Fractional Order PI based UPQC for Improvement of Power Quality in Distribution Power System

D.Krishna,M.Sasikala, V. Ganesh

Abstract**: *This paper presents design of FOPI based UPQC to address power quality issues of load voltage harmonics, current harmonics, voltage swell, sag and THD of nonlinear loads, a FOPI based UPQC proposed to tackle Power Quality issues. The UPQC was wide studied by several as associate ultimate methodology to boost power quality of electrical distribution system. It is the combination of Series APF and Shunt APF. In this proposed work to make the performance of UPQC more roust by introducing novel control strategy known as Fractional Order PI (FOPI) controller. Factional order control strategy called as order change controller. FOPI controller is realized using refined recursive filter. The performance of FOPI based UPQC demonstrated over PI based UPQC. The UPQC is used with static and switching nonlinear burdens.The proposed controller is implemented by using MATLAB/Simulink,***

Index Terms: UPQC, Power Quality (PQ), Fractional Order(FOPI), Voltage Source Inverter (VSI), Active Power filter (APF).

I. INTRODUCTION

The UPQC was wide studied by several as associate ultimate methodology to boost power quality of electrical distribution system [1]-[2]and[3]-[4]. It is a combination of series and shunt APF in[5]-[6]. Ghose et.al (2012) introduced in[7] it can be victimized to reduced current distortions by injecting a voltage proportionate to the source current and the injected series voltage at the PCC such that the design can act a framework to remove voltage sag/swell. Several approaches introduced like PI, PID, FLC, ANN, SMC, etc., are used in [7]-[8]. corresponding to the PI, PID controller requires distinct linear numerical models, which is hard to receive, and hence fails to perform satisfactorily below highly sensitive load disruption. In recent past authors proposed advanced control based controllers are state action controllers, self-calibration controllers, and MRC are used in[9].

This proposed work a controller is designed based on fractional order calculus(i.e.FOFL)for the control of UPQC.Sung-MinWooet.al(2001) proposed These controllers also need numerical models and are consequently sensitive to parameter change.A standard arrangement design of a UPQC is the collection of a series APF and shunt APF are adjoining to a mutual dc link[10]. A simple configuration of a typical UPQC is shown in Fig.1.Isolation of harmonics between sub transmission system and distribution system can be done by series active power filter proposed in[11]. This filter mitigates sag, swell and harmonic compensation at Point of Common Coupling (PCC).The current harmonics are compensated by shunt active power filter. The DC link to regulate DC voltage between two filters[10, 11].

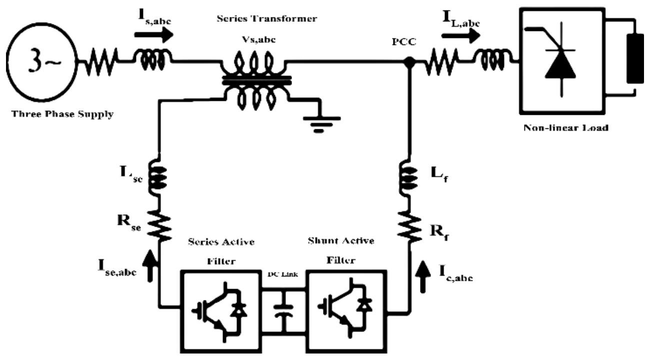

Fig. 1. Unified Power Conditioner configuration

A. SERIES APF ALGORITHM

The series APF is based on the concept of unit vector model (UVM) as proposed in[10]. The UVM is extracted from the deformed supply. The natural process and control algorithm is shown in Fig.2.

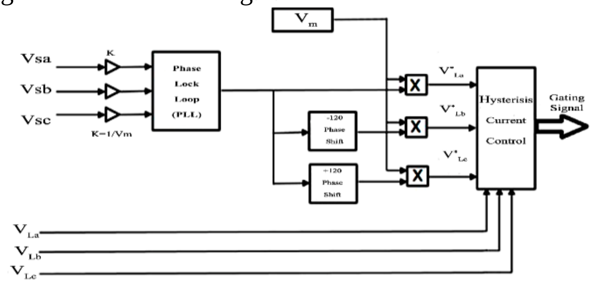

Fig. 2. Series APFConfiguration.

B. SHUNT APF CONTROL ALGORITHM

p-q theory used for controlling the active power filters. Transformation of 3-ϕ voltages and currents from abc to dq coordinates by utilizing these modelling equations

$$\begin{bmatrix} v_0 \\ v_d \\ v_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{s,a} \\ v_{s,b} \\ v_{s,c} \end{bmatrix} \qquad (1)$$

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$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{s,a} \\ i_{s,b} \\ i_{s,c} \end{bmatrix} \quad (2)$$

Active and reactive components are obtained by the give relation in equation-3. Where Active and reactive components are function of load current and phase voltages.

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_d & v_q \\ -v_q & v_d \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (3)$$

$$P_0 = V_0 * I_0 \quad (4)$$

$$P = \bar{P} + \tilde{P} \quad (5)$$

$$\begin{bmatrix} I_{cd,ref} \\ I_{cq,ref} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} -\bar{P} + P_0 + \overline{P_{loss}} \\ -Q \end{bmatrix} \quad (6)$$

Icd,ref , and icq,ref are extension currents of shunt APF in d-q coordinates. These current are changed to 3-- system described in equation-(7).

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{cd,ref} \\ i_{cq,ref} \end{bmatrix} \quad (7)$$

The reference current in 3-- system (Ica,ref, Icb,ref, Icc,ref) are measured in order to alter neutral, harmonic and reactive current at the load. Hysteresis band current control algorithm[12] is used to generate switching signal by comparing actual signal with reference signal, depending on speed and accuracy of reference signal the performance of UPQC can be improved.

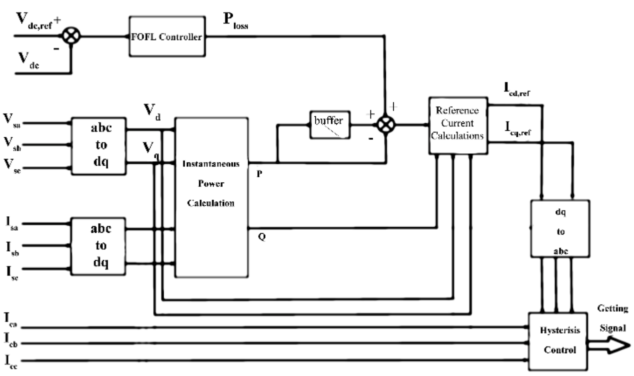


Fig. 3. Shunt APF Configuration.

II. DESIGN OF FRACTIONAL ORDER CONTROL

Sondhi et.al.(2014) introduced the FOPI controller in[13].It is significant to understand the fractional order derivative operator. Once the fractional speculator was numerically formed. The numerical expression for FOPI is

$$c(s) = k_p + \frac{k_i}{s^\lambda} \quad (8)$$

Where $\boldsymbol{\lambda}$ can accept some value in the range (0, 1). If $\boldsymbol{\lambda} \geq 2$ the mechanism is changed to a high-order construction which is different ability in equivalence to formal PI controller. The F.O is described in (8) may be regarded as the common character of the formal PI controller.

III. DESIGN OF FILTER USING FRACTIONAL ORDER CONTROLLER

Molina et.al.(2006) presented the evolution of FOC, there appeared various definitions of FOD's and FOI's[12]. Online practical FOD may be needed in control systems. Using filters is one in all the most effective ways in which to solve the issues. Some consecutive filters are summarized in[13]. Assuming the expected fitting range is (ω_b , ω_h), the fractional order function λ can be approximated by FOF(fractional order filter) can be written as,

$$K(s) = \left(\frac{1 + \frac{bs}{d\omega_b}}{1 + \frac{ds}{d\omega_h}} \right)^\lambda \quad (9)$$

Where $0 < \lambda < 1, s = j\omega, b > 0, d > 0$,and

$$K(s) = \left(\frac{bs}{d\omega_h} \right)^\lambda \left(1 + \frac{-ds + d}{ds^2 + b\omega_h s} \right)^\lambda \quad (10)$$

In the frequency range between $\omega_b < \omega < \omega h$, by using a Taylor polynomial expansion, it acquires

$$K(s) = \left(\frac{bs}{d\omega_h} \right)^\lambda \left(1 + \lambda P(s) + \frac{\lambda(\lambda-1)}{2} P^2(s) \ldots \right)$$

(11)

(11)

Where $$p(s) = \frac{-ds^2 + d}{ds^2 + b\omega_h s} \quad (12)$$

It is initiate that

$$s^\lambda = \frac{(d\omega_b)^\lambda b^{-\lambda}}{\left[1 + \lambda P(s) + \frac{\lambda(\lambda-1)}{2} p^2_{(s)} \ldots\right]} \left(\frac{1 + \frac{bs}{d\omega_b}}{1 + \frac{ds}{d\omega_h}} \right)^\lambda$$

(13)

Estimated the Taylor polynomial to leads to

$$s^\lambda \approx \frac{(d\omega_b)^\lambda}{b^\lambda [+\lambda P(s)]} \left(\frac{1 + \frac{bs}{d\omega_b}}{1 + \frac{ds}{d\omega_h}} \right)^\lambda$$

(14)

Thus, the FOD is defined as

$$s^\lambda \approx \left(\frac{d\omega_b}{b} \right) \left(\frac{ds^2 + b\omega_h s}{d(1-\lambda)s^2 + b\omega_h s + d\lambda} \right) \left(\frac{1 + \frac{bs}{d\omega_b}}{1 + \frac{ds}{d\omega_n}} \right)^\lambda \quad (15)$$

Equation (15) is balanced if and only if all the poles are LHS of the complex s-plane. The poles of the above expression is

$$d(1-\lambda)s^2 + b\omega_h s + d\lambda \quad (16)$$

The negative poles in real part for 0<λ <1. thus, all thepoles of (15) are within the range of (ω_l, ω_h).The magnitude relation fractional-order part of formulation (14) can be approximated by the uninterrupted-time coherent simulation.

$$K(s) = \lim_{N\to\infty} k_N(s) = \lim_{N\to\infty} \Pi_K^N = -N\frac{1+\frac{s}{\omega'_k}}{1+\frac{s}{\omega_k}} \qquad (17)$$

accordant to the algorithmic distribution of actual zeros and poles, the rank k can be written as

$$\omega'_k = \left(\frac{d\omega_b}{b}\right)^{\frac{\lambda-2k}{2N+1}}, \omega_k = \left(\frac{d\omega_h}{b}\right)^{\frac{\lambda+2k}{2N+1}} \qquad (18)$$

Thus, the continual coherent transfer function representation can be written as

$$s^{\lambda} \approx \left(\frac{d\omega_b}{b}\right)^{\lambda}\left(\frac{ds^2+b\omega_n^5}{d(1-\lambda)s^2+b\omega_h s+d\lambda}\right)\Pi_K^N = \frac{s+\omega'_k}{s+\omega_k} \qquad (19)$$

Direct confirmation by enquiry and theoretical analysis, this

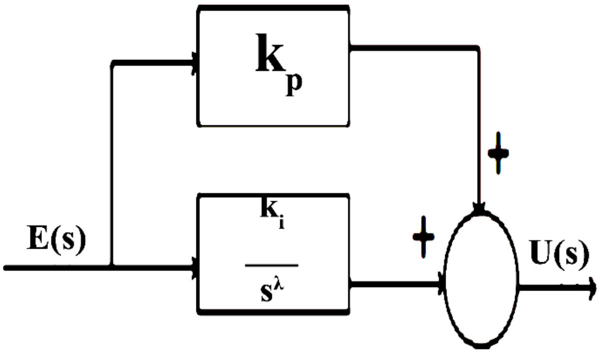


Fig. 4. Structure of FOPI controller.

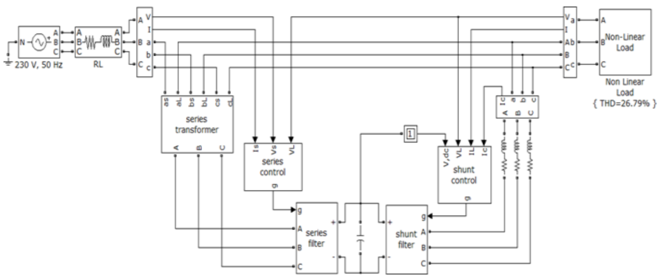
analysis similarity can prevail the good essence when b = 12 and d = 10. Though the estimation method, the FOS may be approximated as the very eminent integer-order system. A fractional-order integration can be obtain changing the sign of order (λ). Hence, the range of λ for integration is $0<\lambda<1$. The structure of FOPI controller is shown in Fig. 4. for design a controller the Kp element, λ are individually designed and place in the structure show in Fig. 4.

IV. SIMULATION RESULTS

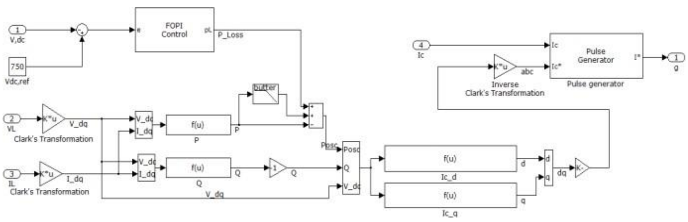
Simulations are performed using MATLAB-SIMULINK.The parameters used to simulate UPQC are given in Table-I.

Table-1: UPQC system parameters

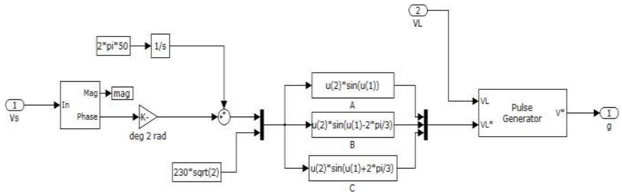
System Parameters		
Supply voltages	$Vs_{,abc\ L\text{-}L}$	380 V
Supply Frequency	f_s	50Hz
DC-link voltage	V_{dc}	750V
Load	R_L, L_L	20Ω, 15mH
Series active power filter parameters		
Series transformer	Rate	1/3
AC filter	R_f,C_f	5Ω, 3μF
AC inductance	Lc	3.5mH
Shunt active power filter parameters		
AC inductance	L_f	1mH
DC resistance	R_d	100 Ω
DC inductance	L_d	10mH
DC capacitor	C_{DC}	2000μF



5 (a). UPQC Configuration



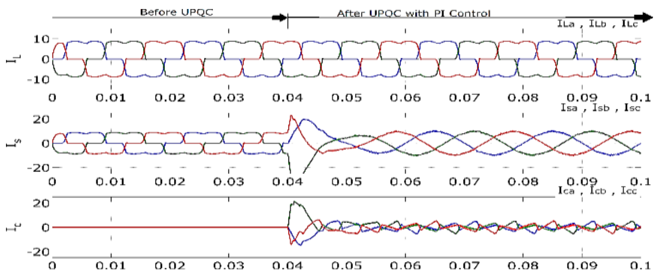
5 (b). Shunt Control block



5 (c). Series Control block

A. Voltage and current harmonics Compensation

In the conventional and proposed control algorithm, the simulation results load current (I_{Labc}), source current (I_{Sabc}), and compensating current (I_{Cabc}) waveforms are shown in Fig. 6 before and after the UPQC is operation with PI control and FOPI control for λ=0.5.Fig. 7 shows the simulation results for load voltage harmonics mitigation with UPQC based PI and FOPI controller when introduction of 5th (20%) and 7th (14%) order voltage at 0.2 sec for a duration of 0.2 sec into the source voltage as shown in Fig. 7(a). The series APF injects an out- of-phase voltage with 5th and 7th harmonics which is difference between the desired load voltage and actual supply.



6 (a). With UPQC based PI control

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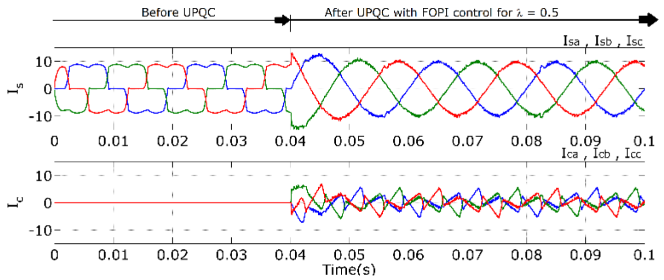

6. (b). With UPQC based FOPI control for λ=0.5 Fig. 8. Load, source and compensating current before and after UPQC operation.

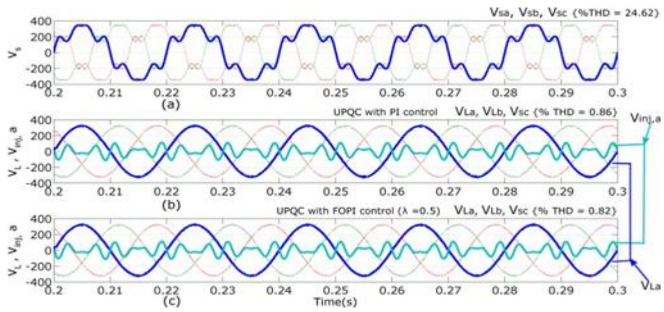

Fig. 7. Mitigation of load voltage harmonics with UPQC based PI control and FOPI control

Simultaneously, shunt APF with PI control and FOPI control regulates the dc-link voltage to the reference dc-link voltage as shown Fig. 8.

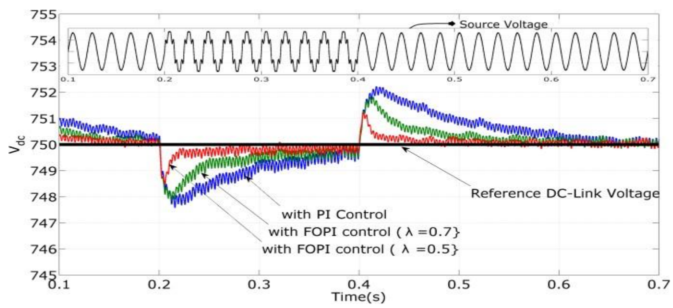

Fig. 8. Regulation of DC-Link voltage for harmonics in source voltage

B. Voltage sag and current harmonic mitigation

The simulation results of voltage sag and current harmonics mitigation for UPQC based PI control and FOPI control is observed in Fig.9 and 10 respectively.

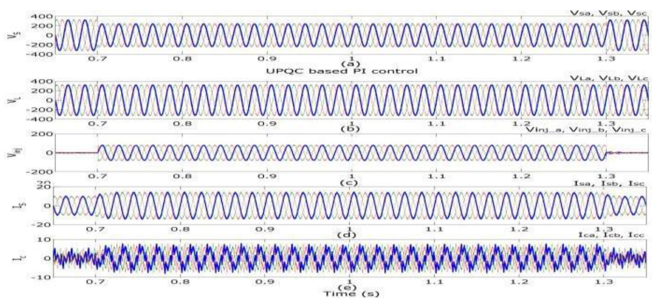

Fig. 9 Mitigation of Load voltage sag and current compensation by UPQC based FOPI control.

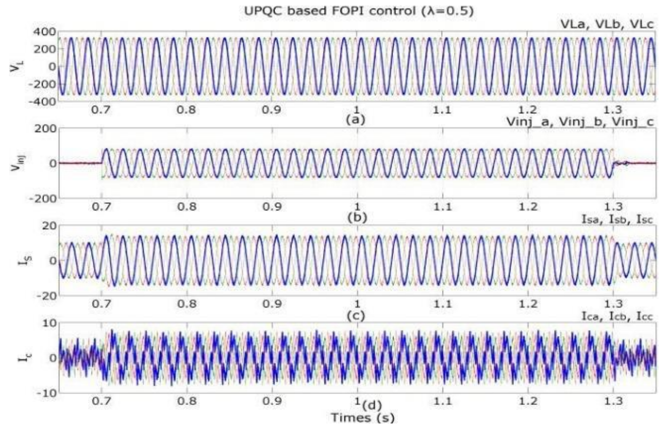

Fig. 10 Mitigation of Load voltage sag and current compensation by UPQC based FOPI control.

in order to keep this DC link voltage at fixed level as shown in Fig. 11. If it is not well-maintained, the DC link voltage will inject to very low value and UPQC fails.

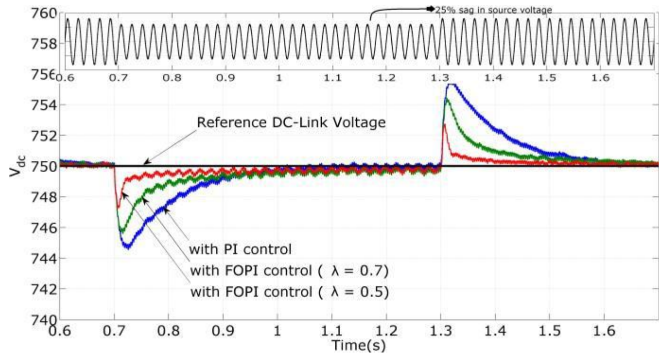

Fig. 11. Regulation of DC-Link voltage for Voltage sag

C. Voltage swell and current harmonics mitigation.

The simulation results of voltage swell reduced by UPQC based PI control and FOPI control is shown in Fig. 12 and Fig. 13respectively.

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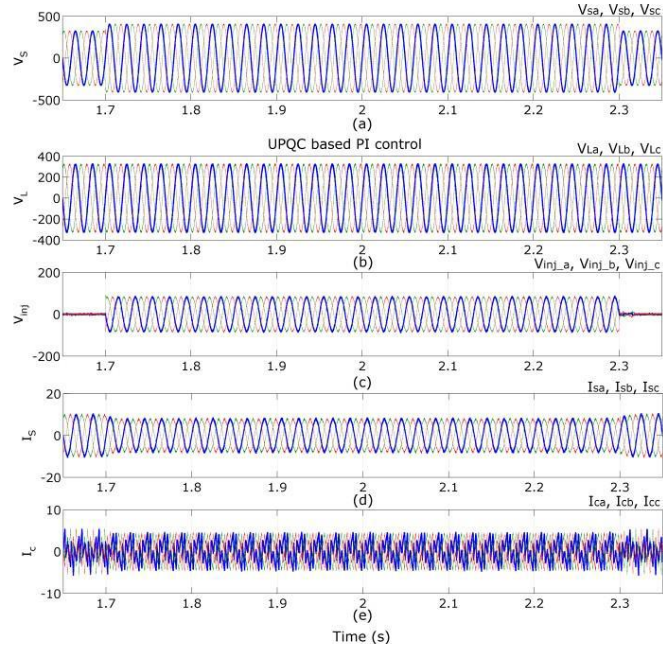

Fig. 12 Mitigation of Load voltage swell and current compensation by UPQC based PI control

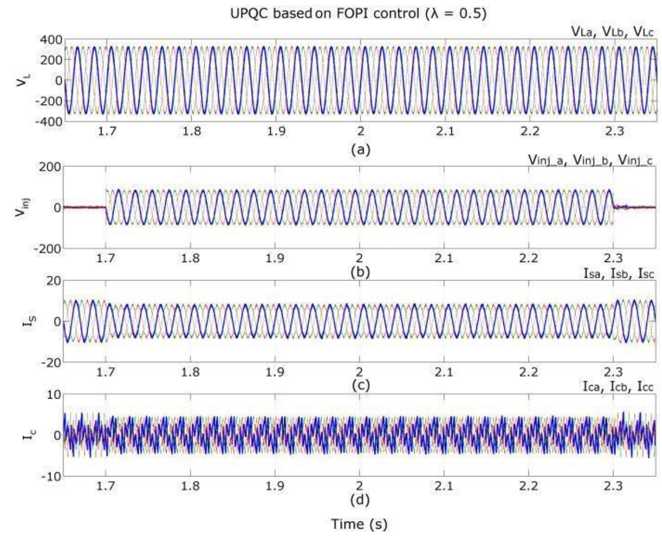

Fig. 13 Mitigation of Load voltage swell and current compensation by UPQC based FOPI control

At the same time, increasing in source voltage consequences in the rise in DC-link voltage and is regulated by shunt APF by respective controller as shown in Fig. 14.

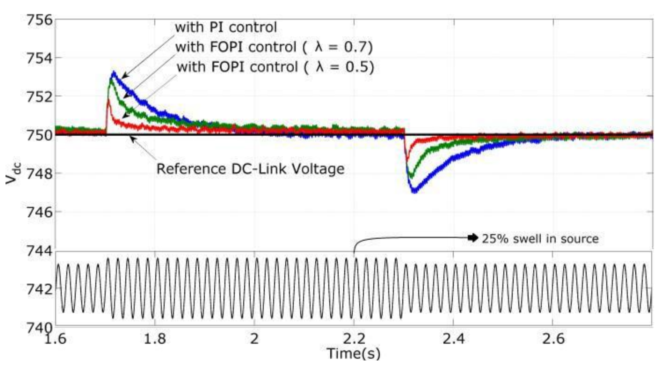

Fig. 14 Regulation of DC-Link voltage for Voltage swell

From Fig. 8, 11 and 14, it is observed that the FOPI controller regulates the dc-link voltage faster than PI control which shows that proposed controller calculates the reference current more efficiently and quickly than conventional controller. Table II gives the harmonic comparison of UPQC based FOPI controller with UPQC based PI controller. Here, Load current is constant throughout the simulation for all controllers with %THD = 25.68. From Table II, the performance is found to be in close approximation with that of the PI controller; however, there is considerable improvement can be observed which shows the FOPI controller has good performance with the extra parameter included into the controller.

Table II

Comparison of %THD in voltage and current for UPQC based PI and FOPI controller.

	PI control	FOPI $\lambda = 1.1$	FOPI $\lambda = 0.7$	FOPI $\lambda = 0.5$
Source voltage contain harmonics (%THD = 24.64)				
Load Voltage	0.86	0.89	0.86	0.82
Source current	2.70	2.48	2.47	2.17
25% sag in Source voltage				
Load Voltage	0.56	0.59	0.55	0.55
Source current	1.60	1.83	1.60	1.57
25% swell in Source voltage				
Load Voltage	0.6	0.66	0.6	0.6
Source current	2.60	2.71	2.52	2.52

IV. CONCLUSION

In this proposed work a FOPI based UPQC is proposed to mitigate the well-known power quality issues, popularly known as harmonic compensation and load voltage sag. The performance of UPQC is demonstrated on power distribution system consisting of nonlinear loads. The UPQC with FOPI controller is quite capable of mitigating power quality issues compared to UPQC with PI controller.

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