Sinusoidal Current Generation by Using 3ph/4wire UPQC under Unbalance and Nonlinear Load Conditions

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Abstract— *In this paper presents a Design of a Unified Power Quality conditioner (UPQC) connected to three phase four wire system (3P4W). The neutral of series transformer used in the fourth wire for the 3P4W system. The neutral current that may flow toward transformer neutral point is compensated by using a four-leg voltage source inverter topology for shunt part. The series transformer neutral will be at virtual zero potential during all operating conditions. In this simulation we observe the power quality problems such as unbalanced voltage and current, harmonics by connecting non linear load to 3P4W system with Unified Power Quality conditioner. A new control strategy such as unit vector template is used to design the series APF to balance the unbalanced current present in the load currents by expanding the concept of single phase P-Q theory. The P-Q theory applied for balanced three phase system. And also be used for each phase of unbalanced system independently. The MATLAB/Simulink based simulations are provided the functionality of the UPQC*

Key words - Series active power filter, Shunt active power filter three-phase four wire system (3P4W), P-Q theory, Harmonics, power quality, unified power quality conditioner (UPQC)

1. INTRODUCTION

The power electronic devices due to their inherent non-linearity draw harmonic and reactive power from the supply. In three phase systems, they could also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor. [12].The design of shunt active filter is described in [1].The use of the sophisticated equipment/loads at transmission and distribution level has increased considerably in recent years due to the development in the semiconductor device technology. The equipment needs clean power in order to function properly. At the same time, the switching operation of these devices generates current harmonics resulting in a polluted distribution system. The power-electronics-based devices have been used to overcome the major power quality problems [1], [2]. A 3P4W distribution system can be realized by providing the neutral conductor along with the 3 power lines from generation station. The unbalanced load currents are very common and an important Problem in 3P4W Distribution system. To improve the power quality by connecting the series active power filter (APF) and shunt (APF).They are two types of filters one is passive filters and another one is active filters. In passive filters they are using L and C components are connected. By connecting passive filters the system is simplicity and cost is very low. And so many dis-advantages is there, that is resonance problems and filter for every frequency and bucky.That's we are choosing the active filters. By using active filters the power converter circuit using active components like IGBTs,MOSFETs,etc.,and energy storage device (L or C).The advantages are filtering for a range of frequencies and no resonance problems and fast response. But only very few dis advantages is there that is cost is high. By connecting series active filters the voltage harmonic compensation, high impedance path to harmonic currents these are the main functions. All these non-linear loads draw highly distorted currents from the utility system, with their third harmonics component almost as large as the fundamental. The increasing use of non-linear loads, accompanied by an increase in associated problems concerns both electrical utilities and utility customer alike [3].

2. UPQC CONTROL ALGORITHM

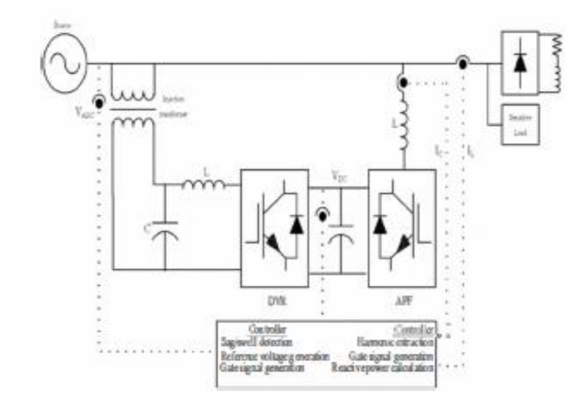

Fig-1 control Diagram of UPQC system

The UPQC consists of two voltage source inverters Connected back to back with each of them sharing a common dc link. Fig-2 shows the control diagram of Upqc system. One inverter work as a variable voltage source is called series APF, and the other as a variable current source in called shunt APF.The main aim of the series APF is harmonic isolation between load and Supply; it has the capability of voltage flicker/ imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer PCC. The shunt APF is used to absorb current harmonics, compensate for reactive power and negative-sequence current, and regulate the dc link voltage between both APFs. The proposed UPQC control algorithm block diagram in Matlab/Simulink simulation software is shown in Fig. 1.

3. THE 3P3W DISTRIBUTION SYSTEM UTILIZING UPQC

Generally, a 3P4W distribution system is realized by providing a neutral conductor along with three power conductors from generation station.Fig.2 shows the 3P3W system is connected to UPQC.Maintaining the Integrity of the Specifications.

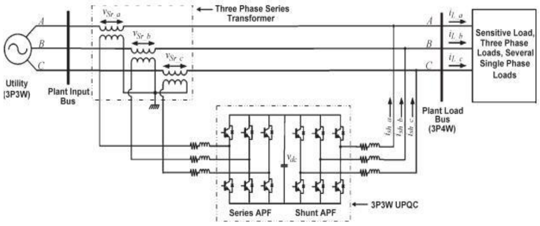

Fig-2 3P3W system is connected to UPQC

If we want to upgrade the system now from 3P3W to 3P4W due to installation of some single-phase loads and if the distribution transformer is close to the plant under consideration, utility would provide the neutral conductor from this transformer without major cost involvement. In recent cases, this may be a costly solution because the$_{A.}$ distribution transformer may not be situated in close vicinity. Recently, the utility service providers are putting more and more restrictions on current total harmonic distortion (THD) limits, drawn by nonlinear loads, to control the power distribution system harmonics pollution. At the same time, the use of sophisticated equipment or load has increases significantly, and it needs clean power for its proper operation.

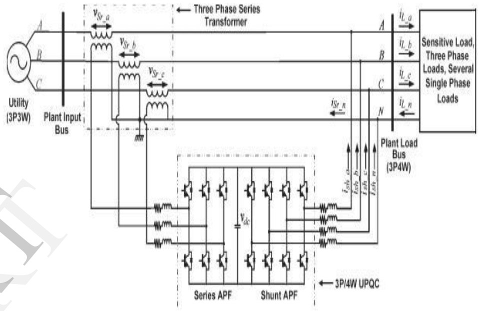

Fig-3 3P4W system is connected to UPQC

Figure3. show the novel 3P4W topology that can be realized from a 3P3W system. In addition to easy expansion of 3P3W system to 3P4W system. As shown in Figure.2 the UPQC should necessarily consist of three-phase series transformer in order to connect one of the inverters in the series with the line to function as a controlled voltage source. If we could use the neutral of three-phase series transformer to connect a neutral wire to realize the 3P4W system, then 3P4W system can easily be achieved from a 3P3W system (figure.2).The neutral current, present if any ,would flow through this fourth wire toward transformer neutral point. This neutral current can be compensated by using a split capacitor topology [4], [5], [6] or a four leg voltage source inverter (VSI) topology for a shunt inverter [4], [7].The four-leg VSI topology requires one additional leg as compared to the split capacitor topology.VSI structure is much easier than that of the split capacitor .But here the UPQC design by using P-Q theory and it is connected to 3P4W system.

The UPQC consists of two voltage source inverters Connected back to back with each of them sharing a common dc link. Fig-1shows the control diagram of Upqc system. One inverter work as a variable voltage source is called series APF, and the other as a variable current source in called shunt APF.The main aim of the series APF is harmonic isolation between load and Supply; it has the capability of voltage flicker/ imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer PCC. The shunt APF is used to absorb current harmonics, compensate for reactive power and negative-sequence current, and regulate the dc link voltage between both APFs. The proposed UPQC control algorithm block diagram in Matlab/Simulink simulation software is shown in Fig. 1.

4. REFERENCE VOLTAGE SIGNAL GENERATION FOR SERIES

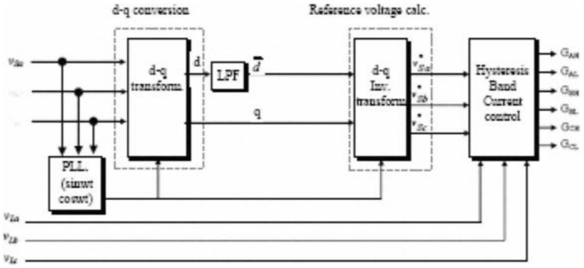

Fig-4 control diagram of Series Active Filter

The series APF control algorithm calculates the reference value to be injected by the series APF transformers, comparing the positive-sequence component with the load side line voltages. In equation (1), supply voltages VSabc are transformed to d-q-O coordinates.

$$\begin{bmatrix} V_{S0} \\ V_{Sd} \\ V_{Sq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \sin(\omega t) & \sin(\omega t - 2\frac{\pi}{3}) & \sin(\omega t + 2\frac{\pi}{3}) \\ \cos(\omega t) & \cos(\omega t - 2\frac{\pi}{3}) & \cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \tag{1}$$

The voltage in d axes (VSd) given in (2) consists of A verage and oscillating components of source voltages (VSd and □VSd). The average voltage VSd is calculated by using second order LPF (low pass filter).

$$V_{sd} = \bar{V}_{sd} + \tilde{V}_{sd} \tag{2}$$

The load side reference voltages V l'!< 12bc are calculated as given in equation (3). The switching signals are assessed by comparing reference voltages V □ L□bc and the load voltages (VLabc) via sinusoidal PWM controller.

$$\begin{bmatrix} V^{*}_{La} \\ V^{*}_{Lb} \\ V^{*}_{Lc} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & 1 \\ \sin(\omega t - 2\frac{\pi}{3}) & \cos(\omega t - 2\frac{\pi}{3}) & 1 \\ \sin(\omega t + 2\frac{\pi}{3}) & \cos(\omega t + 2\frac{\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} V_{Sd} \\ 0 \\ 0 \end{bmatrix} \tag{3}$$

The three-phase load reference voltages are compared with load line voltages and errors are then processed by sinusoidal PWM controller to generate the required switching signals for series APF switches.

The three-phase load reference voltages are compared with load line voltages and errors are then processed by sinusoidal PWM controller to generate the required switching signals for series APF switches.

5. REFERENCE CURRENT SIGNAL GENERATION FOR SHUNT APF

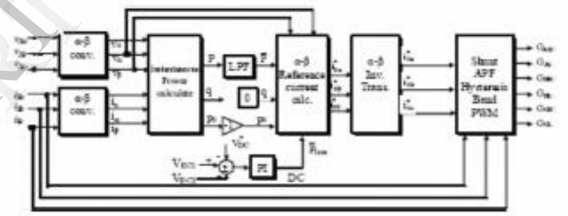

Fig-5 control diagram of Shunt Active Filter

The above figure shows the control diagram of shunt active filter. The shunt active filter compensates the current harmonics and reactive power generated by the nonlinear load. The instantaneous active power (p-q) theory is used to control of shunt APF in real time. In this theory, the instantaneous three-phase currents and voltages are transformed to a-p-O coordinates as shown in equation (4) and (5).

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \tag{5}$$

The source side instantaneous real and imaginary power components are calculated by using source currents and phase-neutral voltages. The instantaneous real and imaginary powers include both oscillating and average components as shown in (7). Average components of p and q consist of positive sequence components (p and q) of source current. The oscillating components (p and q) of p and q include harmonic and negative sequence components of source currents [4]. In order to reduce neutral current, p 0 is calculated by using average and oscillating components of imaginary power and oscillating component of the real power; as given in (8) if both harmonic and reactive power compensation is required. i*sa i *s□, i*so are the reference currents of shunt APF in a-p-O coordinates. These currents are transformed to three-phase system as shown in (9).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{6}$$

$$P_0 = V_0 * i_0 \quad ; \quad p = \bar{p} + \tilde{p} \tag{7}$$

$$\begin{bmatrix} i^*{}_{s\alpha} \\ i^*{}_{s\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} + p_0 + \bar{p}_{loss} \\ 0 \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} i^*{}_{sa} \\ i^*{}_{sb} \\ i^*{}_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*{}_{s0} \\ i^*{}_{s\alpha} \\ i^*{}_{s\beta} \end{bmatrix} \tag{9}$$

The reference currents are calculated in order to compensate neutral, harmonic and reactive currents in the load. These reference source current signals are then compared with sensed three-phase source currents, and the errors are processed by hysteresis band PWM controller to generate the required switching signals for the shunt APF Switches [6].

6. NEUTRAL CURRENT COMPENSATION

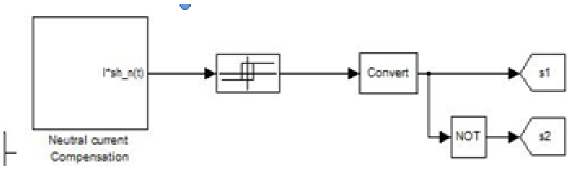

Fig-6 control diagram of Neutral Current Compensation

7. SIMULA TOIN RESULTS

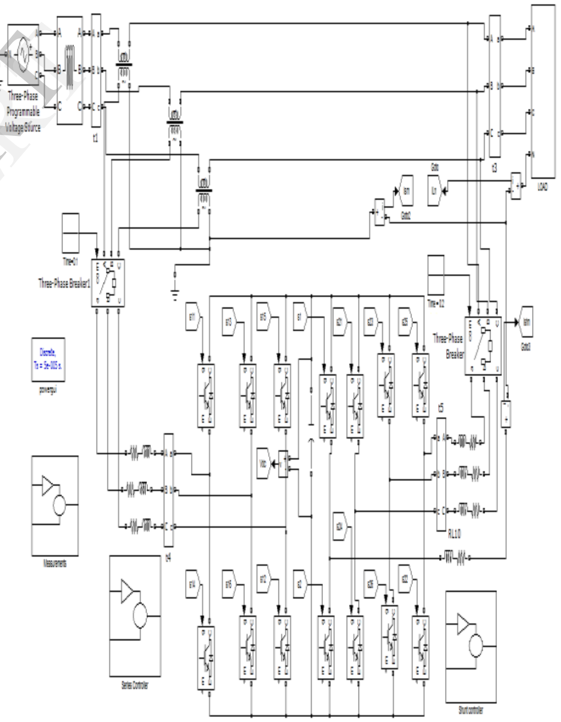

Fig-7 Simulink diagram of Neutral Current Compensation

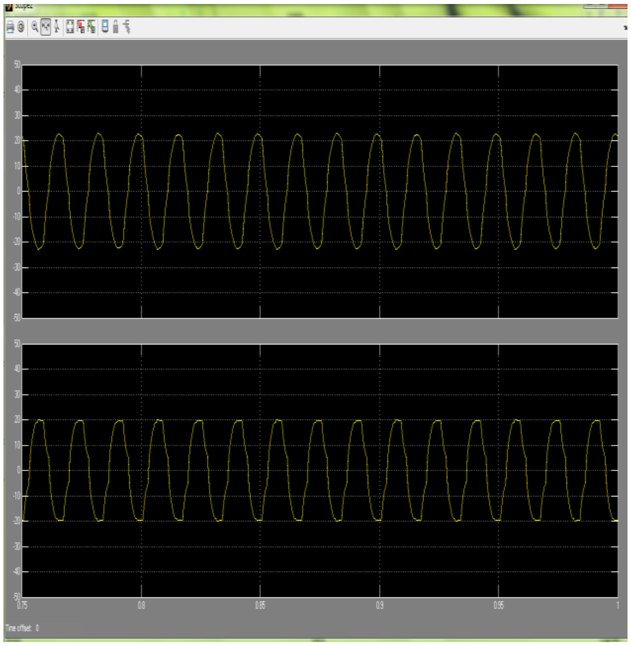

Fig-8 Current flowing through load neutral wire (i_{L_n}), and Shunt neutral compensating current (i_{Sh_n}).

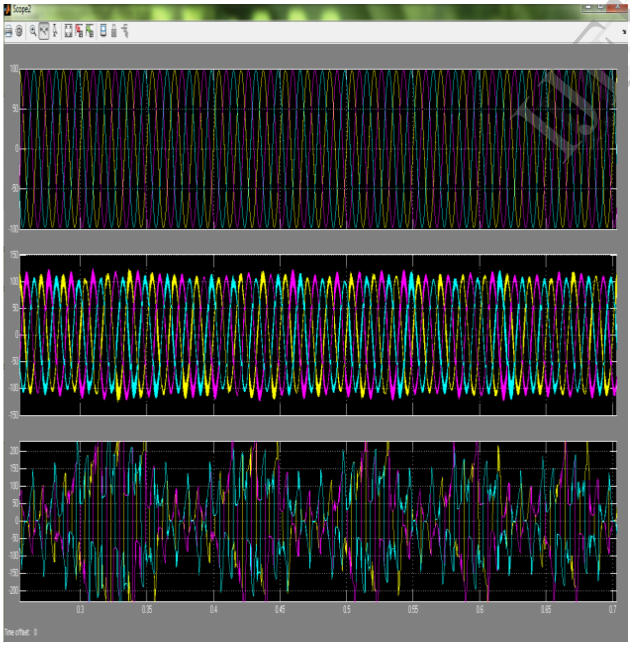

Fig-9 Utility voltage (v_{s_abc}), load voltage (v_{L_abc}) and injected voltage (v_{inj_abc}).

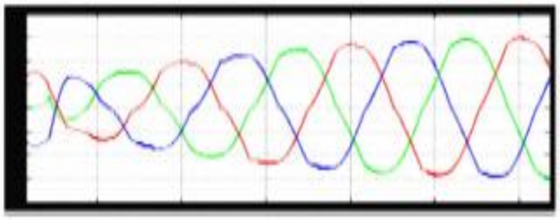

Fig-9 Three phase source current before Compensation

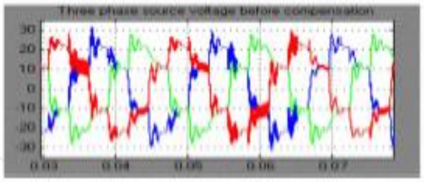

Fig-11 Three phase source voltage before compensation

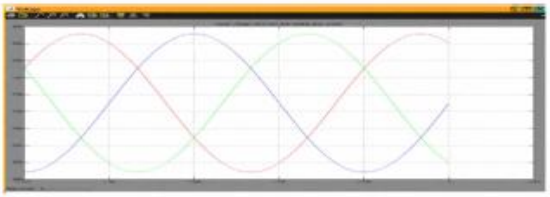

Fig-12 Supply voltage after adding upqc system

Fig-13 Supply current after adding upqc system

8.CONCLUSION

The neutral current compensation control strategy use only minimum measurement like loads and mains voltage measurements for series APF based on the modified PLL with synchronous reference frame theory. The instantaneous reactive power theory is used for shunt APF control algorithm by measuring mains voltage, currents and capacitor voltage. But the conventional methods require measurements of the load, source and filter voltages and currents. The simulation results show that, when unbalanced and Nonlinear load current or unbalanced and distorted mains voltage conditions, the above control algorithms eliminate the impact of distortion and unbalance of load current on the power line, making the power factor unity. Meanwhile, the Series APF isolates the loads voltages and source voltage, the shunt APF provides three-phase balanced and rated currents for the loads.

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Biography

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