IJCTA, 9(10), 2016, pp. 4461-4468

Improving Power Quality in Distributed Generation Using Unified Power Quality Conditioner

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Abstract : This paper describes role of UPQC as applied to a 3P4W system to improve PQ. The Forth wire of 3P4W system is developed by means of neutral of series transformer. Neutral current which flows through neutral terminal of transformer is removed with help of 4 leg voltage source inverter (VSI) topology. Regarding shunt part this point will have 0 potential in all conditions of operation. Simulation is carried out by considering the major PQ issues like voltage, current, harmonic by connecting load which is non linear in nature to 3P4W scheme with UPQC. By extending the principle of single phase PQ theory, series APF can be designed by means of unit vector template as control strategy. The function of UPQC is under stood MATLAB/ Simulink based simulations. The PQ theory as applied to the 3 phase balanced system can even be independently used for unbalanced system.

Key words : Series and Shunt Active power filters, 3 phase four wire system (3P4W), Power Quality concepts, Unified Power Quality Conditioner(UPQC)

1. INTRODUCTION

Power electronics devices take reactive power from the supply because of the existing non linearity. These harmonic, Reactive power as well as excessive neutral circuits results into reduced efficiency of the system and power factor as well. Development in semi conductor device technology enables the utilization of advanced devices /loads at both distribution and transmission levels. These equipments have requirement of clean power for effective functionality. Current harmonic causing PQ problem in distribution system are generated at the time of their switching. The devices build on power electronics are being employed to improve PQ. A 3P4W system of distribution could be formed by facilitating a neutral wire in conjunction to 3 power lines from generation location. Unbalance load circuits is a usual problem in 3P4W distribution system that should be taken into account. The PQ can be improving by employing series and shunt APF in the system. These are 2 classes of filter. Passive and Active filters. Passive filters are comprising of L and C component which provide simplicity as well as economy to system; but they have tendency to suffer from resonance problem and get filter for every frequency and bulky. On other hand active filters comprise of IGBTs, MOSFET, and devices of storage of energy like L and C. The privilege of active filter is that they filter a specific frequency range do not resonate with the system and provide fast response. But their cost is high. The serials APF basically draw out the harmonics in voltage by providing path of large impedance path to harmonic circuits. Non - linear loads highly produce distorted current resulting into third harmonic component.

2. 3P3W DISTRIBUTION SYSTEM UTILIZING UPQC

Normally a secure system of distribution is developed introducing a neutral wire with the 3 power conductors from generating station. Fig.1 gives a typical 3P3W system utilizing a UPQC circuit.

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A 3P3W system can be converted into a 3P3W if utilities provide a neutral conductor from the transformer at distribution if it is nearer to the plant which is to be considered, may not be resulting into high cost. However this process may be a costlier one if the transmission is located for away from the generating station. The THD has been limited by utility service provides in order to control harmonics in distribution station which is caused by non linear loads. Fig. 2 shows the expansion of 3P3W using UPQC.

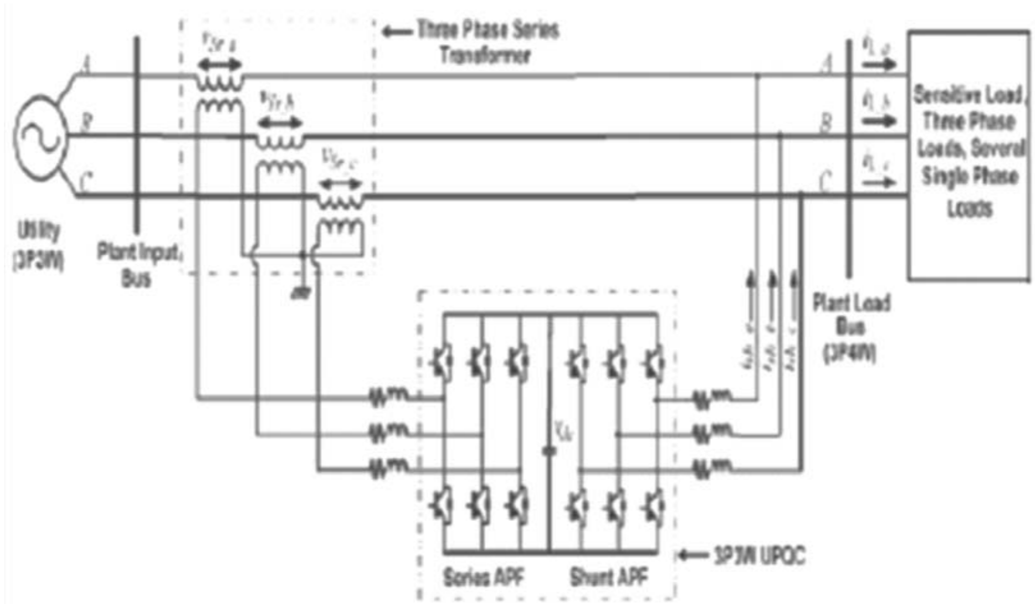

Fig. 1. 3P3W system is connected to UPQC.

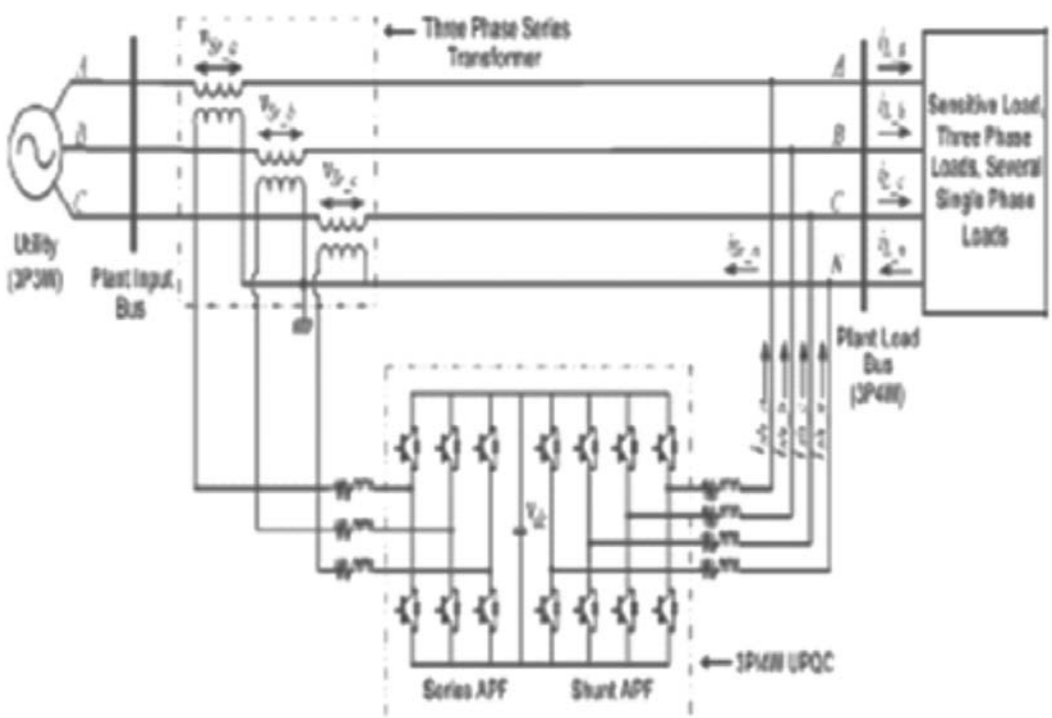

Fig. 2. 3P4W system realized from a 3P3W system utilizing.

The UPQC comprises of 3 phase transformer which connects 1 of the inverter to line in series and which functions like controlled voltage source. 3P3W system can be easily achieved by means of neutral of this series transformer. If neutral circuit is present, it will pass through this 4th wire in the direction of neutral point of transformer.

The system could be prevented from this neutral circuit employing a split capacitor scheme [4] [5] ,[6] or a 4 leg VSI scheme [4],[7]. Inverter in shunt consists of one extra leg in comparison to a split capacitor topology. The split capacitor arrangement is more complicated than VSI. But here the UPQC design based on PQ theory is used which is connected to 3P4W system. Hence the arrangement will be useful to form a 3P4W system at distributed load side. During load conditions a novel strategy of control has been introduced to create balanced reference source circuits, in this paper.

3. DESIGN OF UPQC CONTROLLER

A. How to Implement a Series APF

Basically in a series APF, the voltage is injected in series of line through an inverter that supplies polluted load through transformer. This voltage which is injected is not purely sinusoidal and contains a small DC component in phase with the line current. Due to the voltage injection, for this small sinusoidal in phase component supplies proper active power to inverter. Hence losses inside series APF are much reduced and the DC side capacitive voltage remains unchanged. The amount of this in phase component is followed by DC voltage control loop. The series APF limits the system current distortion caused by non-linearity in load by providing a large Z path to the harmonic current. Fig 3 shows line diagram of APF.

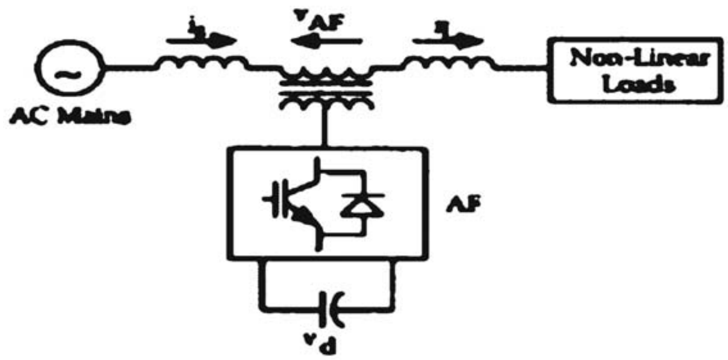

Fig. 3. Line diagram of series of active power filter.

B. How to implement a shunt APF

Power Electronic swing devices are used in the concept of APF to generate the current harmonic as a non-linearity. In a shunt APF, the filter is added in shunt with load of which current harmonic control in desired. Hence the configuration is also termed as active parallel or shunt filter. Fig. 4 shows removal in harmonic.

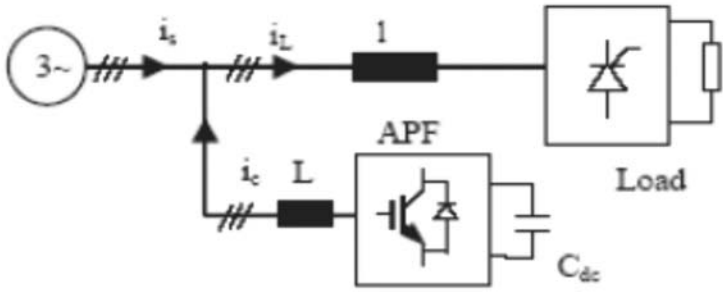

Fig. 4. Shunt Active Power Filter.

Compensation in harmonic current is basically achieved by VSI in the filter. In the inverter DC capacitors are used to generate the supply. The section describes strategy to control shunt APF. Current obtained through generating station mainly depends upon the nature of the load. The PQ theory [3],[10] defines a single phase system as a pseudo 2 phase system having either $\pi/2$ lead or $\pi/2$ lag. The 2 phase system could be expressed as terms of α-β co ordinates; hence PQ theory implemented for balanced 3 phase system [11]. The standard load voltage signal abstracted for series APF is being utilized in spite the original load voltage.

Here we are deriving, α-β co-ordinates of load voltage. The respective formulae for phase '*a*' are represented by equations (1) to (2).

$$\begin{bmatrix} V\alpha\_\alpha \\ V\alpha\_\beta \end{bmatrix} = \begin{bmatrix} V^*\alpha(\omega t) \\ V^*\alpha(\omega t + 90°) \end{bmatrix} = \begin{bmatrix} \text{Vlmsin}(\omega t) \\ \text{Vlmcos}(\omega t) \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} iloada\_\alpha \\ iloada\_\beta \end{bmatrix} = \begin{bmatrix} iloada(\omega t + \varphi l\,) \\ V^*loada\,(\omega t + \varphi l) + 90° \end{bmatrix} \quad (2)$$

Similarly, for phase 'b'. This will include leading angle of 90°

$$\begin{bmatrix} Vb\_\alpha \\ Vb\_\beta \end{bmatrix} = \begin{bmatrix} V^*b(\omega t) \\ V^*b(\omega t + 90°) \end{bmatrix} = \begin{bmatrix} \text{Vlmain}(\omega t - 120°) \\ \text{Vlmcos}(\omega t - 120°) \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} iloadb\_\alpha \\ iloadb\_\beta \end{bmatrix} = \begin{bmatrix} iloada(\omega t + \varphi l) \\ V^*\,loada(\omega t - \varphi l) + 90° \end{bmatrix} \quad (4)$$

For phase 'C' also we will consider leading angle of 90°.

$$\begin{bmatrix} Vc\_\alpha \\ Vc\_\beta \end{bmatrix} = \begin{bmatrix} V^*c(\omega t) \\ V^*c(\omega t + 90°) \end{bmatrix} = \begin{bmatrix} Vlmsin\,(\omega t + 120°) \\ Vlmcos\,(\omega t + 120°) \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} iloadc\_\alpha \\ iloadc\_\beta \end{bmatrix} = \begin{bmatrix} iloada(\omega t + \varphi l\,) \\ V^*\,loada\,(\omega t + \varphi l\,) + 90° \end{bmatrix} \quad (6)$$

With the help of above equations, power equations can be given by (7) to (8)

$$p_{loadabc} = V_{abc\_\alpha} * i_{abc\_\alpha} + V_{abc\_\beta} * i_{abc\_\alpha} \quad (7)$$

$$q_{loadabc} = V_{abc\_\alpha} * i_{abc\_\beta} - V_{abc\_\beta} * i_{abc\_\alpha} \quad (8)$$

4. SIMULATION BLOCK DIAGRAM

Fig.5 & Fig.6 shows simulation model of 3P4W extracted from a 3P3W system by using UPQC. Power electronics devices form non linear loads. Load at plant is considered, as mix of balanced 3 phase diode bridge rectifier with an R-L load that functions like harmonic generating load, and 3 various types of single phase loads on every phase with varying active or reactive demands. Design of series APF based unit vector template followed by equations (1),(3) and (5). The design of shunt APF is based on all above equations.

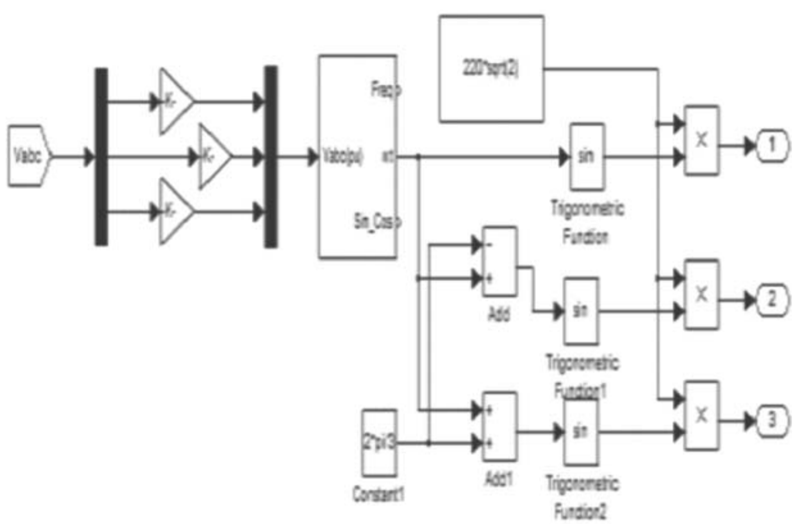

Fig. 5. Simulation block of Unit Vector Template of Series Active Power Filter.

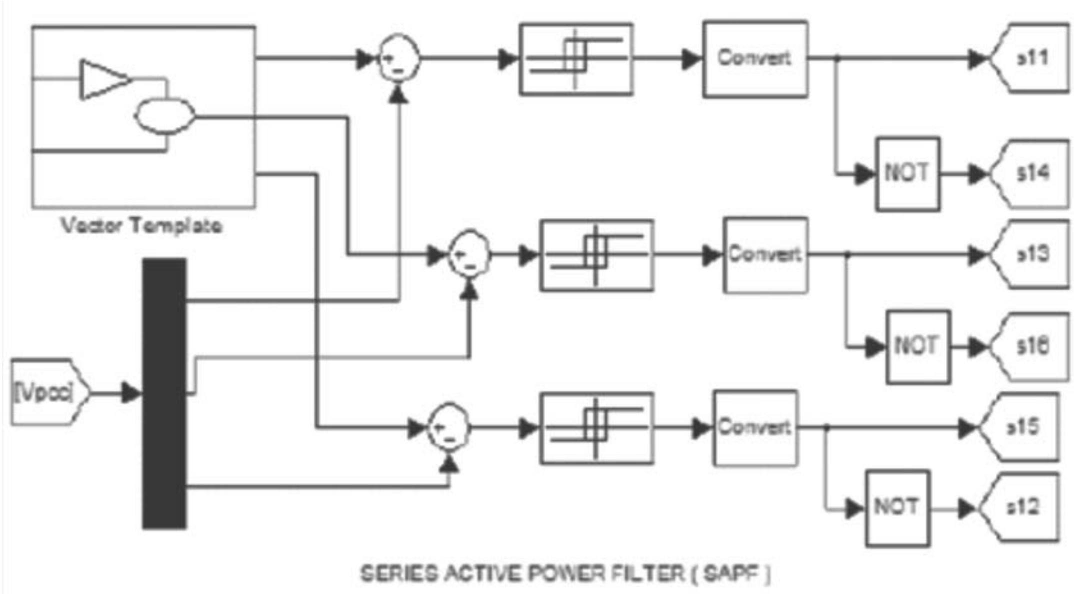

Fig. 6. Simulation block of Series active power filter controller.

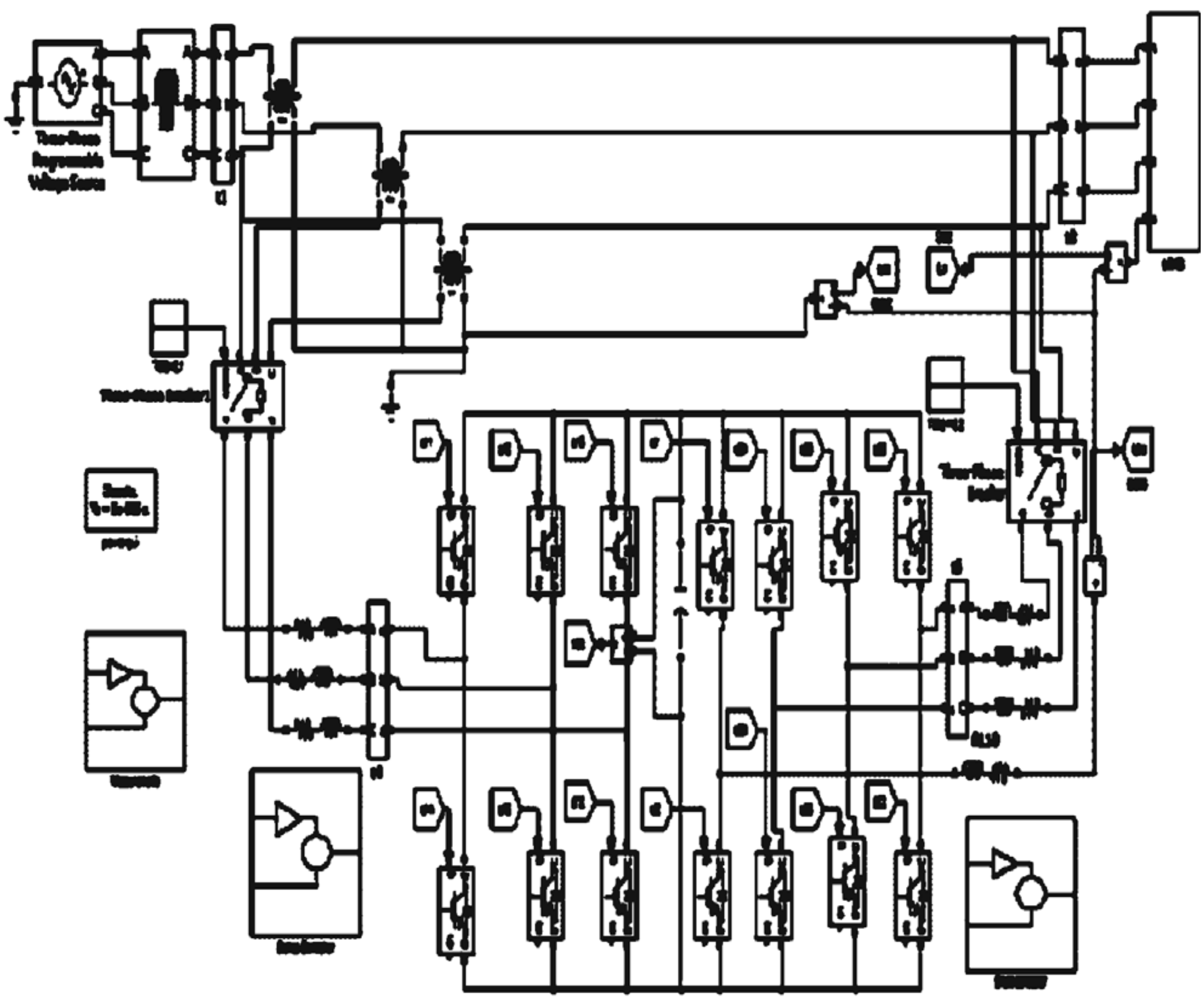

Fig. 7. Simulation Block Diagram of 3P4W system realized from at 3PW system utilizing UPDC.

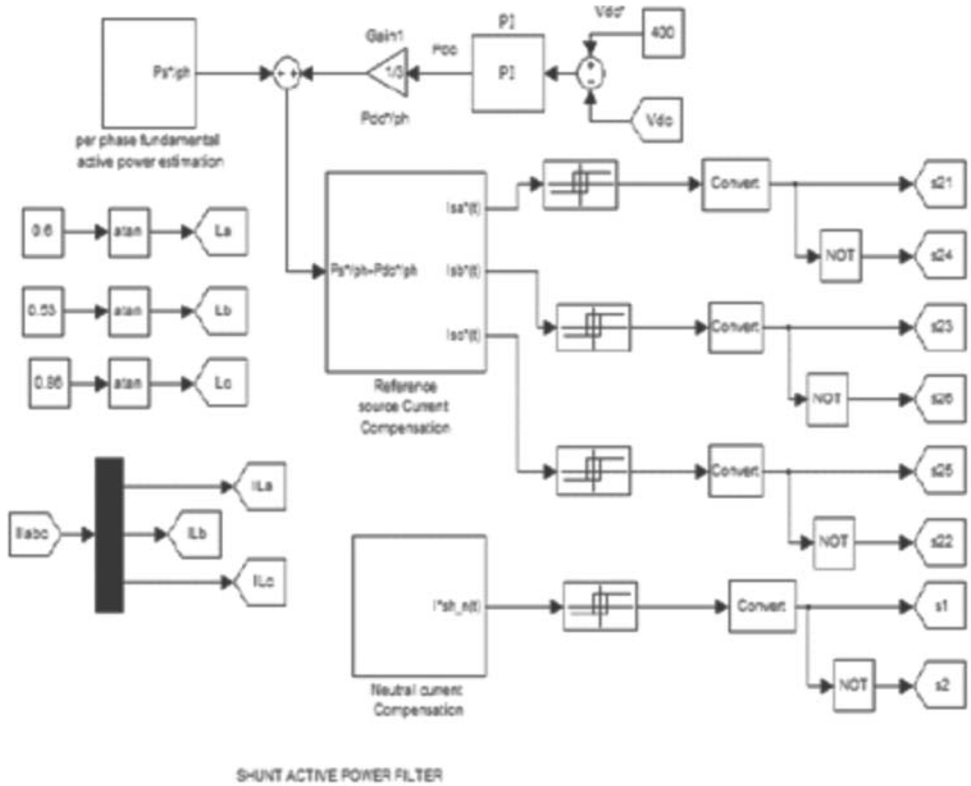

Fig. 8. Simulation block of Shunt active power filter.

5. SIMULATION RESULTS AND DISCUSSION

Simulation inferences regarding recommended 3P4W system developed from a 3P3W system using UPQC are given in the Fig 9 to 12. The voltage distortion in the utility voltage (THD) is considered to be 27.0%. The nature of distortion in voltage is given in Fig . has THD of 12.10%. The UPQC must keep voltage at load end within required range which should contain no distortion. First shunt APF is started at a time t = 0.1sec, in the manner to achieve the DC link voltage for set reference value, here v= 220v, At duration *t* =0.2sec, the series APF supplies necessary compensating voltage by means of series transformer which makes load voltage with no more distortion (THD = 1.46%) and for required level as given in fig 9 in load voltage. Voltage injection through series APF is given in fig 9. The source current compensation given in fig 10 is entirely balanced with THD of 2.26%. Fourth leg of shunt APF supplies the compensating current, given in fig 10. Load neutral current nature is given in fig 11. In fig 12, shunt APF removes current passing through neutral point of transformer. Hence neutral point of series transformer is kept at virtually 0 potential.

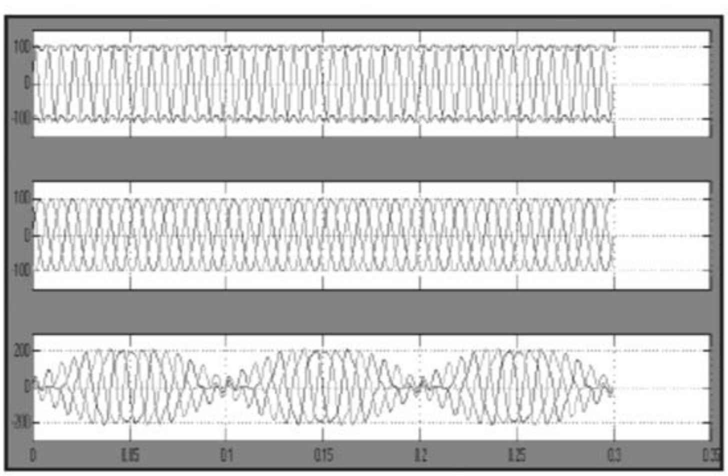

Fig. 9. Utility voltage (V_{s_abc}), load voltage (V_{L_abc}) and injected voltage (V_{inj_abc}).

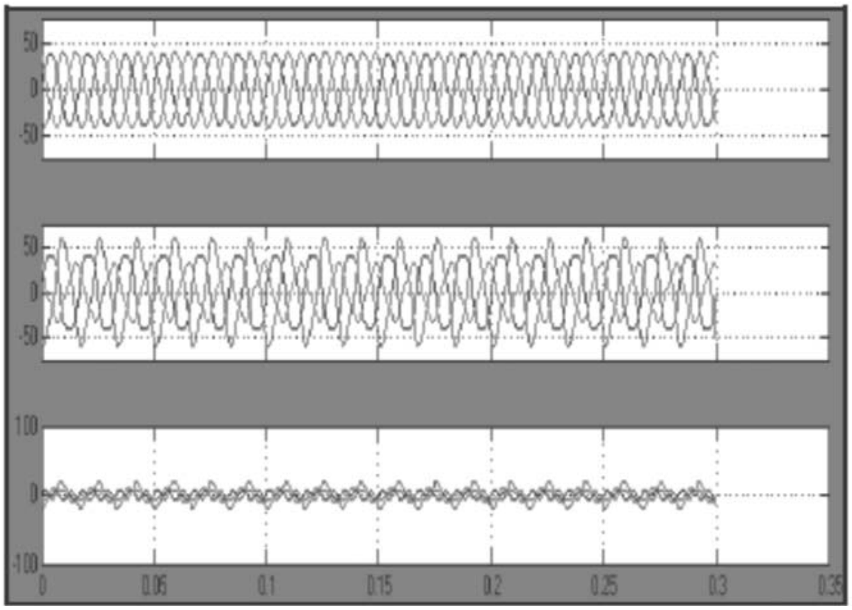

Fig. 10. Source current (i_{s_abc}), load current (i_{L_abc}) and shunt compensating current (i_{Sh_abc}).

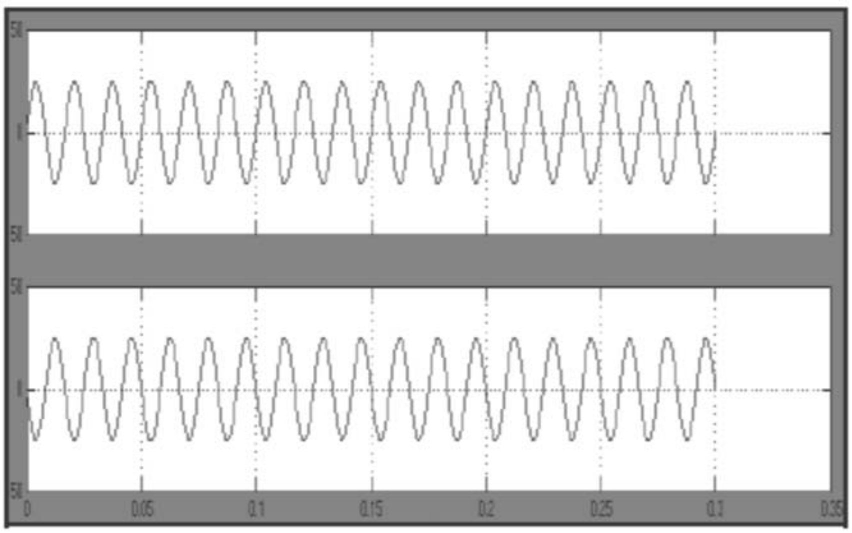

Fig. 11. Current flowing through load neutral wire (i_{L_n}), and Shunt neutral compensating current (i_{Sh_n}).

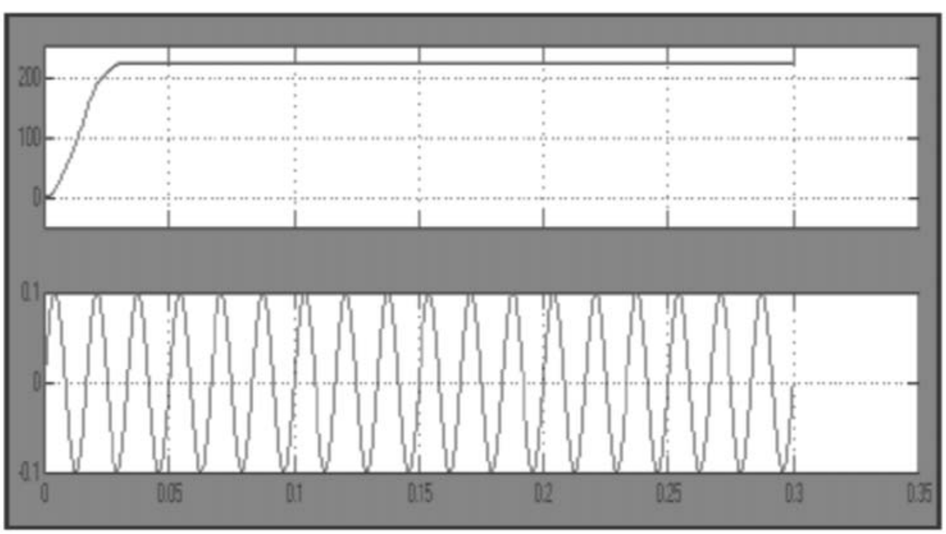

Fig. 12. Dc-link voltage (V_{dc}), and neutral current flowing towards series transoformer (i_{Sr_n})

6. CONCLUSION

This paper describes the design of UPQC as applied to a 3P4W is distortion system, where UPQC is employed to compensate the various types of PQ problems, which can play vital role in the proposed UPQ based distribution system. Simulation inferences indicates distortion and unbalance load current observed from utility side function like totally balanced source current while it doesn't contain distortion. Thus this paper tells effective idea about removing the PQ problems such as voltage, current, and minimizes Total Harmonic Distortion (THD) of 3P4W system by reducing system to 3P3W by connecting the UPQC.

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