

# SYNCHRONOUS REFERENCE FRAME THEORY BASED CONTROLLER FOR UNIFIED POWER QUALITY CONDITIONER IN THREE-PHASE FOUR-WIRE DISTRIBUTION SYSTEM

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**Abstract:** This paper presents a Synchronous Reference Frame (SRF) theory based control strategy for a Three-Phase Four-Wire Unified Power Quality Conditioner (3P4W UPQC) in distribution system to compensate the Power Quality (PQ) problems under unbalanced, distorted supply voltage and /or load conditions. The 3P4W UPQC is realized by a combination of series and shunt Active Power Filters (APF) sharing with common DC link capacitor. The series APF is realized using a three-phase three-leg Voltage Source Inverter (VSI), while shunt APF is realized using a three-phase four-leg VSI. A dynamic model of the 3P4W UPQC system is developed in the MATLAB / SIMULINK sim power system software. The simulation results validates the effectiveness and capabilities of SRF based control strategy of UPQC to mitigate various power quality problems, both steady and transient state operations in the 3P4W distribution system.

**Key words:** Active power filter (APF), Unified Power Quality Conditioner (UPQC), Synchronous Reference Frame (SRF), current harmonics, voltage unbalance, source neutral current mitigation.

## 1. Introduction

In general, the 3P4W power distribution system is feeding power to combinations of three-phase and single phase linear/ non-linear loads. The presence of single-phase load on a three-phase supply system creates a load unbalancing / an excessive neutral current problem. An excessive neutral current cause hazard of cables, overheating of distribution transformers, damage to control of sensitive electronics equipment and interference to the communication system. The proliferation of non-linear loads in domestic, commercial and industrial sectors, which results in the problems of harmonics and reactive power in power distribution system. The non-linear loads draw harmonic current which passing through the source impedance of utility creates problems of voltage harmonics and voltage unbalances at the Point of Common Coupling (PCC). These harmonics create poor power factor, increased losses and mal-operation of sensitive equipment and disturbance to nearby communication systems [1,2,3]. The Power Quality (PQ) problems are also

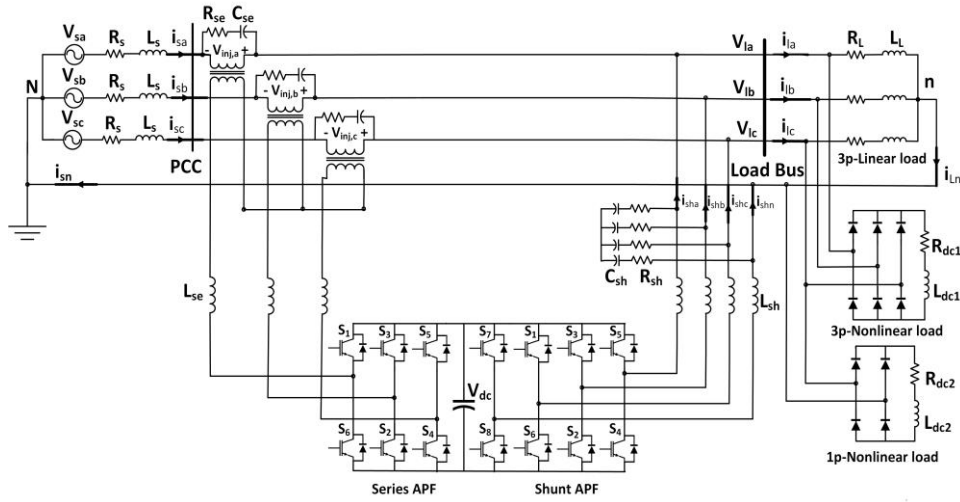
aggravated by the direct injection of non-steady power from renewable energy sources in distributed or embedded generation [1,5].

In this context, active power filter with custom power technology is emerged for enhancing the quality and reliability of electrical supply in distribution system [4, 5]. The power quality conditioners is essential to meet the guideline of IEEE -519-1992 standard [6]. The Unified Power Quality Conditioner (UPQC) is a unique custom power device that can compensate almost all power quality problems at the point of installation on power distribution system [7, 8, 9]. Conventional 3P3W UPQC topology and control algorithm needs some modifications to eliminate harmonics on the neutral wire along with other PQ problems in 3P4W system. Hence many researchers are involving to develop advancement / fine-tuning of control techniques and novel topologies of 3P4W UPQC system [5]. As a result, the various control strategies namely instantaneous reactive power (p-q-r) theory [10], modified single-phase p-q theory [11], instantaneous symmetrical component transform (ISCT) theory [12], Sinusoidal unit vector template (SUVT) technique [13],  $I \cos\phi$  theory [14], one cycle control (OCC) technique [15] synchronous reference frame (SRF) theory [16] have been attempted for 3P4W UPQC system in the literature. The main goal of this paper is to analyse dynamic performance of SRF based controller in the 3P4W UPQC system for better power quality compensation.

This paper is organized as follows. Section 2 describes the power circuit configuration of the 3P4W UPQC system. The SRF theory based control strategy for reference voltage and current signal generation are explained in sections 3 and 4. The simulation results are discussed in section 5 and finally section 6 concludes features of the paper.

## 1. Power Circuit Configuration of the 3P4W UPQC System

Fig.1 shows power circuit configuration of the 3P4W UPQC connected distribution system. The



**Fig. 1.** Power circuit configuration of 3P4W UPQC System.

3P4W UPQC consist of a three-leg voltage controlled VSI and a four-leg current controlled VSI with back to back connection through a common dc link capacitor. The three-leg VSI is acting as series APF, while four-leg VSI acting as shunt APF. The switching devices in VSIs are Insulated-Gate Bipolar Transistors (IGBTs) with antiparallel diodes. Series APF is connected between the supply and load terminals using three single-phase injection transformers. The injection transformer secondary side is connected in series with the utility, while primary sides are connected in star configuration. In addition to inject the required voltage in series, these transformers are used to filter the switching ripple content in the injected voltage. Series APF compensates voltage quality problems of utility. The four-leg shunt APF is connected in parallel with the Point of Common Coupling (PCC) using interfacing inductor. The four-leg shunt APF compensates current related power quality problems. The additional leg of the shunt APF is mainly used for mitigating the source neutral current, thereby relieving the need for a neutral conductor with an excessive rating. The load under consideration is a combination of three-phase and single-phase linear/non-linear loads.

### 3. Control strategy of series active power filter

The series APF acts as a controlled voltage source such that injected voltages ( $v_{inja}, v_{inj b}, v_{inj c}$ ) are eliminates the distortions and/or unbalance in the supply voltages ( $v_{sa}, v_{sb}, v_{sc}$ ) in order to maintain constant, balanced sinusoidal load voltage. The SRF based control algorithm of series APF consists of the generation of three-phase reference load voltages ( $v_{la}^*, v_{lb}^*, v_{lc}^*$ ) and the control scheme of series APF is shown in Fig.2. The instantaneous distorted supply voltages  $v_{sabc}$  are sensed and then transformed into synchronous d-q-0 frame using Parks Transformation given by Eq. (1). The transformation angle ( $wt$ ) is

derived from synchronization circuitry i.e. Phase Locked Loop (PLL).

$$\begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{s0} \end{bmatrix} = T \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \quad (1)$$

The transformation matrix  $T$  and its inverse are

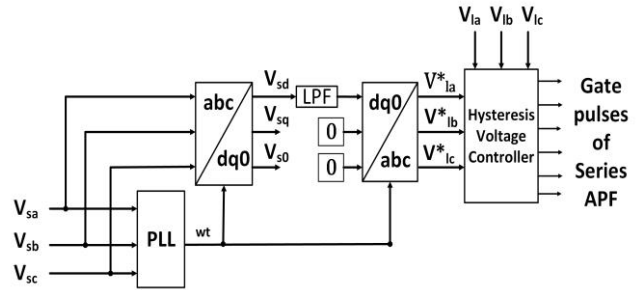
$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin(wt) & \sin(wt - 2\pi/3) & \sin(wt - 2\pi/3) \\ \cos(wt) & \cos(wt - 2\pi/3) & \cos(wt - 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}$$

and  $T = \text{transpose matrix of } T^{-1}$

Now, the instantaneous source voltages ( $v_{sd}, v_{sq}, v_{s0}$ ) in d-q-0 frame is decomposed in to fundamental positive, negative, zero sequence and harmonic components [9] as given by Eq. (2)

$$\begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{s0} \end{bmatrix} = \sqrt{\frac{3}{2}} \left\{ \begin{bmatrix} V_{s1,p} \sin \phi_{1p} \\ V_{s1,p} \cos \phi_{1p} \\ 0 \end{bmatrix} + \begin{bmatrix} V_{s1,n} \sin(2wt + \phi_{1n}) \\ -V_{s1,n} \cos(2wt + \phi_{1n}) \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ V_{s1,0} \sin(wt + \phi_{10}) \end{bmatrix} + \begin{bmatrix} \sum_{k=2}^{\infty} V_k \sin[(k-1)(wt + \phi_k)] \\ \sum_{k=2}^{\infty} V_k \cos[(k-1)(wt + \phi_k)] \\ 0 \end{bmatrix} \right\} \quad (2)$$

$$\begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{s0} \end{bmatrix} = \sqrt{\frac{3}{2}} \left\{ \begin{bmatrix} v_{dp} \\ v_{qp} \\ 0 \end{bmatrix} + \begin{bmatrix} v_{dn} \\ v_{qn} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ v_{d0} \end{bmatrix} + \begin{bmatrix} v_{dh} \\ v_{qh} \\ 0 \end{bmatrix} \right\} \quad (3)$$



**Fig. 2.** Control strategy of series active power filter

$$\begin{bmatrix} v_{sd} \\ v_{sq} \\ v_{s0} \end{bmatrix} = \begin{bmatrix} \bar{v}_{sd} + \tilde{v}_{sd} \\ \bar{v}_{sq} + \tilde{v}_{sq} \\ v_{00} \end{bmatrix} \quad (4)$$

The Eq. (2) to (4) shows that by d-q-0 transform, the fundamental frequency positive sequence components of voltages are transformed into DC quantities in direct and quadrature axis. All harmonics and negative sequence components are transformed into AC quantities with a fundamental frequency shift. Here,  $\varphi_{1p}$  is the phase difference between the positive sequence component and the reference voltage (phase 'a').

In Eq.(3) and (4),  $\bar{v}_{sd}$ ,  $\bar{v}_{sq}$  represent DC (50 Hz) quantities that are responsible for fundamental active ( $v_{dp}$ ) and reactive ( $v_{qp}$ ) components, where  $\tilde{v}_{sd}$ ,  $\tilde{v}_{sq}$  represents AC quantities that responsible for negative sequence ( $v_{dn}, v_{qn}$ ) and harmonics ( $v_{dh}, v_{qh}$ ) components. The zero sequence components  $v_{s0} = v_{00}$  which is present during unbalanced source condition. The  $\bar{v}_{sd}$  is extracted from  $v_{sd}$  using second order Butterworth Low Pass Filter (LPF) with the cut-off frequency 50 Hz. The reference load voltage peak magnitude is  $v_{Lm}^* = \bar{v}_{sd}$ . The source has to supply only fundamental positive sequence active components, while all the other components ( $v_{sq}, v_{s0}$ ) should be eliminated by the series active filter to compensate load voltage harmonics and unbalance. Hence the reference load voltage in a-b-c frame is obtained using inverse Park Transformation by Eq. (5) and (6).

$$\begin{bmatrix} v_{La}^* \\ v_{Lb}^* \\ v_{Lc}^* \end{bmatrix} = T^{-1} \begin{bmatrix} v_{Ld}^* \\ v_{Lq}^* \\ v_{L0}^* \end{bmatrix} = T^{-1} \begin{bmatrix} \bar{v}_{sd} \\ 0 \\ 0 \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} v_{La}^* \\ v_{Lb}^* \\ v_{Lc}^* \end{bmatrix} = \begin{bmatrix} v_{Lm}^* \sin(\omega t) \\ v_{Lm}^* \sin(\omega t - 2\pi/3) \\ v_{Lm}^* \sin(\omega t + 2\pi/3) \end{bmatrix} \quad (6)$$

The series compensator voltage by indirect control method is calculated by Eq. (7). This error signal is given to hysteresis voltage controller to generate the required gate pulses for the IGBT switches in the series APF.

$$\begin{bmatrix} v_{inja} \\ v_{inj b} \\ v_{inj c} \end{bmatrix} = \begin{bmatrix} v_{La}^* \\ v_{Lb}^* \\ v_{Lc}^* \end{bmatrix} - \begin{bmatrix} v_{La} \\ v_{Lb} \\ v_{Lc} \end{bmatrix} \quad (7)$$

## 2. Control strategy of shunt active power filter

The shunt APF acts as a controlled current source to compensate the reactive power and current harmonics generated by non-linear loads. The SRF based control algorithm of shunt APF consists of the generation of three-phase reference supply current ( $i_{sa}^*, i_{sb}^*, i_{sc}^*$ ) and the control scheme of shunt APF is shown in Fig.3. The measured three phase source currents ( $i_{sa}, i_{sb}, i_{sc}$ ) are transformed into the

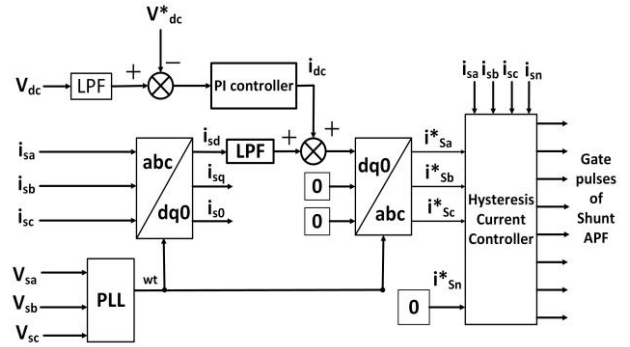


Fig. 3. Control strategy of shunt active filter.

synchronous d-q-0 frame using Park transform with the transformation angle ( $\omega t$ ) coming from PLL circuit as given by Eq.(8).

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{s0} \end{bmatrix} = T \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad (8)$$

Now, the instantaneous source currents ( $i_{sd}, i_{sq}, i_{s0}$ ) in d-q-0 frame is decomposed into fundamental positive, negative, zero sequence and harmonics components [9] as given by Eq. (9) to (11).

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{s0} \end{bmatrix} = \sqrt{\frac{3}{2}} \left\{ \begin{bmatrix} I_{s1,p} \sin \varphi_{1p} \\ I_{s1,p} \cos \varphi_{1p} \\ 0 \end{bmatrix} + \begin{bmatrix} I_{s1,n} \sin(2\omega t + \varphi_{1n}) \\ -I_{s1,n} \cos(2\omega t + \varphi_{1n}) \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ I_{s1,0} \sin(\omega t + \varphi_{10}) \end{bmatrix} + \begin{bmatrix} \sum_{k=2}^{\infty} I_k \sin[(k-1)(\omega t + \varphi_k)] \\ \sum_{k=2}^{\infty} I_k \cos[(k-1)(\omega t + \varphi_k)] \\ 0 \end{bmatrix} \right\} \quad (9)$$

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{s0} \end{bmatrix} = \sqrt{\frac{3}{2}} \left\{ \begin{bmatrix} i_{dp} \\ i_{qp} \\ 0 \end{bmatrix} + \begin{bmatrix} i_{dn} \\ i_{qn} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ i_{00} \end{bmatrix} + \begin{bmatrix} i_{dh} \\ i_{qh} \\ 0 \end{bmatrix} \right\} \quad (10)$$

$$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{s0} \end{bmatrix} = \begin{bmatrix} \bar{i}_{sd} + \tilde{i}_{sd} \\ \bar{i}_{sq} + \tilde{i}_{sq} \\ i_{00} \end{bmatrix} \quad (11)$$

The source has to supply only DC components ( $\bar{i}_{sd}$ ) and all the harmonics / reactive components in the utility supply current has to be eliminated by shunt APF. The current  $i_{dc}$  is required for DC link voltage regulation by PI controller. The output of the PI controller [14], at the  $n^{\text{th}}$  sampling instant is given by Eq. (12).

$$I_{dc(n)} = I_{dc(n-1)} + k_{pdc} \{v_{dcer(n)} - v_{dcer(n-1)}\} + k_{idc} v_{dcer(n)} \quad (12)$$

where  $k_{pdc}$  and  $k_{idc}$  are the proportional and integral gain of the dc bus voltage PI controller. In the above said equation, the error in DC bus voltage at  $n^{\text{th}}$  sampling instant is given by Eq. (13)

$$v_{dcer(n)} = v_{dcr(n)} - v_{dcm(n)} \quad (13)$$

where  $v_{dcr(n)}$  and  $v_{dcm(n)}$  is the reference and

measured DC voltage respectively. Now  $i_{sp}^*$  be amplitude of the reference supply current is sum of the source current DC component and the  $I_{dc}$  current given by Eq. (14)

$$I_{sp}^* = \bar{i}_{sd} + I_{dc} \quad (14)$$

Three-phase reference source currents in a-b-c frame are obtained using inverse Park transformation by the Eq. (15) to (16).

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = T^{-1} \begin{bmatrix} i_{sd}^* \\ i_{sq}^* \\ i_{s0}^* \end{bmatrix} = T^{-1} \begin{bmatrix} I_{sp}^* \\ 0 \\ 0 \end{bmatrix} \quad (15)$$

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \begin{bmatrix} I_{sp}^* \sin(\omega t) \\ I_{sp}^* \sin(\omega t - 2\pi/3) \\ I_{sp}^* \sin(\omega t + 2\pi/3) \end{bmatrix} \quad (16)$$

The shunt compensator current by indirect control method is given by Eq. (16). This error signal is given to hysteresis current controller to generate the gating pulses for the IGBT switches in the shunt APF.

$$\begin{bmatrix} i_{sha} \\ i_{shb} \\ i_{shc} \end{bmatrix} = \begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} - \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad (17)$$

#### 4.1 Neutral current compensation

The gating signals for the fourth-leg of shunt APF is generated by the comparing measured ( $i_{sn}$ ) and reference ( $i_{sn}^*$ ) supply neutral currents through hysteresis current controller. The reference value ( $i_{sn}^*$ ) is set zero for compensating load side neutral current ( $i_{Ln}$ ) in unbalanced load conditions. The compensator current of fourth-leg of shunt APF is given by Eq. (19).

$$i_{sn}^* = 0 \quad (18)$$

$$i_{shn} = i_{sn}^* - i_{sn} \quad (19)$$

Table 1. 3P4W UPQC system parameters

Description	Parameters	Symbol	Value	Unit
System	Supply voltage	$v_{sabc}$	415	$V_{rms}$
	frequency	$f$	50	Hz
	Source impedance	$R_s$ $X_s$	0.1 0.157	$\Omega$ $\Omega$
Series APF	Interfacing inductance	$L_{se}$	7	mH
	Filter resistor	$r_{se}$	5	$\Omega$
	Filter capacitance	$c_{se}$	5	$\mu F$
	Injection transformer	$S_{Tr}$	12	kVA
Shunt APF	Switching frequency	$f_{sw}$	10	kHz
	Interfacing inductance	$L_{sh}$	4.5	mH
	Filter resistor	$r_{sh}$	5	$\Omega$
	Filter capacitor	$c_{sh}$	5	$\mu F$
DC link	Switching frequency	$f_{sw}$	10	kHz
	DC bus capacitor	$C_{dc}$	3000	$\mu F$
	DC bus reference voltage	$v_{dc}^*$	700	V

## 5. Results and discussion

The developed dynamic model of the 3P4W UPQC system in MATLAB / SIMULINK Sim Power System software is shown in Fig.4. The power system consists of a 3P4W, 415 V (L-L, RMS), 50 Hz utility, and a combination of linear and non-linear loads. The 3P4W UPQC system parameters used in the study are given in Table 1. A three-phase 6 kW, 0.8 power factor (lagging) is taken as a balanced linear load, whereas a three-phase diode bridge rectifier (DBR) with  $R=21 \Omega$ ,  $L=80\text{mH}$  load and a single-phase DBR with  $R=9\Omega$ ,  $L=20\text{mH}$  load in phase 'c' are considered as non-linear loads..

The performances of SRF theory based control strategy for the 3P4W UPQC system is evaluated under non-ideal unbalanced supply voltage, unbalanced and distorted load current conditions. For this purpose the circuit has five stages of operation as follows.

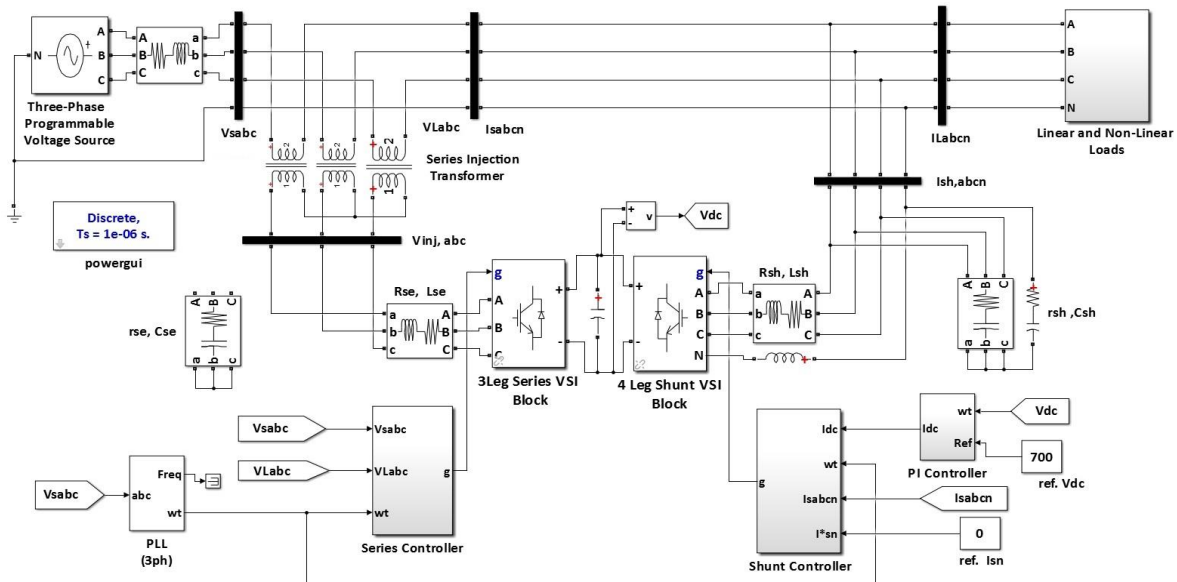


Fig.4. Matlab/Simulink simulation model of the 3P4W UPQC system.

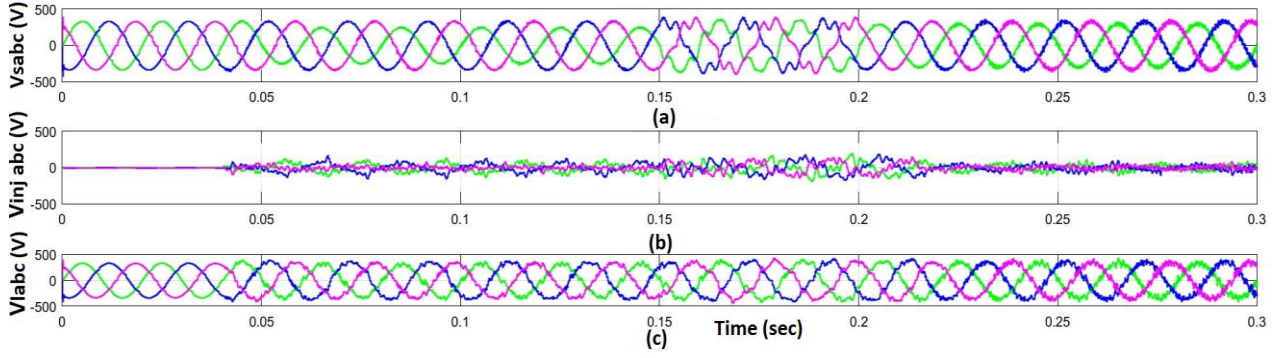


Fig. 5. Dynamic performance of UPQC under unbalanced and distorted supply voltage condition: (a) supply voltages ( $v_{sa}, v_{sb}, v_{sc}$ ) ; (b) series APF injected voltages ( $v_{inja}, v_{inj_b}, v_{inj_c}$ ) ; (c) load voltages ( $v_{sa}, v_{sb}, v_{sc}$ )

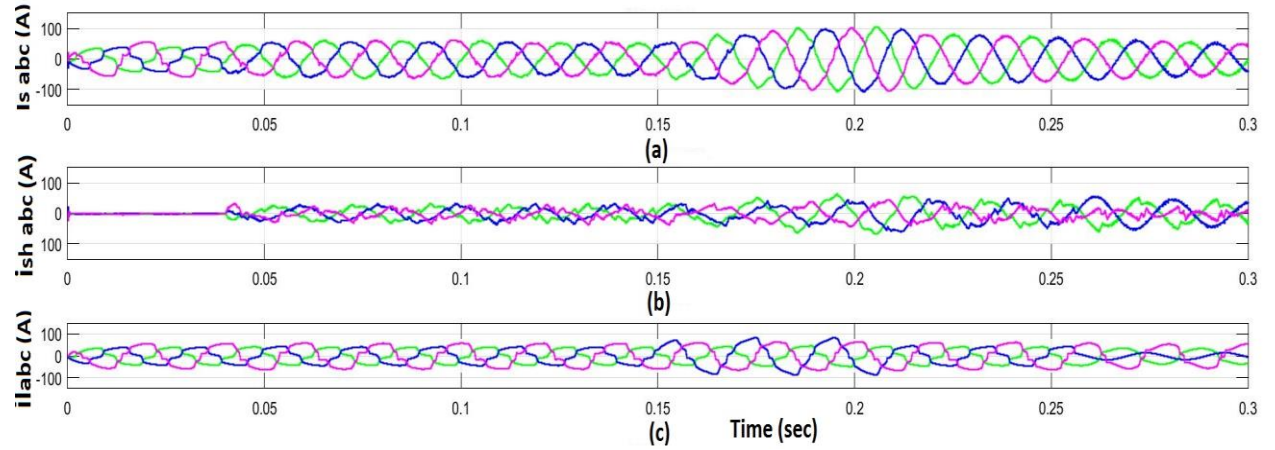


Fig. 6. Dynamic performance of UPQC under for unbalanced and distorted with load condition: (a) source currents ( $i_{sa}, i_{sb}, i_{sc}$ ) ; (b) shunt APF currents ( $i_{sha}, i_{shb}, i_{shc}$ ) ; (c) load currents ( $i_{La}, i_{Lb}, i_{Lc}$ )

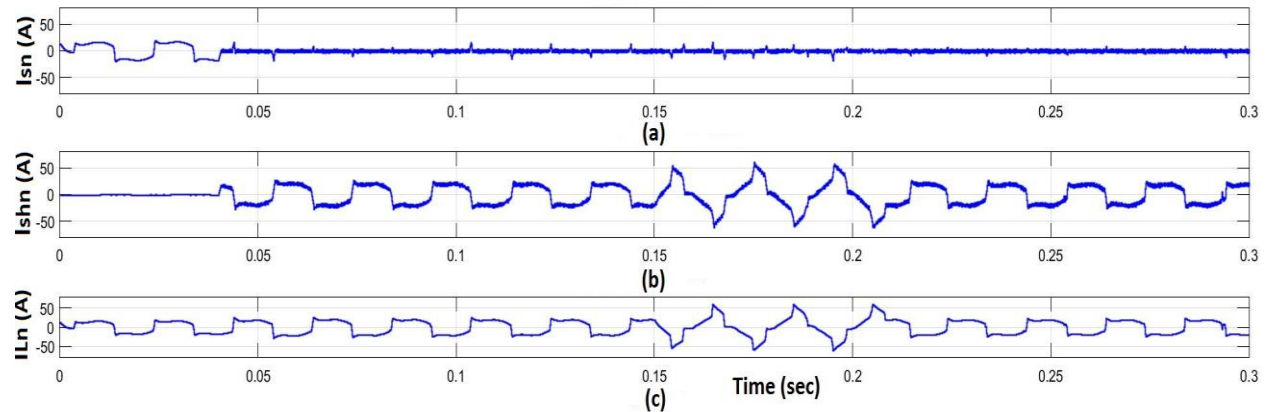


Fig. 7. Neutral current compensation before and after UPQC operation: (a) source neutral current ( $i_{sn}$ ) ; (b) shunt compensator current ( $i_{shn}$ ) ; (c) load neutral current ( $i_{ln}$ )

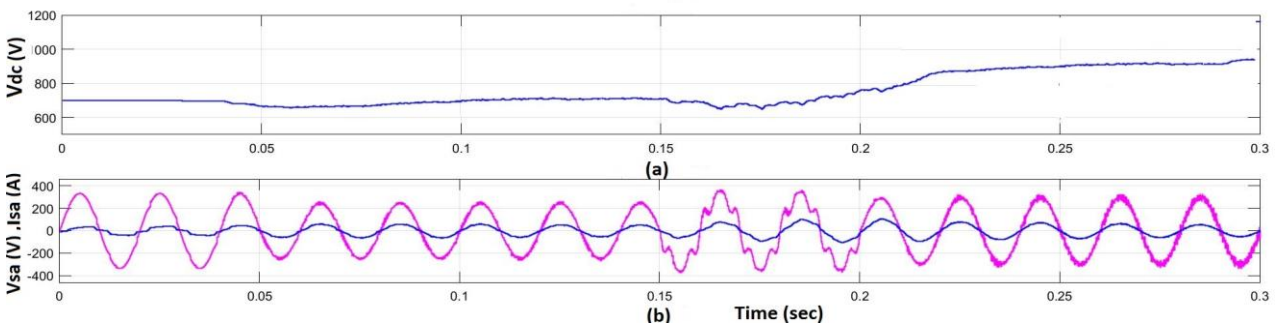


Fig.8 (a) Dynamic performance of dc link voltage ( $V_{dc}$ ) ; (b) Reactive power compensation: source voltage ( $v_{sa}$ ) and source current ( $i_{sa}$ ) of phase a'

1. In this case, an ideal balanced sinusoidal three-phase utility voltage is feeding to all the considered loads from 0 to 0.05 sec. These loads generate unbalance, harmonics and reactive currents in phase currents and zero-sequence harmonics in the neutral current.
2. From 0.05 to 0.20 sec., the RMS value of voltage in the phase 'a' is reduced by 25% (i.e. 60V) to generate unbalanced utility voltage case.
3. In addition, an unbalanced utility voltage in the case (2), at 0.15 to 0.20 sec., fifth order voltage harmonics with RMS magnitude of 17% (i.e. 40 V) of positive sequence is added to the phase 'a' and seventh order voltage harmonics with RMS magnitude of 5% (i.e. 12 V) of negative sequence is added to phase 'b' supply. This situation generate distorted-unbalanced utility voltage case.
4. In the above mentioned case (3), additionally a single phase DBR with RL load between phase 'b' and neutral wire is switched ON at 0.15 sec and switched OFF at 0.20 sec to evaluate dynamic performances of the fourth-leg of shunt APF. It generates load transient operation in distorted-unbalanced voltage case which increases load imbalance/ neutral current.
5. After 0.2 sec, an ideal three-phase balanced sinusoidal supply is applied. However a three-phase to two-phase load change by opening phase 'b' of the three-phase DBR load is considered from 0.25 to 0.30 sec. It explains the load transient operation with the balanced three phase supply case.

Simulation results in all the stages of circuit operation are shown in Fig.5 to Fig.8. From the results the following observations are made.

In the Case: 1 (balanced supply with unbalanced nonlinear loads) after operation of UPQC at 0.04 seconds, the shunt APF current ( $i_{sh\ abc}$ ) compensates the reactive power and harmonics of the load, the source current follows the sinusoidal reference currents. The THD of phase supply current is improved to 3.72%. In the Case: 2 (Unbalanced supply with unbalanced nonlinear loads), due to suitable injected voltage ( $v_{inj,a}$ ) by series APF, the constant balanced sinusoids load voltage is obtained. In the Case:3 (distorted-unbalanced utility voltage with unbalanced nonlinear loads), by injecting out of phase harmonics voltage, the series APF is able to maintain the desired reference voltage at the Point of Common Coupling (PCC). The THD of phase 'c' load current is 18.52% while the supply current THD is 4.73% as shown in Fig.9 and Fig.10 respectively. The load voltage THD in phase 'a' is 9.23 %, while the supply voltage THD is 20.72% as shown in Fig. 11 and Fig.12 respectively.

Fig.6 (a) shows the source current is increases in both Cases 2 and 3, due to the requirement of an additional real power to restore the constant load

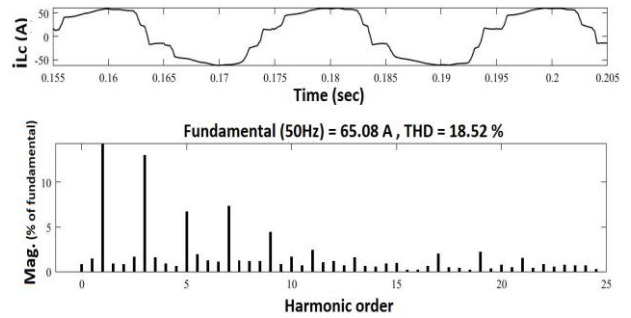


Fig.9. Load current of phase 'c' and its harmonic spectrum

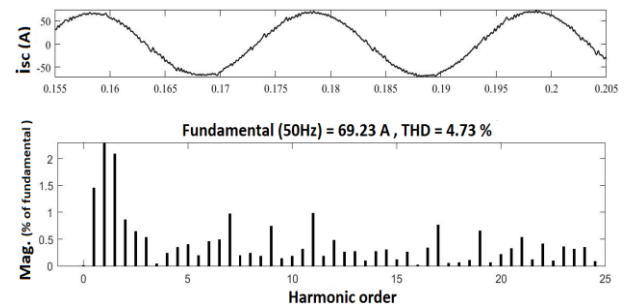


Fig.10. Source current of phase 'c' and its harmonic spectrum

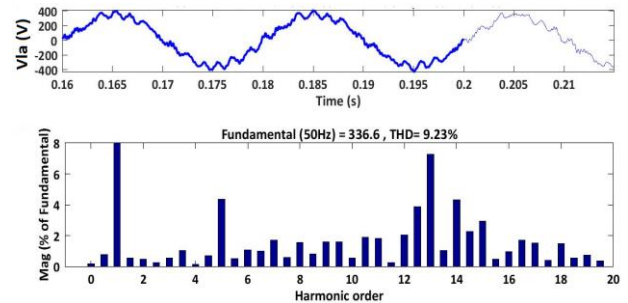


Fig.11 Load voltage of phase 'a' and its harmonics spectrum

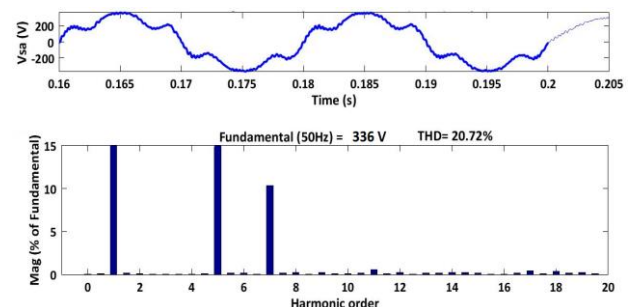


Fig.12. Source voltage of phase 'a' and its harmonic spectrum

voltage and it comes from the utility supply.

A transient load operation under distorted-unbalanced supply and balanced ideal three-phase supply with unbalanced load conditions is considered in the Cases (4) and (5) respectively. In the Case 4, the UPQC is effectively maintains both sinusoidal supply currents and load voltage due to operation of

the shunt APF and series APF simultaneously. In the Case 5, the balanced sinusoidal supply current is obtained due to the operation of the shunt APF.

Due to the unbalanced load, a current ( $i_{Ln}$ ) of 18.57A flows in the load neutral wire and this current  $i_{Ln}$  is increased to 54.22A suddenly due to an additional single-phase load in phase 'b' during the instants 0.15 to 0.2 sec. From Fig.7c, it is observed that load neutral current is compensated by the fourth leg of the shunt APF in all dynamic conditions, thus reducing the supply neutral current ( $i_{sn}$ ) is to near zero. In steady state, shunt APF maintained the dc-link voltage at its reference value of 700V. However, the drop and rise of the voltage in magnitude are observed under unbalanced distorted supply and dynamic load conditions. The source voltage and source current are in-phase in all the dynamic conditions as shown in Fig.8b, which implies that no reactive power is drawn from the utility supply.

## 6. Conclusion

In this paper, the performance of the synchronous reference theory based control strategy for the 3P4W UPQC system has been presented in unbalanced non-linear loads and non-ideal mains voltage conditions. The mathematics-based analytical expression and simulation results have verified that 3P4W UPQC is effectively compensates source neutral current, reactive power and harmonics, unbalanced load current, voltage harmonics and imbalance in the mains voltage.

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