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Elimination & Mitigation of Sag & Swell Using a New UPQC-S Methodology & Fuzzy Logic Controller

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Abstract
This paper presents the enhancement of voltage sags, harmonic distortion and low power factor using Unified Power Quality Conditioner (UPQC) with Fuzzy Logic Controller in distribution system, The series inverter of UPQC is controlled to perform simultaneous 1) voltage sag/swell compensation and 2) load reactive power sharing with the shunt inverter. Since the series inverter simultaneously delivers active and reactive powers, this concept is named as UPQC-S (S for complex power) in this paper; a detailed mathematical formulation of PAC for UPQC-S is carried out. In this paper details are carried out on both series inverter & shunt inverter, and fuzzy logic controller is applied to shunt inverter in order to dc fluctuations and to compensate reactive power. The feasibility and effectiveness of the proposed UPQC-S approach are validated by simulation in using MATLAB software.

Keywords— power quality, active filters, facts, upqc, fuzzy.

I. INTRODUCTION

An increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads to an increased awareness of power quality both by customers and utilities. The most common power quality problems today are voltage sags, harmonic distortion and low power factor. Voltage sags is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs [4]. It is often set only by two parameters, depth/magnitude and duration. The voltage sags magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min. Voltage sags is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing [2, 3].Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems [5]. Harmonic currents in distribution system can cause harmonic distortion, low power factor and additional losses as well as heating in the electrical equipment. It also can cause vibration and noise in machines and malfunction of the sensitive equipment. The development of power electronics devices such as Flexible AC Transmission system(FACTS) and customs power devices have introduced and emerging branch of technology providing the power system with versatile new control capabilities [1].There are different ways to enhance power quality problems in transmission and distribution systems. Among these, the UPQC is one of the most effective devices. A new PWM-based control scheme has been implemented to control the electronic valves in the UPQC. The UPQC has additional capability to sustain reactive current at low voltage, and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage. [6, 7] In this paper, the configuration and design of the UPQC-S are analyzed. It is connected in shunt or parallel and series to distribution system. It also is design to enhance the power quality such as voltage sags, harmonic distortion and low power factor in distribution system.

II. FUNDAMENTALS OF PAC CONCEPT

A UPQC is one of the most suitable devices to control the voltage sag/swell on the system. The rating of a UPQC is governed by the percentage of maximum amount of voltage sag/swell need to be compensated [19]. However, the voltage variation (sag/swell) is a short duration power quality issue. Therefore, under normal operating condition, the series inverter of UPQC is not utilized up to its true capacity. The concept of PAC of UPQC suggests that with proper control of the power angle between the source and load voltages, the load reactive power demand can be shared by both shunt and series inverters without affecting the overall UPQC rating [15]. The phasor representation of the PAC approach under a rated steady-state condition is shown in Fig. 1 [15]. According to this theory, a vector *V*Sr with proper magnitude *V*Sr and phase angle *ϕ*Sr when injected through series inverter gives a power angle *δ* boost between the source *VS* and resultant load *V_L* voltages maintaining the same voltage magnitudes. This power angle shift causes a relative phase advancement between the supply voltage and resultant load current *I_L* , denoted as angle *β*. In other words, with PAC approach, the series inverter supports the load reactive power demand and thus, reducing the reactive power demand shared by the shunt inverter. For a rated steady-state condition

$$1 + k_f = n_O.$$

$$w = l(CH) = n_O \cdot k - y$$

$$|V'_{\mathrm{Sr}}| = \sqrt{(k \cdot \sin\delta)^2 + (n_O \cdot k - k\cos\delta)^2}$$

$$|V'_{\mathrm{Sr}}| = k.\sqrt{1 + n_O^2 - 2 \cdot n_O \cdot \cos\delta}.$$

-7,8,9

To compute the phase of _*V*S_r

$$\angle CHB = \angle\psi = \tan^{-1}\left(\frac{x}{w}\right) = \tan^{-1}\left(\frac{\sin\delta}{n_O - \cos\delta}\right)$$

---------10

Therefore,

$$|V_S| = |V_L| = |V_L^*| = |V_L'| = k.$$

--------1

$$\begin{aligned} \vec{V}_{\mathrm{Sr}} &= |V_{\mathrm{Sr}}| \angle\varphi_{\mathrm{Sr}} \\ &= \left(k.\sqrt{2}.\sqrt{1-\cos\delta}\right) \angle \left\{180^\circ - \tan^{-1}\left(\frac{\sin\delta}{1-\cos\delta}\right)\right\} \\ &= \left(k \cdot \sqrt{2} \cdot \sqrt{1-\cos\delta}\right) \angle \left(\frac{90^\circ + \delta}{2}\right) \end{aligned}$$

-----2

$$\delta = \sin^{-1}\left(\frac{Q_{\mathrm{Sr}}}{P_L}\right)$$

--3

A. Series Inverter Parameter Estimation under Voltage Sag:

In this section, the required series inverter parameters to achieve simultaneous load reactive power and voltage sag compensations are computed. Fig. below shows the detailed phasor diagram to determine the magnitude and phase of series injection voltage.

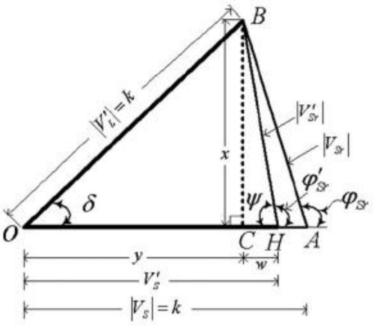


Fig. 1 Detailed phasor diagram to estimate the series inverter parameters for the proposed UPQC-S approach under voltage sag condition

The voltage fluctuation factor *kf* which is defined as the ratio of the difference of instantaneous supply voltage and rated load voltage magnitude to the rated load voltage magnitude is represented as

$$k_f = \frac{V_S - V_L^*}{V_L^*}.$$

-----4

$$k_f = \frac{V_S' - V_L'}{V_L'} = \frac{V_S' - k}{k}.$$

-----5

Let us define

Equations (9) and (10) give the required magnitude and phase of series inverter voltage of UPQC-S that should be injected to achieve the voltage sag compensation while supporting the load reactive power under PAC approach.

III. UPQC-S CONTROLLER

A detailed controller for UPQC based on PAC approach is described in [15]. In this paper, the generation of reference signals for series inverter is discussed. Note that, as the series inverter maintains the load voltage at desired level, the reactive power demanded by the load remains unchanged (assuming load on the system is constant) irrespective of changes in the source voltage magnitude. Furthermore, the power angle *δ* is maintained at constant value under different operating conditions. Therefore, the reactive power shared by the series inverter and hence by the shunt inverter changes as given by (47) and (54). The reactive power shared by the series and shunt inverters can be fixed at constant values by allowing the power angle *δ* to vary under voltage sag/swell condition.

A. Series controller:

The control block diagram for series inverter operation is shown in Fig. below. The instantaneous power angle *δ* is determined using the procedure give in [15]. Based on the system rated specifications, the value of the desired load voltage is set as reference load voltage *k*. The instantaneous value of factors *kf* and n_o is computed by measuring the peak value of the supply voltage in real time. The magnitudes of series injected voltage *V*Sr and its phase angle *ϕ*Sr are then determined using (15) and (17). A phase locked loop is used to synchronize and to generate instantaneous time variable reference signals *v*∗Sr,*a* , *v*∗Sr,*b* , *v*∗Sr,*c* . The reference signals thus generated give the necessary series injection voltages that will share the load reactive power and compensate for voltage sag/swell as formulated using the proposed approach. The error signal of actual and reference series voltage is utilized to perform the switching operation of series inverter of UPQC-S. The control diagram for the shunt inverter is as given in

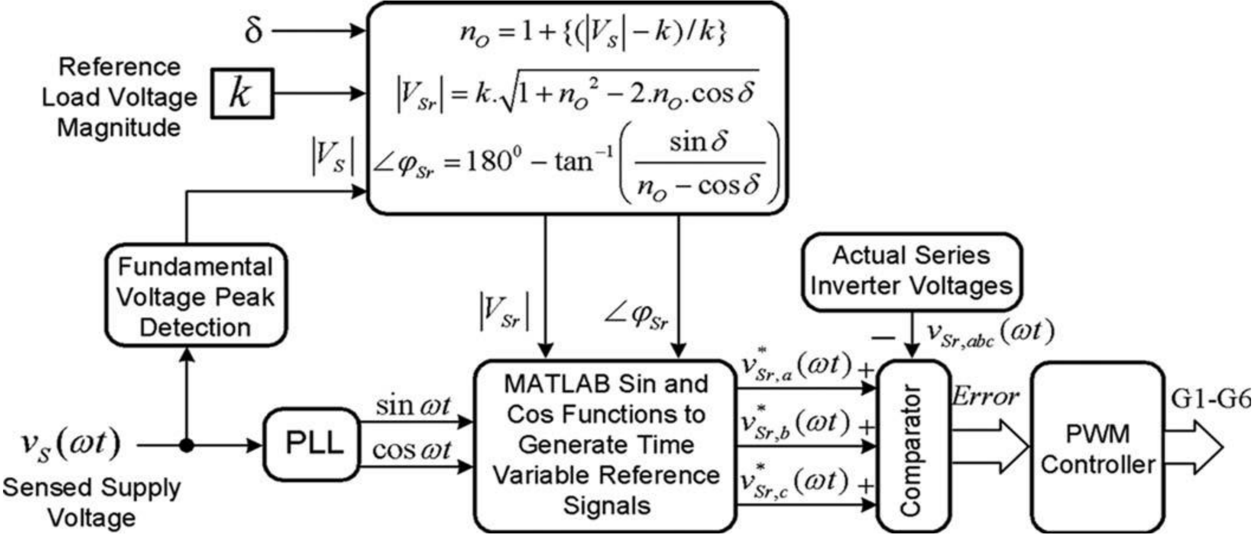


Fig. 2 Series controller

B.Shunt controller:

On the other hand, the shunt converter of UPQC is used to filter the active and reactive power pulsations generated Thus, the power injected into the grid from t compensator set will be free from pulsations, which are the origin of voltage fluctuation that can propagate into the system. This task is achieved by appropriate electrical currents injection in PCC. Also, the regulation of the DC bus voltage has been assigned to this converter. Fig. below shows a block diagram of the shunt converter controller. This controller generates both voltages commands Ed shuC ∗ and Eq shuC ∗ based on power fluctuations _P and _Q, respectively. Such deviations are calculated subtracting the mean power from the instantaneous power measured in PCC. The mean values of active and reactive power are obtained by low–pass filtering, and the bandwidth of such filters are chosen so that the power fluctuation components selected for compensation, fall into the flicker band as stated in IEC61000- 4-15 standard. In turn, Ed shuC∗ also contains the control action for the DC–bus voltage loop. This control loop will not interact with the fluctuating power compensation, because its components are lower in frequency than the flicker–band. The powers PshuC and QshuC are calculated in the rotating reference frame, as follows:

$$P_{shuC}(t) = \frac{3}{2} \cdot V_d^{PCC}(t) \cdot I_d^{shuC}(t)$$

$$Q_{shuC}(t) = -\frac{3}{2} \cdot V_d^{PCC}(t) \cdot I_q^{shuC}(t) \quad \text{-----11,12}$$

Ignoring PCC voltage variation, these equations can be written as follows

$$P_{shuC}(t) = k'_p \cdot I_{d\_shuC}(t)$$
$$Q_{shuC}(t) = k'_q \cdot I_{q\_shuC}(t) \quad \text{------13}$$

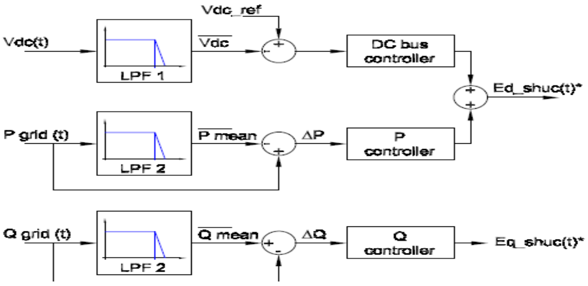
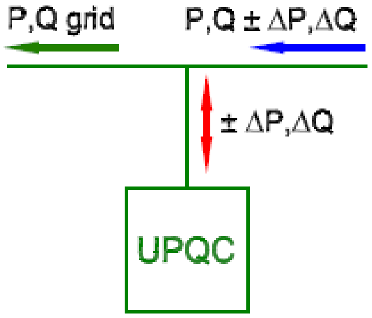


Fig. 3 Shunt controller

Taking in consideration that the shunt converter is based on a VSI, we need to generate adequate voltages to obtain the currents in (6). This is achieved using the VSI model proposed in [10], leading to a linear relationship between the generated power and the controller voltages. The resultant equations are:

$$\begin{aligned} P_{shuC}(t) &= k_p'' \cdot E_{d\_shuC}{}^*(t) \\ Q_{shuC}(t) &= k_q'' \cdot E_{q\_shuC}{}^*(t) \end{aligned} \qquad \text{-------14}$$

P and Q control loops comprise proportional controllers, while DC–bus loop, a fuzzy controller. In summary, in the proposed strategy the UPQC can be seen as a "*power buffer*", leveling the power injected into the power system grid. The Fig. below illustrates a conceptual diagram of this mode of operation. It must be remarked that the absence of an external DC source in the UPQC bus, forces to maintain zero–average power in the storage element installed in that bus. This is accomplished by a proper design of DC voltage controller. Also, it is necessary to note that the proposed strategy cannot be implemented using other CUPS devices like D–Statcom or DVR. The power buffer concept may be implemented using a D-Statcom, but not using a DVR. On the other hand, voltage regulation during relatively large disturbances cannot be easily coped using reactive power only from D-Statcom; in this case, a DVR device is more suitable.



IV. Fuzzy logic controller

The FLC uses a set of fuzzy rules representing a control decision mechanism to adjust the effect of certain system stimuli. Therefore, the aim of using FLC is to replace a skilled human operator with a fuzzy rules-based system. The fuzzy input vectors are the change in DC voltage deviation ΔV and the voltage V. The fuzzy set for inputs and output membership functions are shown seven linguistic variables (LV) are used for each input variables. These are PL (Positive Large), PM (Positive Medium), PS (Positive Small), Z (Zero), NS (Negative Small), NM (Negative Medium) and NL (Negative Large). The fuzzy output is the change in reference voltage (ΔVref {k}) which is to be added to the previous value of reference voltage (Tref{k-1}). The output fuzzy sets have the same linguistic variables used for input except T is added to indicate the fuzzy sets are used for voltage. A look-up table, in which the relation between the input variables, Δω and Δώ, are defined and the output variable of the fuzzy logic controller was developed and used in the simulation. The look-up table is given in Table-1. The Maximum of Minimum method has been used to find the output fuzzy rules stage, as follow

$$\Delta T\ \{k\} = \frac{\int y \times \mu(y) \times dy}{\int \mu(y) \times dy}$$

Δ_{iq_ref}		e_2						
		NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
e_1	**NB**	PB	PB	PB	PM	PM	PM	PS
	NM	PB	PB	PM	PM	PM	Z	NB
	NS	PB	PM	PM	PM	PS	NS	NB
	Z	PB	PM	PS	Z	NS	NM	NB
	PS	PB	PS	NS	NM	NM	NM	NB
	PM	PB	Z	NM	NM	NM	NB	NB
	PB	NS	NM	NM	NM	NB	NB	NB

Table-1

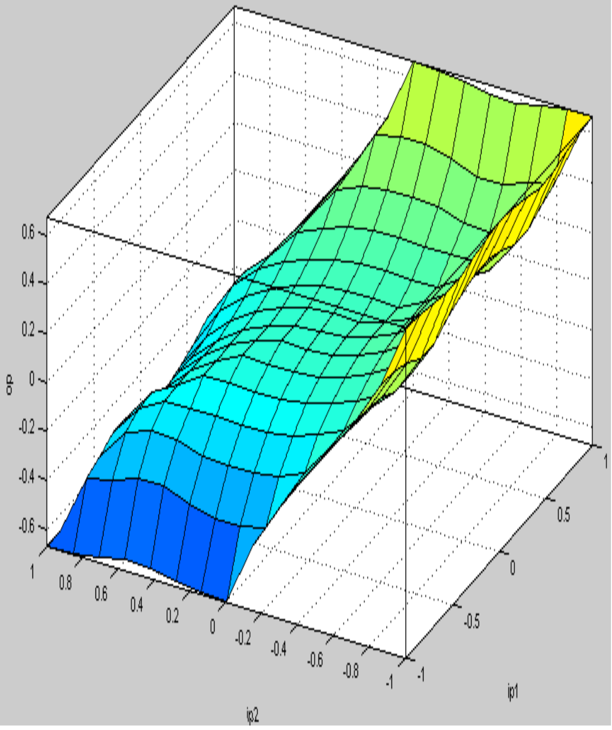


Fig. 4 Surface viewer

V. SIMULATION RESULTS

The performance of the proposed concept of simultaneous load reactive power and voltage sag/swell compensation has been evaluated by simulation. To analyze the performance of UPQC-S, the source is assumed to be pure sinusoidal. Furthermore, for better visualization of results the load is considered as highly inductive. The supply voltage which is available at UPQC terminal is considered as three phase, 60 Hz, 600 V (line to line) with the maximum load power demand of 15 kW + j 15 kVAR (load power factor angle of 0.707 lagging). The simulation results for the proposed UPQC-S approach under voltage sag and swell conditions are given in below Fig. Before time t1, the UPQC-S system is working under steady state condition, compensating the load reactive power using both the inverters. A power angle δ of 21◦ is maintained between the resultant load and actual source voltages. The series inverter shares 1.96 kVAR per phase (or 5.8 kVAR out of 15 kVAR) demanded by the load. Thus, the reactive power support from the shunt inverter is reduced from 15 to 9.2 kVAR by utilizing system (sag last till time t = 0.7 s). Between the time period t = 0.7 s and t = 0.8 s, the system is again in the steady state. A swell of 10% is imposed on the system for a duration of t2 = 0.8–0.9 s. The active and reactive power flows through the source, load, and UPQC are given in Fig. below. The distinct features of the proposed the concept of PAC. In other words, the shunt inverter rating is reduced by 20% of the total load kilovolt ampere rating. At time t1 = 0.6 s, a sag of 10% is introduced on the UPQC-S approach are outlined as follows. 1) From Fig 5. (a) And (b), the load voltage profile is maintained at a desired level irrespective of voltage sag (decrease) or swell (increase) in the source voltage magnitudes.

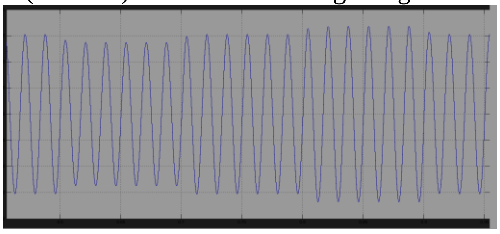


Fig 5.a source voltage with 10%sags & swells

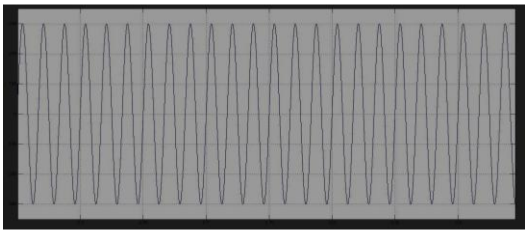


Fig 5.b Load voltage

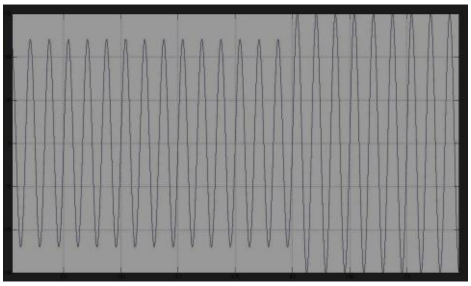


Fig 5.c series inverter voltage

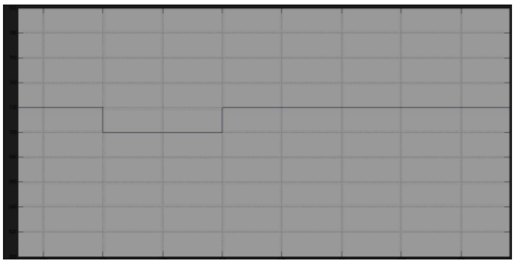


Fig 5.d Vdc

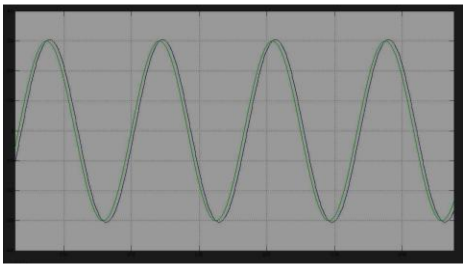


Fig 5.e power angle b/w Vs,Vl at ST

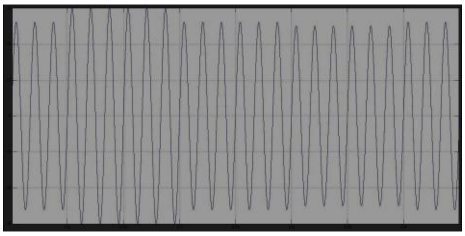


Fig 5.f I_s

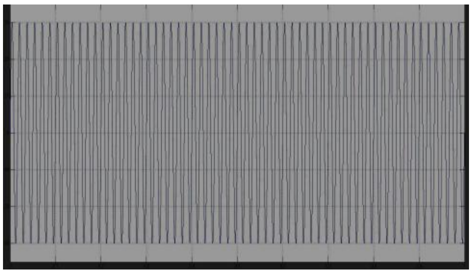


Fig 5.g load current

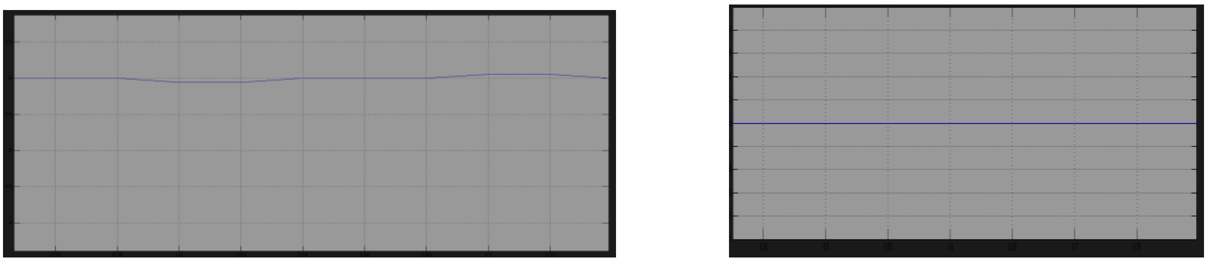


Fig 5.h Source active and reactive power

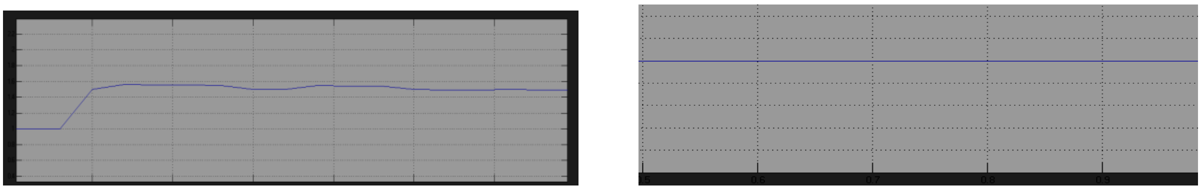


Fig 5.i series active power and reactive power

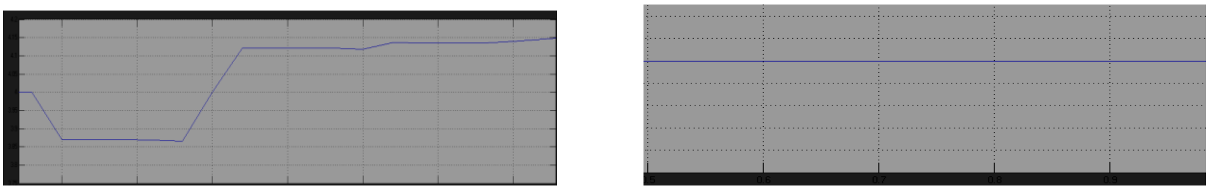


Fig 5.j shunt active and reactive power

VI. CONCLUSION

In this paper, a new concept of controlling complex power (simultaneous active and reactive powers) through series inverter of UPQC is introduced and named as UPQC-S. The proposed concept of the UPQC-S approach is mathematically formulated and analyzed for voltage sag and swell conditions. The developed comprehensive equations for UPQC-S can be utilized to estimate the required series injection voltage and the shunt compensating current profiles (magnitude and phase angle), and the overall VA loading both under voltage sag and swell conditions. The simulation studies demonstrate the effectiveness of the proposed concept of simultaneous voltage sag/swell and load reactive power sharing feature of series & shunt part of UPQC-S with fuzzy logic controller. The significant advantages of UPQC-S over general UPQC applications are: 1) the multifunction ability of series inverter to compensate voltage variation (sag, swell, etc.) while supporting load reactive power; 2) better utilization of series inverter rating of UPQC; and 3) reduction in the shunt inverter rating due to the reactive power sharing by both the inverters.

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