

# An Advanced Approach to Power Quality Issues by Using Unified Power Quality Conditioner

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**Abstract**—In this paper presents an advanced approach to power quality issues by using unified power quality conditioner (UPQC) connected to three phase four wire system (3P4W). In the fourth wire for the 3P4W system uses the neutral of series transformer and it will be at virtual zero potential during all operating conditions. A four-leg voltage source inverter topology is used for shunt part to compensate the neutral current flow toward transformer neutral point. By connecting nonlinear load to 3P4W system with Unified Power Quality conditioner there exist many power quality problems, mainly unbalanced voltage and current. We can compensate the current unbalance present in the load currents by expanding the concept of single phase P-Q theory. This theory applied for balanced three phase system and for each phase of unbalanced system independently. Based on unit vector template generation a new control strategy is proposed to the control algorithm for series APF. The functionality of the UPQC is provided the MATLAB/Simulink based simulations.

**Index Terms**—Series active power filter, shunt active power filter three-phase four wire systems (3P4W), P-Q theory, harmonics, power quality, unified power quality conditioner (UPQC).

## I. INTRODUCTION

The power electronic devices draw harmonic and reactive power from the supply due to their inherent nonlinearity. In three phase systems the injected harmonics, reactive power burden, unbalance, and extra neutral currents cause low system efficiency and poor power factor. In recent years due to the development in the semiconductor device technology the use of the sophisticated equipment/loads at Transmission distribution level has increased. The equipment needs clean power in order to function properly. At the same time, this device generates current harmonics, resulting in a polluted distribution system due to the switching operation. The major power quality problems can overcome by using power-electronics-based devices. by providing the neutral conductor along with the 3 power lines from generation station a 3P4W distribution system can be accomplished. We get more power quality by

connecting the series active power filter (APF) and shunt (APF). They are two types of filters, passive filters and active filters.

Active filter is better than passive filter. In passive filters they are using L and C components. By connecting passive filters the system is simplicity and cost is very low, it is an advantage of it but there are so many disadvantages. Resonance problems and filter for every frequency and Bucky are some disadvantage of passive 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 of active filter are filtering for a range of frequencies and no resonance problems and fast response, Only very few disadvantages is there mainly its cost is high. Main functions of connecting series active filters are the voltage harmonic compensation, high impedance path to harmonic currents. All these non-linear loads with their third harmonics component almost as large as the fundamental draw highly distorted currents from the utility system. The increasing use of non-linear loads increase problems concerns both electrical utilities and utility customer alike. Here we can solve the power quality problems like voltage and current unbalanced and also reduce the total harmonic distortion (THD) of 3P4W system utilizing 3P3W system to connect the UPQC.

## II. THE 3P3W DISTRIBUTION SYSTEM UTILIZING UPQC

A 3P4W distribution system consist of a neutral conductor along with three power conductors from generation station. Fig.1 shows the 3P3W system is connected to UPQC.

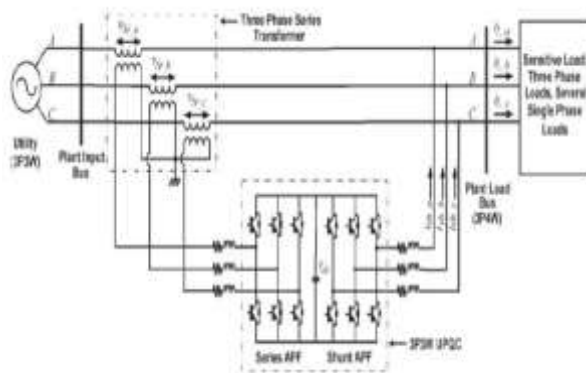


Fig. 1.3P3W system is connected to UPQC.

By installation of some single-phase loads we can upgrade the system now from 3P3W to 3P4W. utility would provide the neutral conductor from this transformer without major cost involvement, if the distribution transformer is close to the plant under consideration. Because of distribution transformer may not be situated in close vicinity this may be a costly solution in some cases. to control the power Distribution system harmonics pollution the utility service providers are putting more and more restrictions on current total harmonic distortion (THD) limits, drawn by nonlinear loads .the use of sophisticated equipment or load has increases significantly, it needs clean power for its proper operation. Fig. 2 shows the novel 3P4W topology that can be realized from a 3P3W system. In addition to easy expansion of 3P3W system to 3P4W system. In order to connect one of the inverters in series with the line to function as a controlled voltage source As shown in Fig.1 UPQC should necessarily consist of three-phase series transformer. 3P4W system can easily be achieved from a 3P3W system by using the neutral of three-phase series transformer to connect a neutral wire (fig.2). if any neutral current present it flow through this fourth wire toward transformer neutral point. by using a split capacitor topology or a four leg voltage source inverter (VSI) topology for a shunt inverter [4], [5] neutral current can be compensated. as compared to the split capacitor topology the four-leg VSI topology requires one additional leg. VSI structure is much easier than that of the split capacitor .But here going through the UPQC design by using P-Q theory and it is connected to 3P4W system.

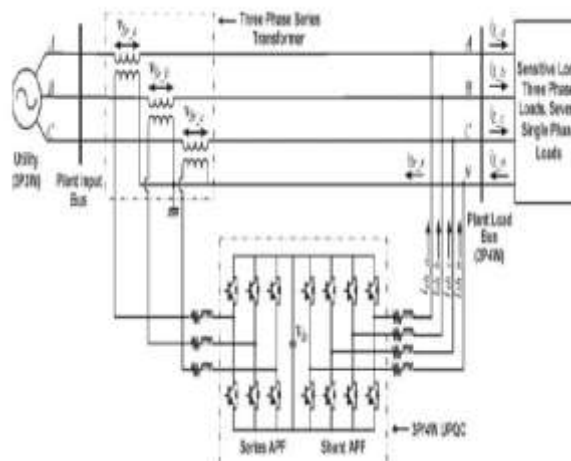


Fig.2.3. 3P4W system realized from a 3P3W system utilizing UPQC

Thus, the structure would help to accomplish a 3P4W system at distribution load end. At last this would result in easy expansion from 3P3W to 3P4W systems. in this paper we also explain A new control strategy to generate balanced reference source currents under load condition and UPQC design by using P-Q theory in the next section

### III. DESIGN OF UPQC CONTROLLER

#### A. Description of Implementation of Series APF

The Inverter injects a voltage In series APF in series with the line which feeds the polluting load through a transformer and the injected voltage will be mostly harmonic with a small amount of sinusoidal component which is in-phase with the current flowing in the line. This sinusoidal component results compensate for the losses within the Series APF by right amount of active power flow into the Inverter and to maintain the D.C side capacitor voltage constant. The amount of this in-phase component will decide by the D.C voltage control loop. Current system distortion caused by nonlinear load is compensate by Series active power filter by imposing a high impedance path to the harmonic current [6]. The line diagram of series active power filter is shown in below fig.3

#### B. Description of Implementation of Shunt APF

The active filter generates Harmonic current components that cancel the harmonic current components from the non- linear loads.

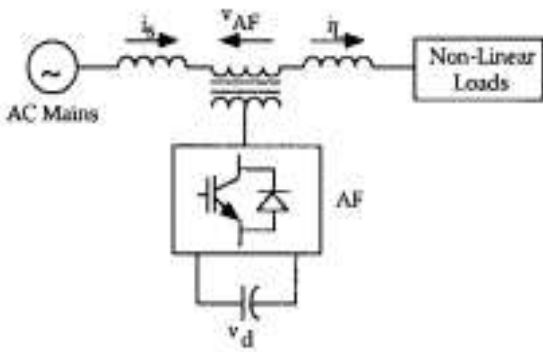


Fig.3.Line diagram of series active power filter.

In this configuration, the filter is connected in parallel with the load being compensated. Therefore the configuration is often referred to as an active parallel or shunt filter [7],[8].

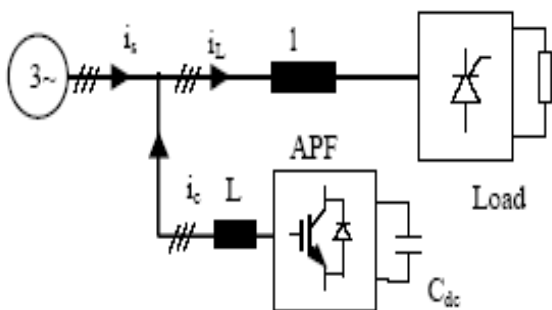


Fig.4. Shunt active power filter

Fig.4 illustrates the concept of the harmonic current cancellation so that the current being supplied from the source is sinusoidal. For making the harmonic control possible a voltage source inverter used in the active filter. This inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal that will cancel the harmonics from the non-linear load.

Control strategy for shunt APF is discussed in this section. The control algorithm for series APF is based on unit vector template generation scheme [9].the current drawn from the utility can be unbalanced depending on the load on the 3P4W system. In this paper, the concept of single phase P-Q theory [10] is used, by this theory, a single phase system can be defined as a pseudo two-phase system by giving  $\pi/2$  lead or  $\pi/2$  lag, that is each phase voltage and current of the original three phase systems. This resultant two phase systems can be represented in  $\alpha$ - $\beta$  coordinates, and thus P-Q theory applied for balanced three phase system[11] can also be used for each phase of unbalanced system independently. To avoid these limitations we use the reference load

voltage signals extracted for series APF instead of actual load voltage[12],[13].

For phase a, the load voltage in  $\alpha$ - $\beta$  coordinates can be represented by  $\pi/2$  lead as

$$\begin{bmatrix} v_{La-\alpha} \\ v_{La-\beta} \end{bmatrix} = \begin{bmatrix} v_{La}^*(\omega t) \\ v_{La}^*(\omega t + \pi/2) \end{bmatrix} = \begin{bmatrix} V_{Lm} \sin(\omega t) \\ V_{Lm} \cos(\omega t) \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{La-\alpha} \\ i_{La-\beta} \end{bmatrix} = \begin{bmatrix} i_{La}(\omega t + \varphi_L) \\ i_{La}[(\omega t + \varphi_L) + \pi/2] \end{bmatrix} \quad (2)$$

Where  $V_{La}^*(\omega t)$  represents the reference load voltage and  $V_{Lm}$  represents the desired load voltage magnitude. Similarly, for phase b, the load voltage in  $\alpha$ - $\beta$  coordinates can be represented by  $\pi/2$  lead as

$$\begin{bmatrix} v_{Lb-\alpha} \\ v_{Lb-\beta} \end{bmatrix} = \begin{bmatrix} v_{Lb}^*(\omega t) \\ v_{Lb}^*(\omega t + \pi/2) \end{bmatrix} = \begin{bmatrix} V_{Lm} \sin(\omega t - 120^\circ) \\ V_{Lm} \cos(\omega t - 120^\circ) \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} i_{Lb-\alpha} \\ i_{Lb-\beta} \end{bmatrix} = \begin{bmatrix} i_{Lb}(\omega t + \varphi_L) \\ i_{Lb}[(\omega t + \varphi_L) + \pi/2] \end{bmatrix} \quad (4)$$

In addition, for phase c, the load voltage in  $\alpha$ - $\beta$  coordinates can be represented by  $\pi/2$  lead as

$$\begin{bmatrix} v_{Lc-\alpha} \\ v_{Lc-\beta} \end{bmatrix} = \begin{bmatrix} v_{Lc}^*(\omega t) \\ v_{Lc}^*(\omega t + \pi/2) \end{bmatrix} = \begin{bmatrix} V_{Lm} \sin(\omega t + 120^\circ) \\ V_{Lm} \cos(\omega t + 120^\circ) \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i_{Lc-\alpha} \\ i_{Lc-\beta} \end{bmatrix} = \begin{bmatrix} i_{Lc}(\omega t + \varphi_L) \\ i_{Lc}[(\omega t + \varphi_L) + \pi/2] \end{bmatrix} \quad (6)$$

By using the definition of three-phase system [2], the instantaneous power components can be represented as Instantaneous active power

$$p_{L,abc} = v_{L,abc-\alpha} \cdot i_{L,abc-\alpha} + v_{L,abc-\beta} \cdot i_{L,abc-\beta} \quad (7)$$

Instantaneous reactive power

$$q_{L,abc} = v_{L,abc-\alpha} \cdot i_{L,abc-\beta} - v_{L,abc-\beta} \cdot i_{L,abc-\alpha} \quad (8)$$

Considering phase a, the phase-  $\alpha$  instantaneous load active and instantaneous load reactive powers can be represented by

$$\begin{bmatrix} p_{La} \\ q_{La} \end{bmatrix} = \begin{bmatrix} v_{La-\alpha} & v_{La-\beta} \\ -v_{La-\beta} & v_{La-\alpha} \end{bmatrix} \cdot \begin{bmatrix} i_{La-\alpha} \\ i_{La-\beta} \end{bmatrix} \quad (9)$$

Where

$$p_{La} = \overline{p_{La}} + \widetilde{p_{La}} \quad (10)$$

$$q_{La} = \overline{q_{La}} + \widetilde{q_{La}} \quad (11)$$

In(10)and(11),  $\overline{p_{La}}$ and  $\overline{q_{La}}$ represent the dc components that are responsible for fundamental load active and reactive powers, whereas  $\widetilde{p_{La}}$ and  $\widetilde{q_{La}}$ represent the ac components that are responsible for harmonic powers. The fundamental instantaneous load active and reactive power components can be extracted from  $p_{La}$  and  $q_{La}$ , respectively, by using low pass filter (LPF).

Therefore, the instantaneous fundamental load active power for phase a is given by

$$p_{La,1} = \overline{p_{La}} \quad (12)$$

And the instantaneous fundamental load reactive power for phase a is given by

$$q_{La,1} = \overline{q_{La}} \tag{13}$$

The instantaneous fundamental load active power for phase b is given by

$$p_{Lb,1} = \overline{p_{Lb}} \tag{14}$$

The instantaneous fundamental load reactive power for phase a is given by

$$q_{Lb,1} = \overline{q_{Lb}} \tag{15}$$

The instantaneous fundamental load active power for phase b is given by

$$p_{Lc,1} = \overline{p_{Lc}} \tag{16}$$

The instantaneous fundamental load reactive power for phase a is given by

$$q_{Lc,1} = \overline{q_{Lc}} \tag{17}$$

The aforementioned task can be achieved by summing instantaneous fundamental load active power demands of all the three phases and redistributing it again on each utility phase from (12), (14), (16)

$$p_{L,total} = p_{La,1} + p_{Lb,1} + p_{Lc,1} \tag{18}$$

$$p_{S/ph}^* = \frac{p_{L,total}}{3} \tag{19}$$

Thus, the reference compensating currents are representing a perfectly balanced 3-phase system can be extracted by taking the inverse of (9)

$$\begin{bmatrix} i_{sa-a}^* \\ i_{sa-b}^* \end{bmatrix} = \begin{bmatrix} v_{La-a} & v_{La-b} \\ -v_{La-b} & v_{La-a} \end{bmatrix}^{-1} \cdot \begin{bmatrix} p_{S/ph}^* + p_{dc/ph} \\ 0 \end{bmatrix} \tag{20}$$

In (20),  $p_{dc/ph}$  is the precise amount of per-phase active power that should be taken from the source in order to maintain the dc-link voltage at a constant level and to overcome the losses associated with UPQC. Therefore, the reference source current for phase a, b and c can be estimated as

$$i_{sa}^*(t) = \frac{v_{La-a}(t)}{v_{La-a}^2 + v_{La-b}^2} \cdot [p_{S/ph}^*(t) + p_{dc/ph}(t)] \tag{21}$$

$$i_{sb}^*(t) = \frac{v_{Lb-a}(t)}{v_{Lb-a}^2 + v_{Lb-b}^2} \cdot [p_{S/ph}^*(t) + p_{dc/ph}(t)] \tag{22}$$

$$i_{sc}^*(t) = \frac{v_{Lc-a}(t)}{v_{Lc-a}^2 + v_{Lc-b}^2} \cdot [p_{S/ph}^*(t) + p_{dc/ph}(t)] \tag{23}$$

The reference neutral current signal can be extracted by simply adding all the sensed load currents, without actual neutral current sensing, as

$$i_{L-n}(t) = i_{La}(t) + i_{Lb}(t) + i_{Lc}(t) \tag{24}$$

$$i_{sh-n}(t) = -i_{L-n}(t) \tag{25}$$

By using above equations to design the both series and shunt active power filters by connecting the 3P4W system as shown in next section.

#### IV. SIMULATION BLOCK DIAGRAM

The simulation block diagram of 3P4W system obtain from a 3P3W system applying UPQC is shown in

below fig.5.

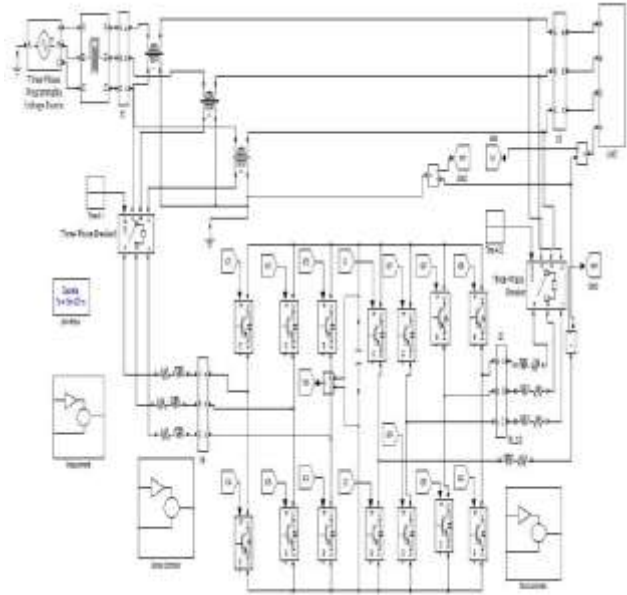


Fig. 5. Simulation block diagram of 3P4W system realized from a 3P3W system utilizing UPQC.

Non-linear loads means by connecting power electronics devices to system. The plant load is assumed to be the combination of a balanced three-phase diode bridge rectifier followed by an R-L load, which acts as a harmonic generating load, and three different single phase loads on each phase, with different load active and reactive power demands. By using equations (1), (3) and (5) to design the unit vector template of series APF is shown in fig.6 and fig.7 is Series active power filter controller shown in below. And also shunt APF is design by using all above equations is shown in below fig.8.

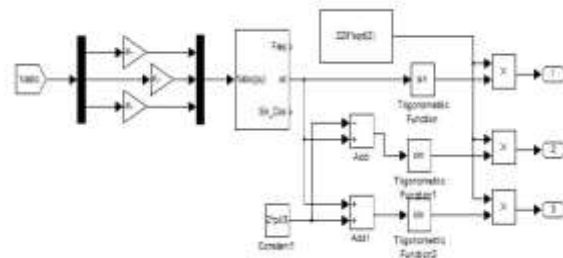


Fig. 6. Simulation block of Unit vector template of series active power filter



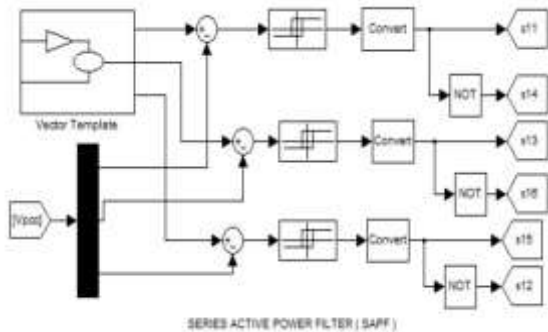


Fig.7. Simulation block of Series active power filter controller

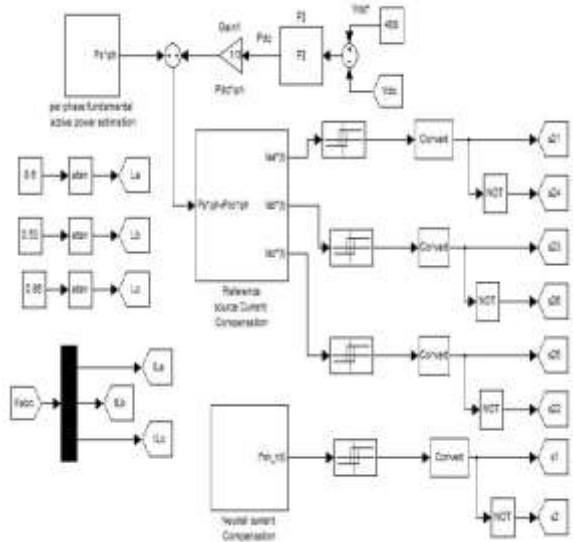


Fig. 8. Simulation block of shunt active power filter

V. SIMULATION RESULTS AND DISCUSSION

Below fig. 9 to 12 shows The simulation results for the proposed 3P4W system realized from a 3P3W system utilizing UPQC. Utility voltage are assumed to be distorted with voltage THD of 14.03 %.The distorted voltage profiles in utility voltage and the resulting load current profile are shown in fig.10.TheUPQC should maintain the voltage at load bus at a desired value and free from distortion. The shunt APF is turned on first at time t=0.1sec, such that it maintains the dc-link voltage at a set reference value, here V=220V.At time t=0.2sec (is shown in fig.5), the series active power filter gives the compensating voltages through series transformer, making the load voltage free from distortion (THD = 1.46%) and at a desired level as shown in figure.9 in load voltage. The series active power filter injected voltage profile is shown in fig.9.

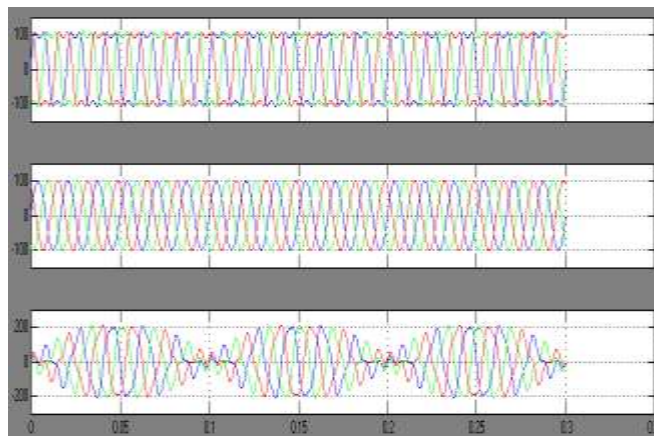


Fig. 9. Utility voltage ( $v_{s\_abc}$ ) and load voltage ( $v_{L\_abc}$ ) and injected voltage ( $v_{inj\_abc}$ ).

The compensated source currents are perfectly balanced with the THD of 2.26% and the compensating current injected through the fourth leg of the shunt APF are shown in fig.10.

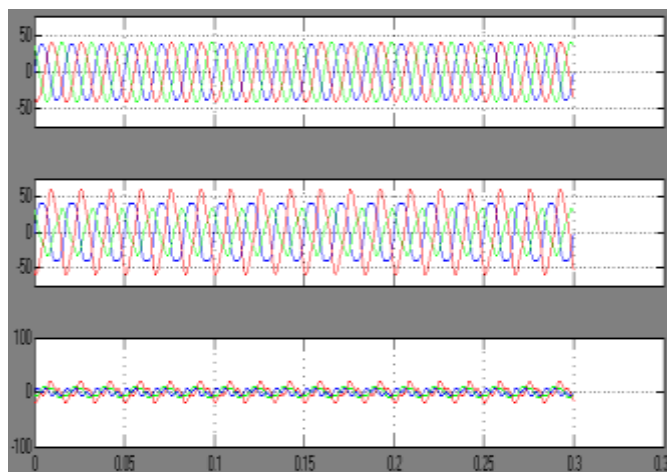
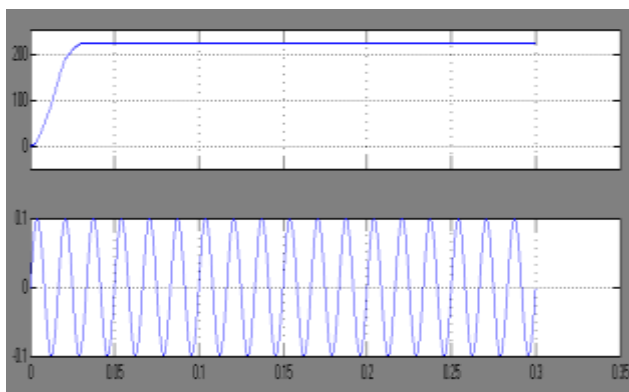
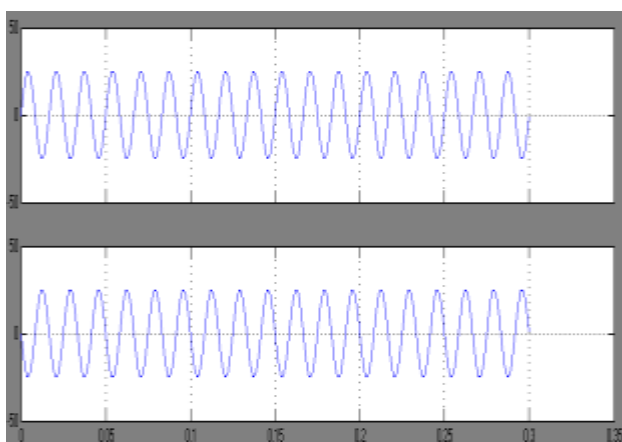


Fig.10. Source current ( $i_{s\_abc}$ ) and load current ( $i_{L\_abc}$ ) and shunt compensating current ( $i_{sh\_abc}$ ).

The load neutral current profile is shown in fig.11.In fig.12, the shunt APF effectively compensates the current flowing toward the transformer neutral point. Thus, the series transformer neutral point is maintained at virtual zero potential.



**Fig. 11. Current flowing through load neutral wire ( $i_{L\_n}$ ), and Shunt neutral compensating current ( $i_{sh\_n}$ ).**



**Fig. 12. Dc-link voltage ( $v_{dc}$ ), and neutral current flowing towards series transformer ( $i_{sr\_n}$ )**

## VI. CONCLUSION

In this paper we discussed about An advanced approach to power quality issues by using unified power quality conditioner (UPQC) connected to three phase four wire system (3P4W). By actuating this system we get a solution for many power quality problems such as unbalanced voltage and current and finding the total harmonic distortion (THD) of 3P4W system utilizing 3P3W system .which may play an important role in future UPQC- based distribution system. The simulation results the utility side act as perfectly balanced source currents and are free from distortion. The series transformer neutral will be at virtual zero potential during all operating conditions.

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