Fig. 2. Schematic diagram of series control block

The overall series control block representation realized is shown in Fig.2. Whenever there is a harmonics distortion in the waveform or a slight deviation from its fundamental value, the load voltage is regulated to its predetermined value with the help of series controller. It's another function is to provide a constant load voltage under voltage sag condition, by injecting a sizeable amount of injection voltage to keep the load voltage constant. First, the 3 phase supply voltage, the load voltage and ideal load voltage generator is transformed to synchronous d-q-0 frame. During sag, the source voltage V_s is subtracted from the reference load voltage and forms the forward path. Further, a feedback path is added by subtracting the load voltage V_L from its reference value which is fed to a PI controller to force the steady state error to zero, thus keeping the load voltage constant to its reference value. For harmonics compensation, the load voltage is subtracted from its reference value in the synchronous d-q-0 frame. The fundamental frequency components, which

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appear as DC when transformed to d-q, are filtered out. The harmonic components of voltage are multiplied with a suitable gain and reference harmonic compensating voltage is obtained. This voltage added with sag compensating voltage is then subtracted from the measured series voltage and fed to a PI controller. The output of the PI controller forms the series reference voltage which is sent to hysteresis current controller to obtain gate pulses for the series active filter. This damps the propagation of voltage harmonics in the distribution line as well as maintains the load voltage at the desired value.

B. Shunt Control Block

The SHUC of the UPQC acts as a controlled current source which supplies the necessary current component at the PCC such that the source current at that point is always sinusoidal and at unity power factor. The overall block representation of the shunt current controller is given in Fig.3.

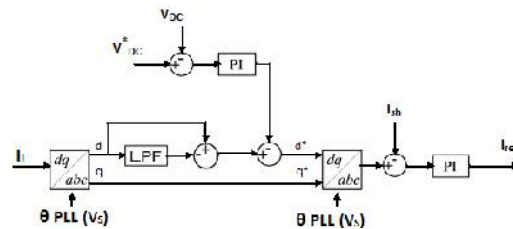


Fig. 3. Schematic diagram of shunt control block

The load current at the point of common coupling is measured and converted to d-q components. The fundamental frequency components when transformed to d-q are filtered out and the harmonic components of current are extracted. The shunt active filter then injects the same magnitude of harmonics but with the opposite polarity so that the harmonic distortions in the source current are cancelled out and remains distortion free. Thus, the source current always remains sinusoidal even if any non-linear load is connected.

The value of DC-link voltage depends on voltage level of the point of connection and has to be higher than the peak value of the voltage at the point of connection so that it can compensate for the reactive and harmonic currents of the load. In parallel, the difference between the dc link voltage and its constant reference value is fed to the d axis of current through a PI controller, thus forcing the error to be zero every time the DC voltage deviates from its normal value. The sum of outputs obtained from the filter and the PI regulator is then compared with measured shunt current through a PI controller to obtain the shunt reference current. A hysteresis current controller is used to control the source current as it is an attractive choice because of its simplicity and robustness.

IV. SYSTEM IN STUDY

We have to study our system at the PCC, which is the interest of this kind of research. Studying at the PCC will give Main idea of the system behaviour at any other Bus. Fig. 4 shows the grid or the infinite bus connected to the PCC, it shows the WTIG, a non-linear load for harmonics generation.

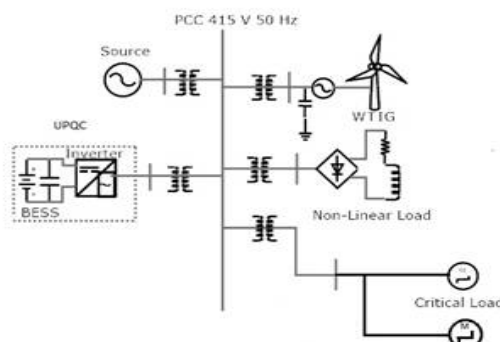


Fig. 4. Proposed system in study

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The unified power quality conditioner (UPQC) is used for Active filtering. This cancels the effect of voltage sags and swells by injecting a voltage into the system, and remove the harmonics by injecting a current into the system. Fig. 5 will show the system model in MATLAB/SIMULINK. The hybrid system along with non-linear loads and UPQC is modelled completely. The UPQC is modelled as a sub system in which whole control scheme is modelled.

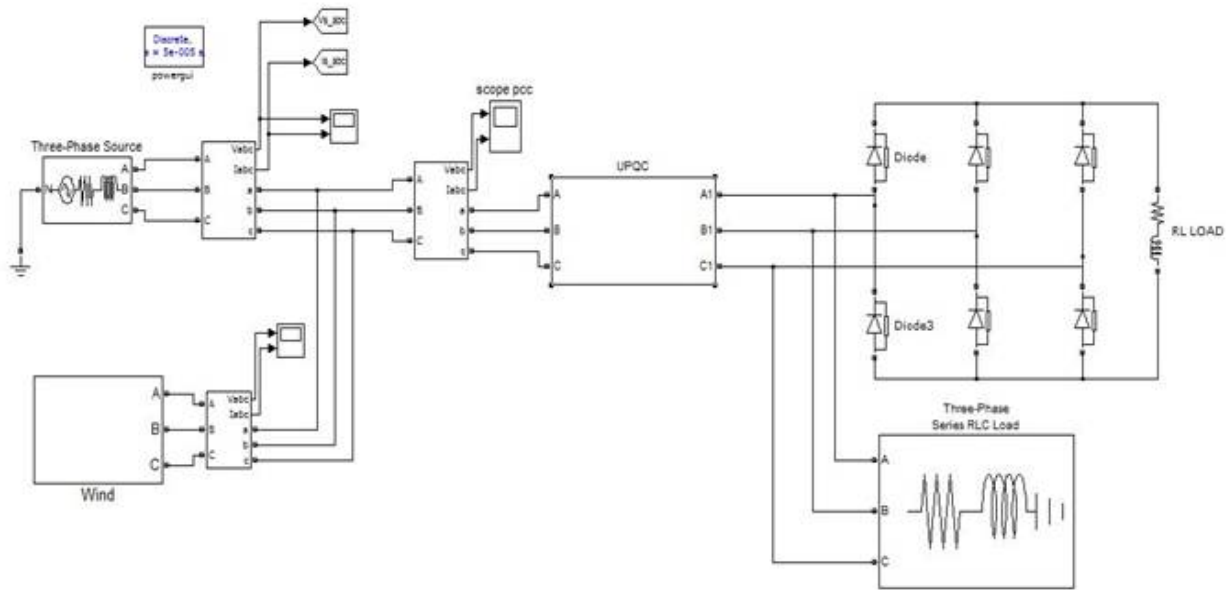


Fig. 5. MATLAB/SIMULINK modelled system

The above explained SERC and SHUC blocks of UPQC are modelled with the help of phase locked loops(PLL), PI controllers and low pass filter(LPF) and are shown in Fig. 6. The Fig. 6a shows the SERC scheme of UPQC and Fig. 6b shows the SHUC scheme of UPQC.

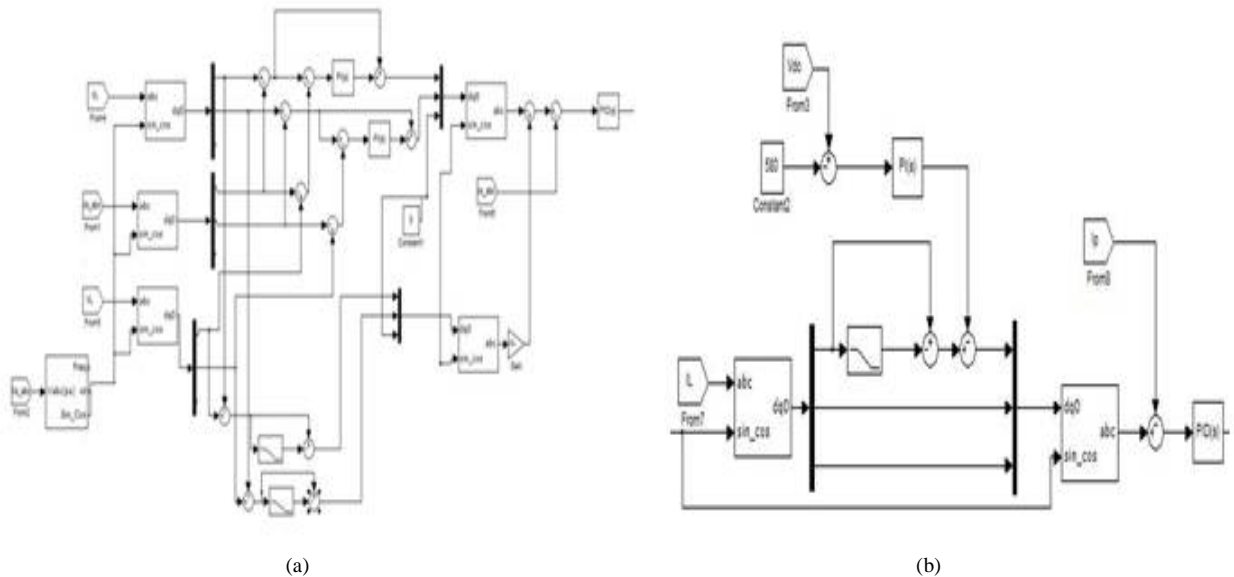


Fig. 6. MATLAB/SIMULINK model of (a) SERC of UPQC (b) SHUC of UPQC

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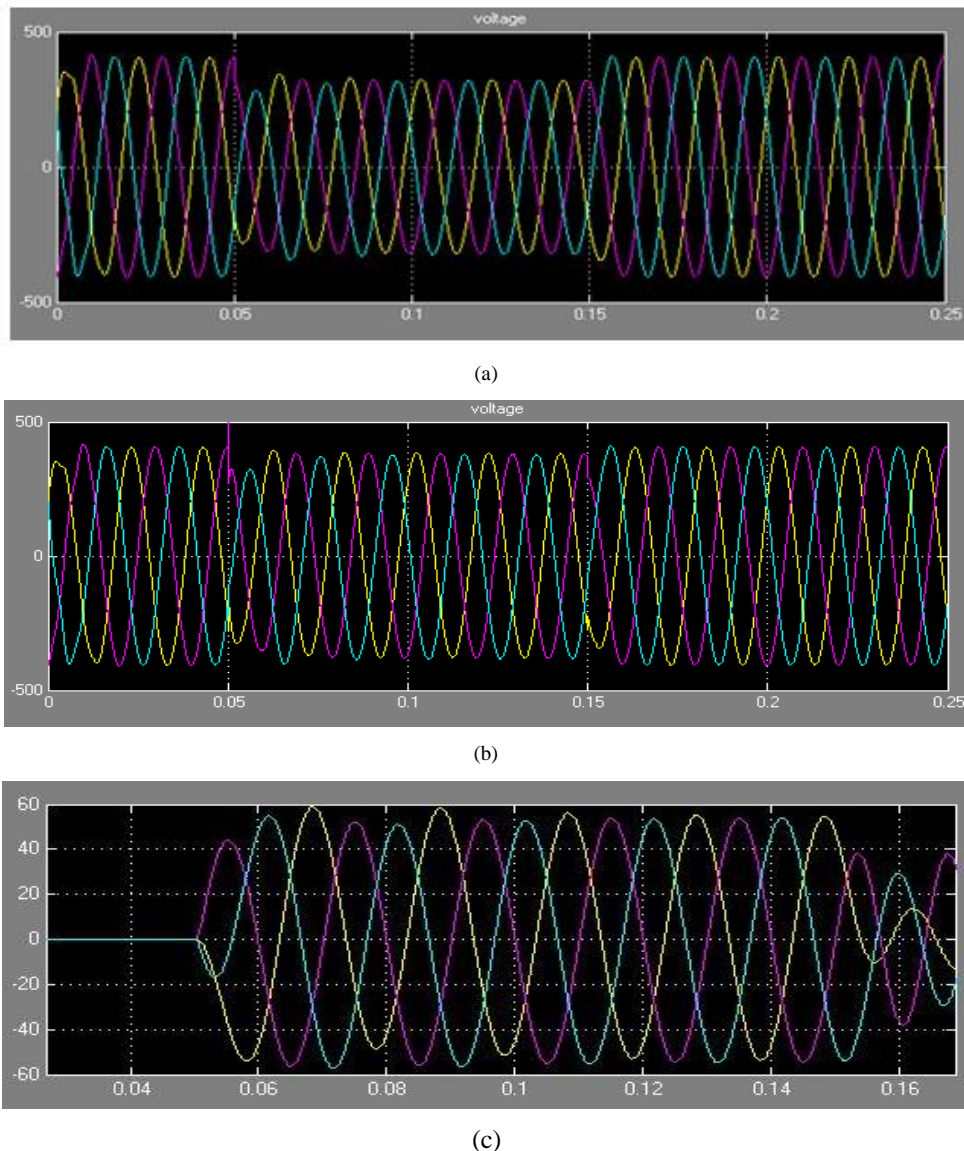
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V. SIMULATION AND RESULTS

A. Voltage balancing operation

When a wind turbine is initially connected to the grid, it needs reactive power for the induction generator to start producing electric power. In another case, when the reactive loads are connected they draw more reactive power cause the voltage drop at the PCC. Fig. 7 shows that the voltage drop at PCC without control, voltage at PCC with SERC control of UPQC and injected voltage by SERC of UPQC. where the line voltage is stepped down when the reactive loads are connected. During voltage sag, the series compensator injects the amount of deficient voltage into the transmission lines and the sag is therefore compensated with the required amount, thus the system voltage is regulated at a constant predetermined value.



Figs. 7. a) Voltage drop at PCC without control, b) Voltage at PCC with SERC control of UPQC, c) Injected voltage by SERC of UPQC

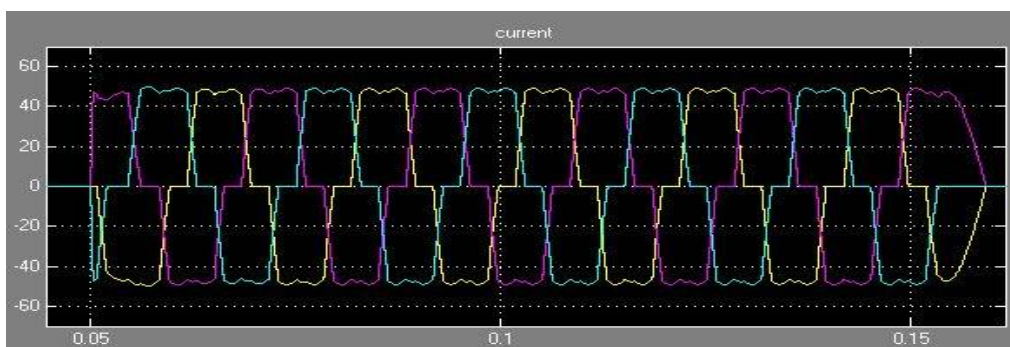
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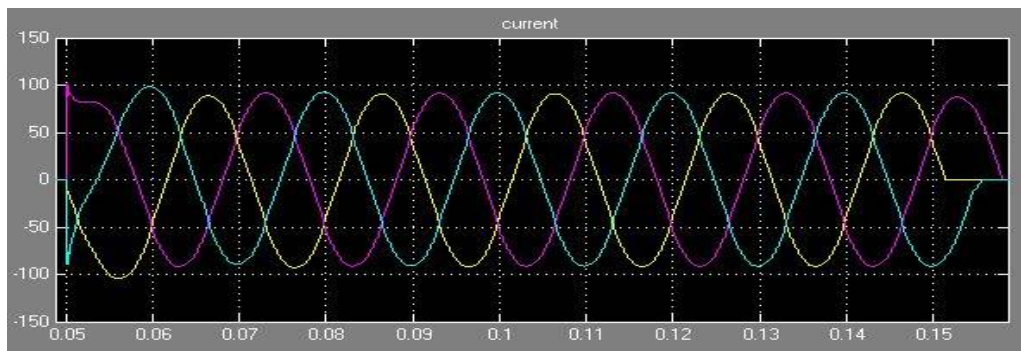
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B. Harmonics suppression operation

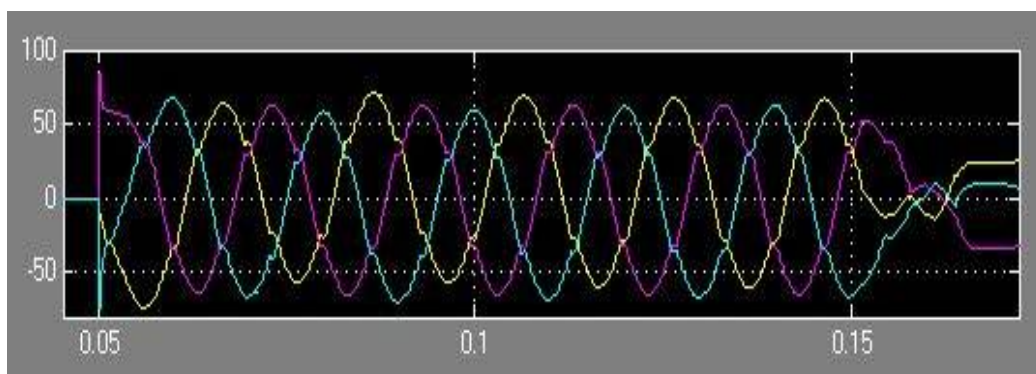
Due to the non-linear load, both the load current and the source current is heavily distorted, but with the help of shunt compensator, a uniform sinusoidal current is drawn from the source as intended. SHUC is activated and will inject the exact current into the system needed to cancel the effect of the harmonics. This reference injected current is generated by the hysteresis control technique. Fig. 8a shows the current at the PCC with UPQC being OFF. Fig. 8b shows the current after turning ON the UPQC. Fig. 8c shows the injected current from the UPQC's SHUC block which is highly distorted current that cancels the effect of the harmonics present at the PCC.



(a)



(b)



(c)

Fig. 8. a) Current at PCC with UPQC being OFF, b) Current at PCC after turning ON the UPQC, c) Injected current by SHUC of UPQC

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The non-linear loads in the system injected the harmonics into the system and degraded the power quality of whole system. The UPQC injects the current that has the needed content to mitigate the power quality issues, the Fourier analysis in Figs. 9a and 9b show that the current THD has dropped from an unacceptable 19.4% to an acceptable 3.93%.

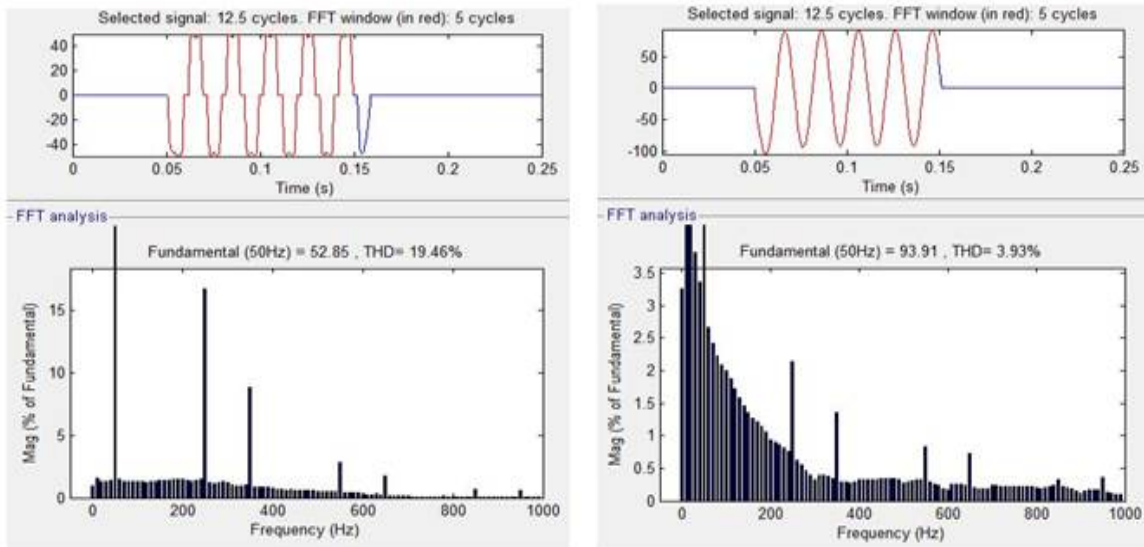


Fig. 9. a) Current THD without UPQC, b) Current THD with UPQC

The reactive loads and wind turbine induction generator consume much reactive power which causes voltage sag along with some content of harmonics in the system. The UPQC injects the voltage that has the needed content to mitigate the power quality issues, the Fourier analysis in Figs. 10a and 10b show that the voltage THD has dropped from an unacceptable 19.4% to an acceptable 3.93%.

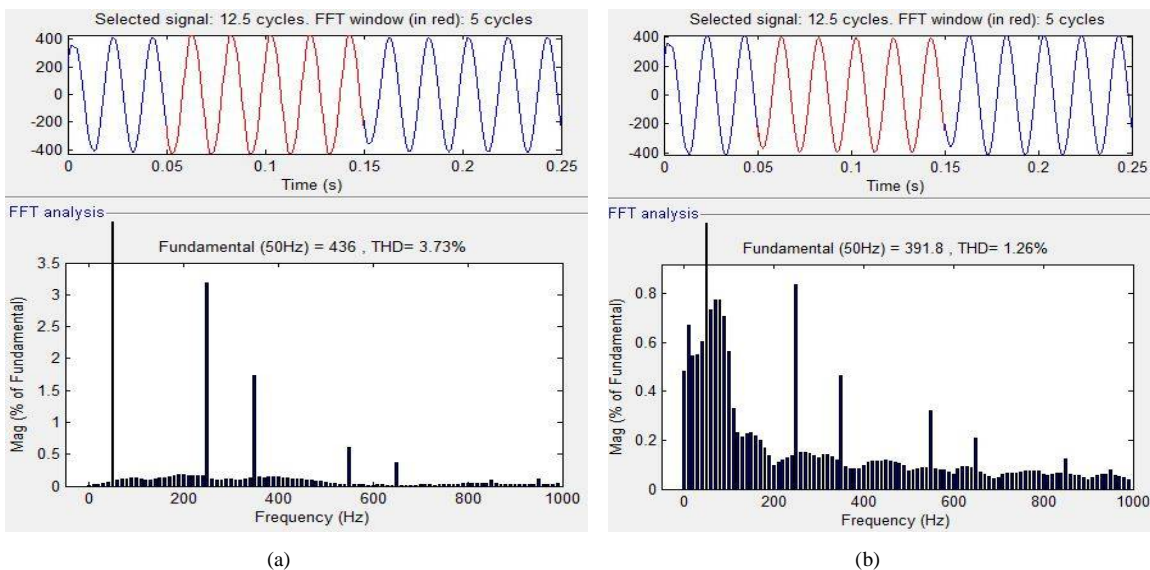


Fig. 10. a) Voltage THD before UPQC, b) Voltage THD after UPQC

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VI. CONCLUSION

This paper offers a new model of UPQC with proper shunt and series control for hybrid power systems, by which harmonics, reactive power, and voltage sags, swells and imbalance are compensated promptly within the allowable limits. Ability of all the systems for the current harmonic cancellation, and sag conditioning has been studied in this paper and the corresponding simulation results are presented. The total harmonic distortion (THD) of the source current and the load voltage is brought down well within IEEE specifications. This newly proposed UPQC is therefore seen to be effective in improving the power quality at the point of installation, while using less complex series and shunt control without compromising its performance.

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