**International Journal of Engineering Research and Development**
**e**-ISSN: 2278-067X, **p**-ISSN: 2278-800X, www.ijerd.com
Volume 5, Issue 11 (February 2013), PP. 40-47

# Mitigation of Power Quality Problems with Unified Power Quality Conditioner for Different Load Conditions Using P-Q Theory

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**Abstract:-** This paper presents a Design of a Unified Power Quality conditioner-right (UPQC-R) connected to three-phase four-wire system(3P4W) will makes the neutral current to zero, load balancing, mitigation of voltage, current harmonics, mitigation of voltage sag, and voltage swell in a three-phase four-wire distribution system for different combinations of linear and non-linear loads. A new control strategy is proposed to the control algorithm for series active power filter (APF) is based on unit vector template generation to compensate the current unbalance present in the load currents by expanding the concept of single phase P-Q theory. The MATLAB/Simulink based simulations are provided which supports the functionality of the UPQC-R. In this paper four cases like linear balanced, linear unbalanced, nonlinear balanced and nonlinear unbalanced conditions are studied. Also voltage sag, voltage swell and zero neutral current waveforms are presented.

**Keywords:-** series active power filter, shunt active power filter, three-phase four wire systems (3P4W), Instantaneous Active Reactive Power (P-Q) theory, Harmonics, Power quality, Unified Power Quality Conditioner (UPQC).

## I. INTRODUCTION

Power Quality problems are becoming a major concern of today's power system engineers. Harmonics play important role in determining the power quality the disturbance due to harmonics is called harmonic distortion. Harmonic distortion in electric distribution system is increasingly growing due to the widespread use of nonlinear loads. Here we observe the power quality problems such as unbalanced voltage, currents by connecting the nonlinear loads and linear loads to 3P4W system [1].The effective control of ac power using semiconductor switches such as Thyristors are widely employed to feed the controlled electric power to electrical loads such as adjustable speed drives (ASD's) arc welding machines, arc furnace and computer power supplies etc.Such controllers are also used in High Voltage DC systems and renewable electric power generation. As the nonlinear loads and the solid-state converters draw harmonics, reactive power components of current from ac mains [1]. The injected harmonics, reactive power burden, unbalance and excessive neutral currents cause low system efficiency and poor power factor. The harmonics also cause disturbance to other consumers and interference in nearby communication networks.

The power electronics based devices have been used to overcome the major power quality problems [2].In order to reduce the power quality problems present in the 3P4W system, the Unified Power Quality Conditioner (UPQC) is one of the best solutions to compensate both current and voltage related problems. As the UPQC is a combination of series and shunt active power filters (APF's).The series active power filter (APF) suppresses and isolates voltage-based distortions, whereas the shunt active power filter (APF) cancels current based distortions. At the same time, the shunt active power filter (APF) compensates the reactive current of the load and improves power factor[4]-[5].A 3P4Wdistribution system is generally realized by providing a neutral conductor along with the three power lines from substation or by utilizing a delta–star transformer at the distribution level. The neutral of series transformer used as the series part of UPQC, is considered as a neutral for 3P4W system. Thus, even if the power supplied by utility is 3P3W an easy expansion to 3P4W system can be achieved in UPQC based applications that is by adding a fourth leg to the existing 3P3W UPQC.Ensure that the neutral current flowing toward transformer neutral point should be zero. Thus, the transformer neutral point can be maintained at virtual zero potential [6].The unbalanced load currents are very common in 3P4W distribution system can be reduced by injecting the currents using shunt active power filter (APF) [7].

## II. UNIFIED POWER QUALITY CONDITIONER (UPQC)

UPQC is the combination of a series active power filter and shunt active power filter with a common self-supporting dc bus. The general UPQC will be installed at various substations by the electric power utilities in the near future. The main purpose of the series active power filter is harmonic isolation between a sub transmission system and a distribution system. In addition, to that the series active power filter has the capability of voltage flicker/imbalance compensation as well as voltage regulation and harmonic compensation at the utility consumer point of common coupling (PCC). The main purpose of the shunt active filter is to absorb current harmonics, compensation for reactive power, negative-sequence current and regulate the dc-link voltage between both active filters [4].

UPQC is employed in a power distribution system means at substation side to perform the shunt and series compensation simultaneously [7] from the block diagram of UPQC shunt coupling inductor $L_{sh}$ is used to interface the shunt inverter to the network. It also helps in smoothing the current wave shape. A common dc link that can be formed by using a capacitor or an inductor. In Fig.2 the dc link is realized using a capacitor which interconnects the two inverters and also maintains a constant self-supporting dc bus voltage across it. An LC filter that serves as a passive low-pass filter (LPF) and helps to eliminate high-frequency switching ripples on generated inverter output voltage. The series injection transformer that is used to connect the series inverter in the network. A suitable turns ratio is often considered to reduce the current or voltage rating of the series inverter.

## III. 3P4W DISTRIBUTION SYSTEM REALIZED WITH UPQC

Generally, a 3P4W distribution system is realized by providing a neutral conductor along with three power conductors from generating station or by utilizing a three-phase Δ–Y transformer at distribution level. Fig.1shows a 3P4W network in which the neutral conductor is provided from the generating station itself, assume a plant site where three-phase three-wire UPQC is already installed to protect a sensitive load and to restrict any entry of distortion from load side toward utility. If we want to upgrade the system now from 3P3W to 3P4W due to installation of some single-phase loads the distribution transformer is close to the plant under consideration, utility would provide the neutral conductor from this transformer without major cost involvement. In certain cases, this may be a costly solution because the distribution transformer may not be situated in close vicinity [6].

In this paper, the four-leg VSI topology is considered to compensate the neutral current flowing toward the transformer neutral point. A fourth leg is added on the existing 3P3W UPQC, such that the transformer neutral point will be at virtual zero potential.

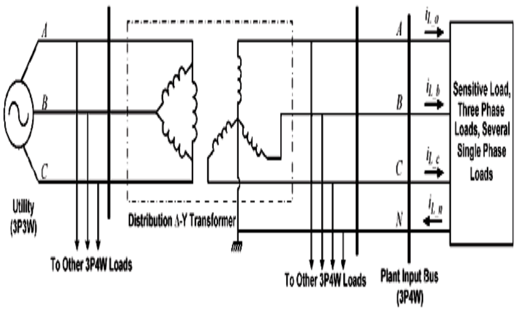


**Figure 1.** 3ph4w distribution system:neutral provided from Δ–Y transformer

Thus, the proposed structure would help to realize a 3P4W system from a 3P3W system at distribution load end. This would eventually result in easy expansion from 3P3W to 3P4W systems. A new control strategy to generate balanced reference source currents under unbalanced load condition is also proposed in this paper and is explained in the next section.

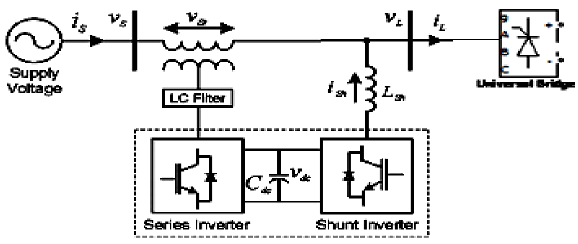


**Figure 2.** 3 ph UPQC structrure wth nonlinear load

## IV. INSTANTANEOUS ACTIVE REACTIVE POWER (P-Q) THEORY

A simple controller scheme for UPQC, called as unit vector template generation (UVTG) is used. This method uses a phase-locked loop (PLL) to generate unit vector template(s) for single-/three-phase system [1]. In this paper, a new control strategy is proposed to compensate the current unbalance present in the load currents by expanding the concept of single-phase p–q theory. According to this theory, a single-phase system can be defined as a pseudo two phase system by giving $\pi/2$ lead or $\pi/2$ lag, i.e., each phase voltage and current of the original three-phase system can be considered as three independent two-phase systems. These resultant two phase systems can be represented in α–β coordinates, and thus, the p–q theory applied for balanced three-phase system can also be used for each phase of unbalanced system independently.

The actual load voltages and load currents are considered as α-axis quantities, whereas the $\pi/2$ lead load or $\pi/2$ lag voltages and $\pi/2$ lead or $\pi/2$ lag load currents are considered as β-axis quantities. In this paper $\pi/2$ lead is considered to achieve a two-phase system for each phase. The major disadvantage of p–q theory is that it gives poor results under distorted and/or unbalanced input/utility voltages In order to eliminate these limitations, the reference load voltage signals extracted for series APF are used instead of actual load voltages [6].

For phase a, the load voltage and current in α–β coordinates can be represented by π/2 lead as

$$v_{La-\alpha} = v^*_{La}(\omega t) \quad (1.1)$$

Where $v^*_{La}(\omega t) = V_{Lm}\sin(\omega t)$

$$v_{La-\beta} = V_{Lm}\sin\left(\frac{\pi}{2} + \omega t\right) \quad (1.2)$$

$$i_{La-\alpha} = i_{La}\left(\omega t + \varphi_L\right) \quad (1.3)$$

$$i_{La-\beta} = i_{La}\left[\left(\omega t + \varphi_L\right) + \pi/2\right] \quad (1.4)$$

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 and current in α–β coordinates can be represented by π/2 lead as

$$v_{Lb-\alpha} = v^*_{Lb}(\omega t) \quad (1.5)$$

$$\text{Where } v^*_{Lb}(\omega t) = V_{Lm}\sin(\omega t - 120^\circ) \quad (1.6)$$

$$v_{Lb-\beta} = V_{Lm}\sin\left(\frac{\pi}{2} + (\omega t - 120^\circ)\right) \quad (1.7)$$

$$i_{Lb-\alpha} = i_{Lb}\left(\omega t + \varphi_L\right) \quad (1.8)$$

$$i_{Lb-\beta} = i_{Lb}\left[\left(\omega t + \varphi_L\right) + \pi/2\right] \quad (1.9)$$

In addition, for phase c, the load voltage and current in α–β coordinates can be represented by π/2 lead as

$$v_{Lc-\alpha} = v^*_{Lc}(\omega t) \quad (1.10)$$

$$\text{Where } v^*_{Lc}(\omega t) = V_{Lm}\sin(\omega t + 120^\circ) \quad (1.11)$$

$$v_{Lc-\beta} = V_{Lm}\sin\left(\frac{\pi}{2} + (\omega t + 120^\circ)\right) \quad (1.12)$$

$$I_{Lc-\alpha} = i_{Lc}\left(\omega t + \varphi_L\right) \quad (1.13)$$

$$i_{Lc-\beta} = i_{Lc}\left[\left(\omega t + \varphi_L\right) + \pi/2\right] \quad (1.14)$$

By using the above equation we can develop the following simulation block diagram.

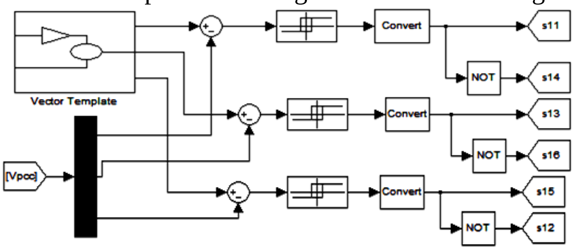


**Figure.3**.Simulation block of Series active power filter controller.

By using the definition of three-phase p–q theory for balanced three-phase system, the instantaneous power components can be represented as

Instantaneous active power

$$p_{L,a} = v_{L,a-\alpha} \cdot i_{L,a-\alpha} + v_{L,a-\beta} \cdot i_{L,a-\beta} \quad (1.15)$$

Instantaneous reactive power

$$q_{L,a} = v_{L,a-\alpha} \cdot i_{L,a-\beta} - v_{L,a-\beta} \cdot i_{L,a-\alpha} \quad (1.16)$$

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

$$\begin{bmatrix} p_{La} \\ q_{La} \end{bmatrix} = \begin{bmatrix} v_{La-\alpha} & v_{La-\beta} \\ -v_{La-\beta} & v_{La-\alpha} \end{bmatrix} \cdot \begin{bmatrix} i_{La-\alpha} \\ i_{La-\beta} \end{bmatrix} \quad (1.17)$$

Where

$$p_{La} = \overline{p_{La}} + \widetilde{p_{La}} \quad (1.18)$$

$$q_{La} = \overline{q_{La}} + \widetilde{q_{La}} \quad (1.19)$$

In (1.18) and (1.19), $\overline{p_{La}}$ 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 phase-a fundamental instantaneous load active and reactive power components can be extracted from $p_{La}$ and $q_{La}$ , respectively, by using a low pass filter.

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

$$p_{La,1} = \overline{p_{La}} \quad (1.20)$$

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

$$q_{La,1} = \overline{q_{La}} \quad (1.21)$$

Similarly, the fundamental instantaneous load active and the fundamental instantaneous load reactive powers for phase's b and c can be calculated as

Instantaneous fundamental load active power for phase b

$$p_{Lb,1} = \overline{p_{Lb}} \quad (1.22)$$

Instantaneous fundamental load reactive power for phase b

$$q_{Lb,1} = \overline{q_{Lb}} \quad (1.23)$$

Instantaneous fundamental load active power for phase c

$$p_{Lc,1} = \overline{p_{Lc}} \quad (1.24)$$

Instantaneous fundamental load reactive power for phase c

$$q_{Lc,1} = \overline{q_{Lc}} \quad (1.25)$$

Since the load current drawn by each phase may be different due to different loads that may be present inside plant, therefore, the instantaneous fundamental load active power and instantaneous fundamental load reactive power demand for each phase may not be the same. In order to make this load unbalanced power demand, seen from the utility side, as a perfectly balanced fundamental three-phase active power. The unbalanced load power should be properly redistributed between utility, UPQC, and load, such that the total load seen by the utility would be linear and balanced load. The unbalanced or balanced reactive power demanded by the load should be handled by a shunt active power filter (APF) [5]. 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, i.e., from (1.20), (1.22), and (1.23)

$$p_{L,total} = p_{La,1} + p_{Lb,1} + p_{Lc,1} \quad (1.26)$$

$$p^*_{S/ph} = \frac{p_{L,total}}{3} \quad (1.27)$$

Equation (1.20) gives the redistributed per-phase fundamental active power demand that each phase of utility should supply in order to achieve perfectly balanced source currents. From (1.20), it is evident that under all the conditions, the total fundamental power drawn from the utility but with perfectly balanced way even though the load currents are unbalanced [1]. Thus, the reference compensating currents representing a perfectly balanced three-phase system can be extracted by taking the inverse of (1.17)

$$\begin{bmatrix} i^*_{sa-\alpha} \\ i^*_{sa-\beta} \end{bmatrix} = \begin{bmatrix} v_{La-\alpha} & v_{La-\beta} \\ -v_{La-\beta} & v_{La-\alpha} \end{bmatrix}^{-1} \cdot \begin{bmatrix} p^*_{S/ph} + p_{dc/ph} \\ 0 \end{bmatrix} \quad (1.28)$$

In (1.28), $p_{dc/ph}$ 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.The oscillating instantaneous active power should be exchanged between the load and shunt APF. The reactive power term ($q_{La}$) in (1.21) is considered as zero, since the utility should not supply load reactive power demand. In the above matrix, the α- axis reference compensating current represents the instantaneous fundamental source current, since α-axis quantities belong to the original system under consideration and theβ-axis reference compensating current represents the current that is at π/2 lead with respect to the original system.

Therefore,

$$i^*_{sa}(t) = \frac{v_{La-\alpha}(t)}{v^2_{La-\alpha} + v^2_{La-\beta}} \cdot \left[p^*_{S/ph}(t) + p_{dc/ph}(t)\right] \quad (1.29)$$

Similarly, the reference source current for phases b and c can be estimated as

$$i^*_{sb}(t) = \frac{v_{Lb-\alpha}(t)}{v^2_{Lb-\alpha} + v^2_{Lb-\beta}} \cdot \left[p^*_{l/ph}(t) + p_{dc/ph}(t)\right] \quad (1.30)$$

$$i^*_{sc}(t) = \frac{v_{Lc-\alpha}(t)}{v^2_{Lc-\alpha} + v^2_{Lc-\beta}} \cdot \left[p^*_{l/ph}(t) + p_{dc/ph}(t)\right] \quad (1.31)$$

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

The simulation block diagram of shunt active power filter is obtained from the above mentioned equations, the reference neutral current generation are shown in Fig 4.

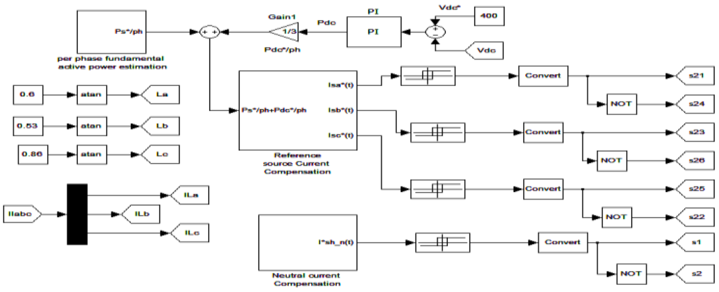


**Figure.4.** Simulation block of Shunt Active Power Filter.

$$i_{L-n}(t) = i_{La}(t) + i_{Lb}(t) + i_{Lc}(t) \quad (1.32)$$
$$i_{sh-n}(t) = -i_{L-n}(t) \quad (1.33)$$

## V. MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

Therefore by using the above control strategies for series active power filter, shunt active power filter combindly helps to design a UPQC .The following MATLAB/SIMULINK model for UPQC for 3P4W distribution system is simulated and the results are observed.

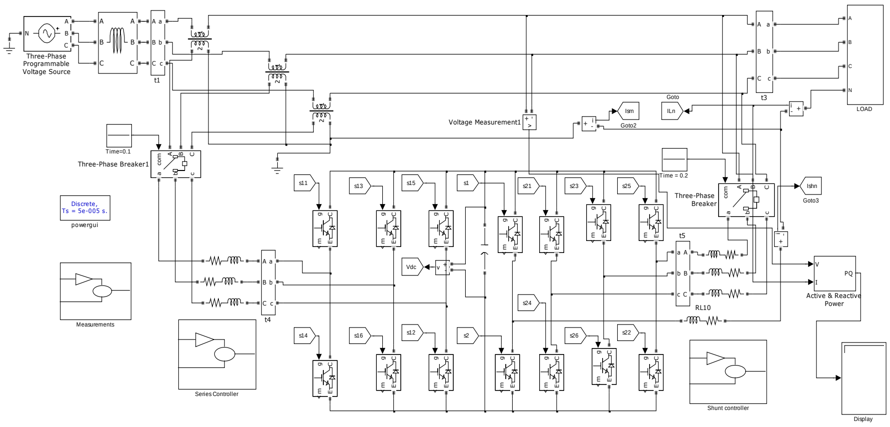


**Fig 5**.Simulation Block Diagram of 3P4W system realized from a 3P3W system utilizing UPQC.

The simulation results for the proposed 3P4W system realized from a 3P3W system utilizing UPQC are shown in below figs 6.1 to 6.11Utility voltage are assumed to be distorted with voltage THD of 27.0 % The distorted voltage profile is shown in fig 6.1 The resulting load current profile shown in fig 6.5 has THD of 12.10%.

The series active power filter injects the required compensating voltages through series transformer, making the load voltage free from distortion (THD = 1.52%) and at a desired level as shown in figure 6.2 The series active power filter injected voltage profile is shown in fig 6.3 with load voltage has a THD of 1.52%.
The compensated source currents shown in fig 6.6 are perfectly balanced with the THD of 2.32%.The compensating current injected through the fourth leg of the shunt APF is shown in fig 6.6. 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 is shown in fig 6.7. Fig 6.9 shows the power quality improvement during voltage sag condition fig 6.10 shows the power quality improvement during voltage swell condition. The fig 6.11 shows the source current improvement for linear balanced load condition

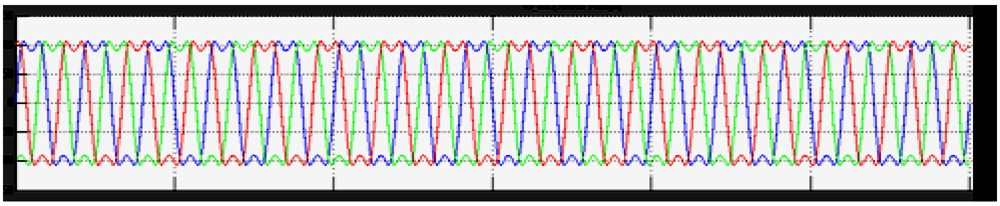

**Figure 6.**1. Utility Voltage.

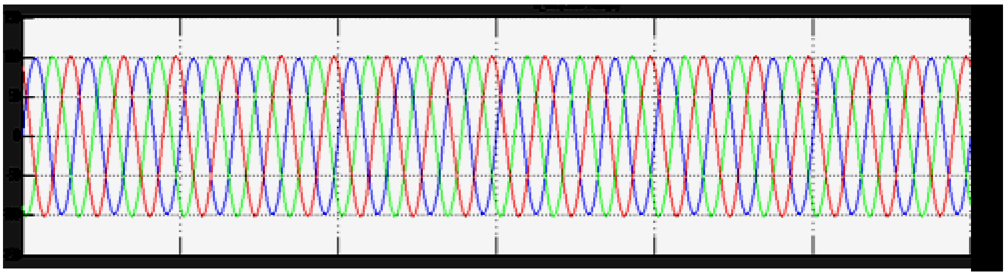

**Figure 6.**2. Load Voltage.

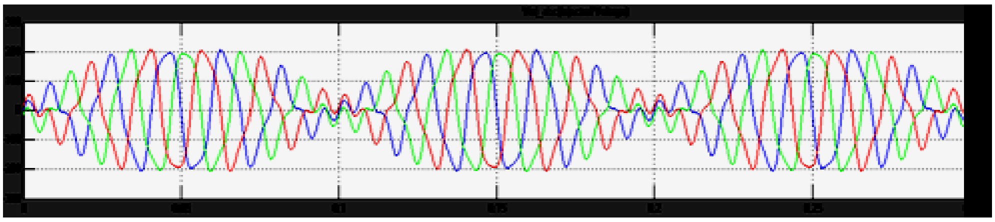

**Figure 6.**3.Injected Voltage.

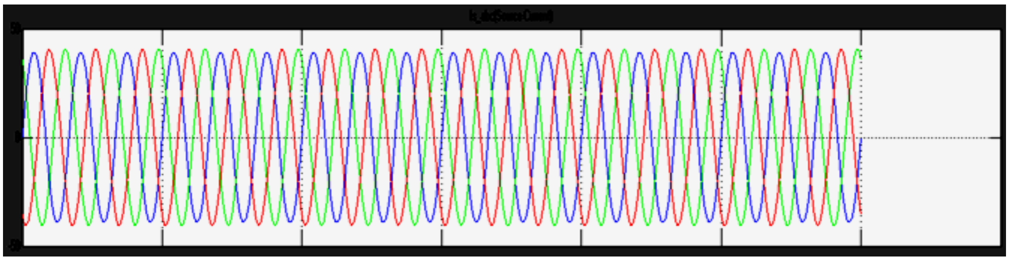

**Figure.6.**4. Source Current.

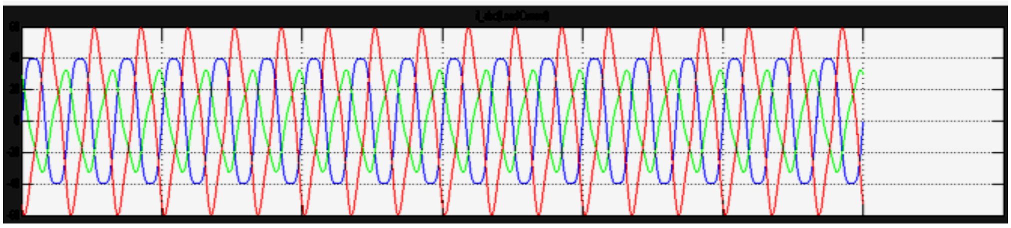

**Figure 6**.5. Load Current.

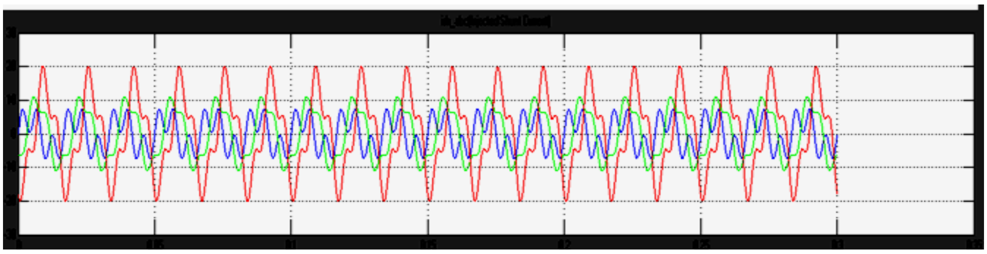

**Figure.6.6**. shunt compensating current.

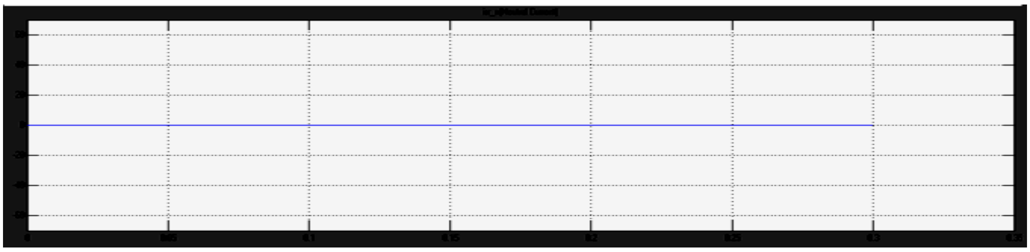

**Figure.6.7**. Neutral current flowing towards series transformer.

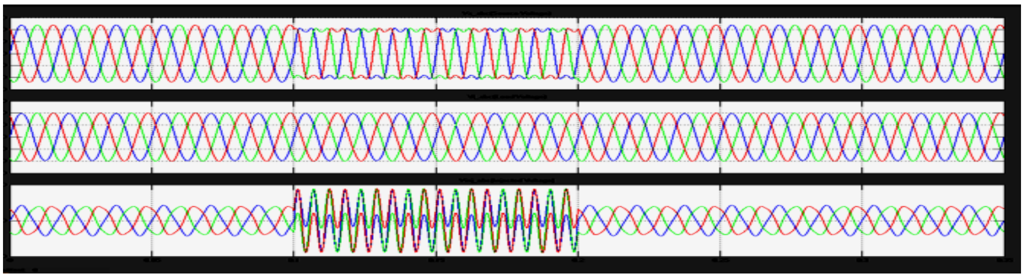

**Figure.6.**8. power quality improvement using ANN in load voltage.

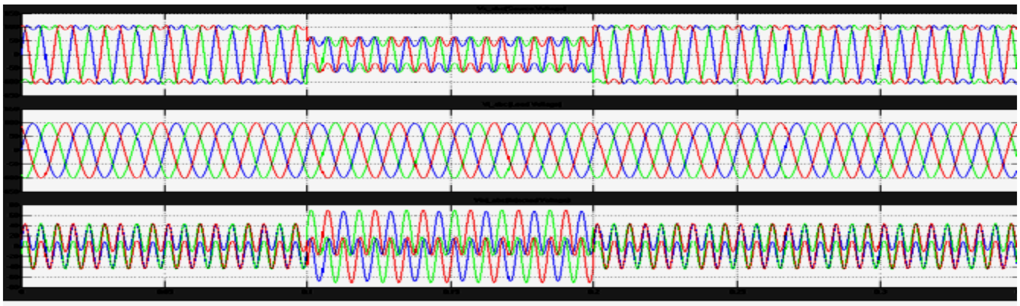

**Figure.6.9**. power quality improvement during voltage sag condition.

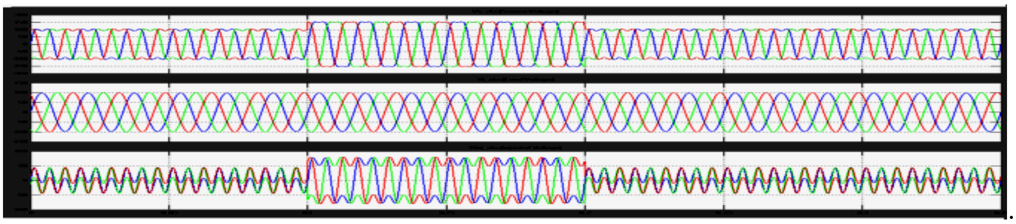

**Figure.6.10.** power quality improvement during voltage swell condition.

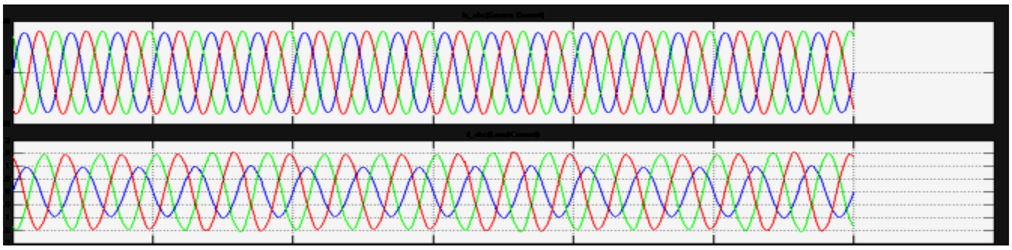

**Figure.6.1**1source current improvement for linear balanced load conditions.

## VI. CONCLUSION

The design of a unified power quality conditioner (UPQC) connected to 3P4W distribution system has been presented in this paper. Where UPQC is installed to compensate the different power quality problems, which may play an important role in future UPQC based distribution system. The simulation results shows that the distorted and unbalanced load currents seen from the utility side act as perfectly balanced source currents and are free from distortion. We can also observed that there will be reduction in THD and improvement in perfectly balanced source voltage and current. The neutral current that may flow toward the transformer neutral point is effectively compensated such that the transformer neutral point is always at virtual zero potential. Power quality can also be improved during voltage sag & voltage swell conditions. Power quality can also improved for linear unbalanced condition.

**Acknowledgement**

The authors would like to thank the authorities of Aditya Institute of Technology And Management, K.Kotturu, Tekkali, Srikakulam (Dist), India for all the cooperation and encouragement in carrying out this work.

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