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Optimal Utilization of Series Inverter of UPQC to Mitigate Voltage Sag/Swell and Load Reactive Power Compensations By the Combination of APC and PAC

U.M. Sandeep Kumar[1], C.H. Phanidra[2]

PG student, QISCET, ONGOLE[1], Assistant professor, QISCET, ONGOLE[2]

***Abstract*— This paper presents a concept of optimal utilization of series inverter of a unified power quality conditioner (UPQC). The series inverter of UPQC is controlled to perform simultaneous voltage sag/swell compensation and load reactive power sharing with the shunt inverter by active power control approach and power angle control (PAC) of UPQC to coordinate the load reactive power between the two inverters. Since the series inverter simultaneously delivers active and reactive powers, this concept is named as UPQC-S (S for complex power). The mathematical analysis of the proposed method is presented in this paper. Results are discussed to support the proposed concept through MATLAB/Simulink.**

***Keywords*—Active power filter (APF), Power angle control(PAC) power quality, reactive power compensation, unified power quality conditioner (UPQC), voltage sag and swell compensation, series voltage (v_{ser}), shunt current (I_{shu}), Active power control(APC), reactive power control.**

I. INTRODUCTION

The different power quality problems arise in present modern power system. The main reasons for power quality problems are due to the extensive use of nonlinear loads, the penetration level of small/large-scale renewable energy systems based on wind energy, solar energy, fuel cell, etc., installed at distribution as well as transmission systems, faults like open circuits and short circuits, capacitance switching, lightning effects, loading effects etc…[1], [2]. To maintain the controlled power quality regulations some kind of compensation at all the power levels is becoming a common practice [5]–[9]. At the distribution level, UPQC is a most attractive solution to compensate several major power quality problems [7]–[9], [14]–[28].

In this paper, the power supply is assumed to be a 3-phase, three wire system. The UPQC is composed with two active filters i,e.. Two 3-leg voltage source inverters (VSI) connected back to back with dc link capacitor. Functionally, the series filter is used to compensate for the voltage distortions like voltage sag, voltage swell, under voltages, over voltages etc.. while the shunt filter is needed to provide the reactive power and counteract the harmonic current injected by the load. Also the voltage of the dc link capacitor is controlled to a desired value by the shunt active filter.

The general block diagram representation of a UPQC-based system is shown in Fig. 1.

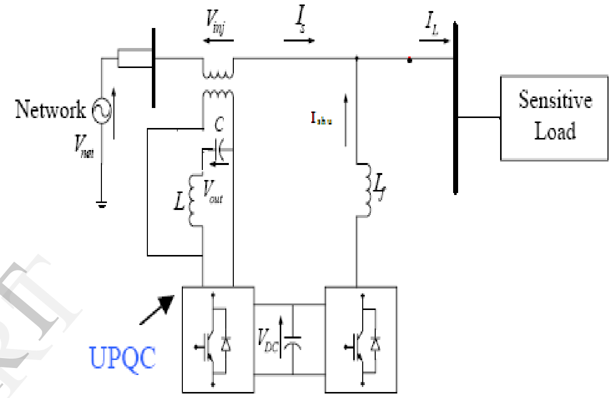

Fig.1. Unified power quality conditioner (UPQC) system configuration.

The voltage sag/swell on the system is one of the most important power quality problems [1], [2]. The voltage sag/swell can be effectively compensated using a dynamic voltage restorer, series active filter, UPQC, etc. [7]–[28]. Among the available power quality enhancement devices, the UPQC has better sag/swell compensation capability.

The UPQC can be controlled to compensate the voltage distortion problems by the following ways.

1) The first way of controlling UPQC is in such a way that the series inverter injected the voltage in-phase under voltage sag condition and out of phase under voltage swells condition with the source voltage. So it is called as a active power control, popularly known as a UPQC-P.

2) The second way of controlling UPQC is in such a way that the series inverter injected a quadrature voltage under voltage sag condition. So it is called as a reactive power control, popularly known as UPQC-Q.

3) The third way of controlling UPQC is in such a way that the series inverter injected voltage at a certain angle by power angle control (PAC) to minimum VA loading approach called as UPQC-VAmin.

4) The fourth way of controlling the UPQC is in such a way both active power control (APC) and power angle control (PAC) is used to inject voltage in phase or out phase to compensate voltage sag/swell and to load reactive power compensation i,e. to decrease the burden on shunt inverter.

II. COMPENSATION OF VOLTAGE SAG/SWELL BY ACTIVE POWER CONTROL (APC) AND REACTIVE POWER CONTROL (QPC).

The voltage sag on a system can be compensated through active power control and reactive power control for voltage sag and swell compensation using active power control and reactive power control. The voltage sag (V_{sag}) can be compensated by injecting a voltage in-phase by active power control shown in figure 2(a). Similarly voltage swell (V_{swell}) also compensated using reactive power control, by injecting series inverter voltage out of phase with the source voltage shown in figure 2(c). The voltage sag (V_{sag}) can be compensated by injecting a voltage in-quadrature by reactive power control shown in figure 2(b). If the series inverter voltage injected in quadrature under voltage swell (Vswell) does not intersect with the rated voltage locus shown in figure 2(d). Thus, the reactive power control approach is limited to compensate the sag on the system. However, the active power control approach can effectively compensate both voltage sag and swell on the system. Furthermore, to compensate an equal percentage of sag, the reactive power control requires lager magnitude of series injection voltage than the active power control ($V_{SerQ} > V_{Serp}$).

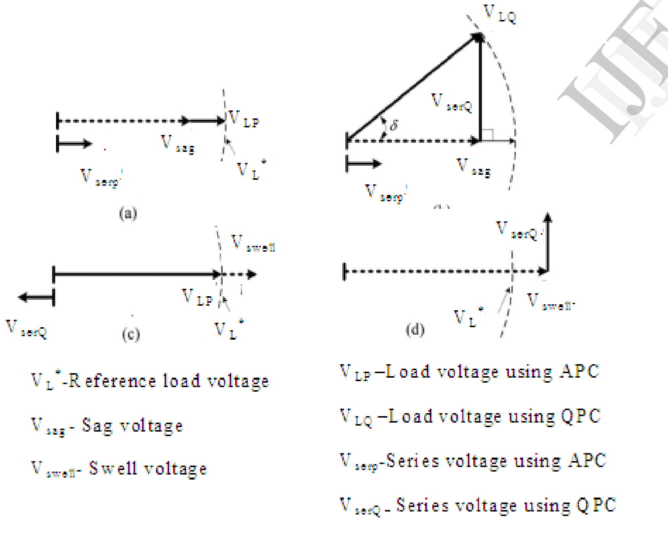

Fig. 2. Vector representation of Voltage sag and swell compensation using Active power control and Quadrature power control. (a) Voltage Sag (APC). (b) Voltage Sag (QPC). (c) Voltage Swell (APC). (d) Voltage Swell (QPC)

Interestingly, QPC also gives a power angle shift between resultant load and source voltages, but this shift is a function of amount of sag on the system. Thus, the phase shift in QPC cannot be controlled to vary the load reactive power support. Additionally, the phase shift in QPC is valid only during the voltage sag condition.

III. 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. 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. 3. According to this theory, a vector V_{Ser} with proper magnitude V_{Ser} and phase angle ϕ_{Ser} when injected through series inverter gives a power angle δ_1 boost between the source V_S and resultant load V_L voltages maintaining the same voltage magnitudes.

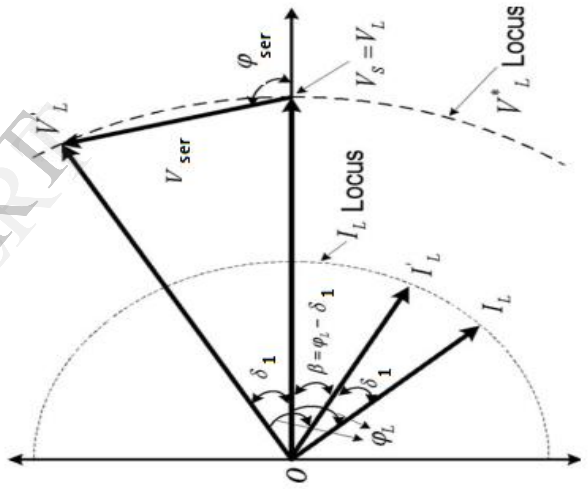

Fig. 3. Concept of PAC of UPQC.

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.

IV. VOLTAGE SAG COMPENSATION BY THE COMBINATION OF ACTIVE POWER AND POWER CONTROL APPORACH

Consider that the UPQC system is already working under PAC approach, i.e., both the inverters are compensating the load reactive power and the injected series voltage gives a power angle δ_1 between resultant load and the actual source voltages. If a sag/swell condition occurs on the system, both the inverters should keep supplying the load reactive power, as they were before the sag. Additionally, the series inverter should also compensate the voltage sag/swell by injecting the appropriate voltage component. In other words, irrespective of the variation in the supply voltage the series inverter should maintain same power angle δ_1 between both the voltages. However, if the load on the system changes during the voltage sag condition, the PAC approach will give a different δ angle. The increase or decrease in new $\delta 1$ angle would depend on the increase or decrease in load reactive power, respectively.

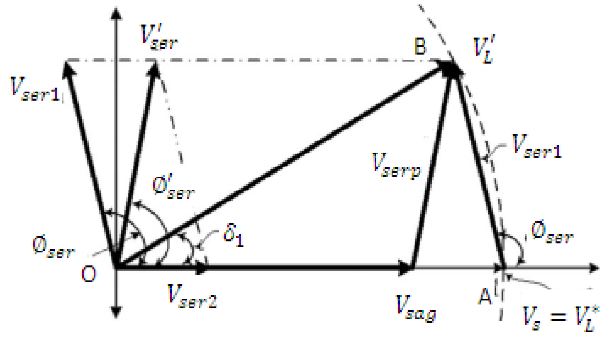

Fig. 4. Vector representation of the combined APC and PAC approach under voltage sag condition.

Let us represent a vector VSer1 responsible to compensate the load reactive power utilizing PAC concept and vector VSer2 responsible to compensate the sag on the system using active power control approach. Thus, for simultaneous compensation as noticed from Fig. 4, the series inverter should now supply a component which would be the vector sum of VSer1 and VSer2. This resultant series inverter voltage VSer will maintain the load voltage magnitude at a desired level such that the drop in source voltage will not appear across the load terminal. Furthermore, the series inverter will keep sharing the load reactive power demand.

For a rated steady-state condition

$$|V_S| = |V_L| = |V_L^*| = |V_L| = a. \tag{1}$$

For load reactive power compensation using PAC

$$V_{ser1} = V'_L - V_s \tag{2}$$

$$V_{ser1}\angle\emptyset_{ser1} = V'_L\angle\delta 1 - V_s\angle 0^0 \tag{3}$$

For voltage sag compensation using active power control approach

$$V_{ser2} = V'_L - V'_s \tag{4}$$

$$V_{ser2}\angle 0^0 = V_L^*\angle 0^0 - V'_L\angle 0^0 \tag{5}$$

For simultaneous load reactive power and sag compensation

$$V'_{ser} = V_{ser1} + V_{ser2} \tag{6}$$

$$V'_{ser}\angle\emptyset'_{ser} = V_{ser1}\angle\emptyset_{ser1} + V_{ser2}\angle 0^0 \tag{7}$$

A. *Estimation of Series Inverter Parameters Under Voltage Sag*

In order to achieve both load reactive power sharing with shunt inverter and voltage sag compensation, the series inverter injects the voltage at a appropriate angle. So the series inverter parameters are estimated as follows by using vector representation shown in figure below 5.

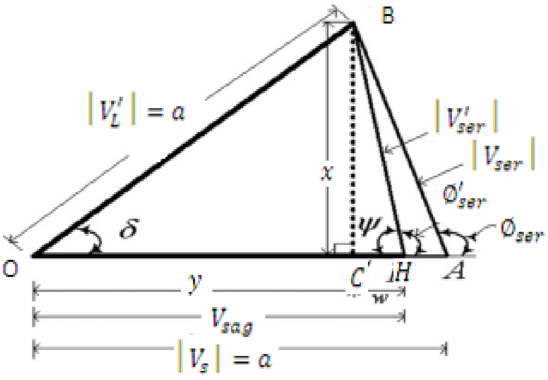

Fig. 5. Vector representation diagram to estimate the series inverter parameters for the combined APC and PAC approach under voltage sag condition.

The voltage fluctuation factor a_f 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 [19]

$$a_f = \frac{(V_s - V_L^*)}{V_L^*} \tag{8}$$

Representing (10) for sag condition under PAC

$$a_f = \frac{(V'_s - V'_L)}{V'_L} = \frac{(V'_s - a)}{a} \tag{9}$$

Let us define

$$1 + a_f = \left(\frac{V_s}{a}\right) = a_0 \tag{10}$$

$$w = l(CH) = a_0.a - y \tag{11}$$

Δ^{le} CHB $|V_{ser}|$ can be calculated as follows

$$|V_{ser}| = \sqrt{x^2 + w^2}$$

$$|V'_{ser}| = \sqrt{(a.\sin\delta 1)^2 + (a_0.a - a\cos\delta 1)^2} \tag{12}$$

$$|V'_{ser}| = a.\sqrt{1 + a_0^2 - 2.a_0.\cos\delta 1} \tag{13}$$

To compute the phase of VSer'

$$\angle CHB = \angle\psi = \tan^{-1}\frac{x}{w} = \tan^{-1}\left(\frac{\sin\delta 1}{a_0 - \cos\delta 1}\right) \tag{14}$$

Therefore,

$$\angle\emptyset'_{ser} = 180^0 - \angle\psi \tag{15}$$

Equations (13) and (15) 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.

B. *Estimation of Shunt Inverter Parameter Under Voltage Sag*

Before voltage sag on the system, the UPQC is compensating load reactive power using PAC approach, injecting the current I'_{Shu} through shunt inverter. To achieve the voltage sag compensation through active power control approach the source should supply increased current I_S. Thus, to support the series inverter to inject the required voltage for load reactive power and sag compensations, the shunt inverter should now deliver the current I''_{Shu}. This resultant shunt compensating current will maintain the dc link voltage at the constant level. Thus, it facilitates the required active power transfer between the source and shunt inverter, shunt inverter and series inverters (through dc link) and finally, from series inverter to the load. The shunt inverter current magnitude and its phase angle are estimated as follows by using below figure 7.

. During voltage sag [19]

$$I'_s = \left(\frac{I_L}{1+a_f}\right).\cos \varnothing_L \qquad (16)$$

Let

$$\frac{1}{1+a_f} = a_1 \qquad (17)$$

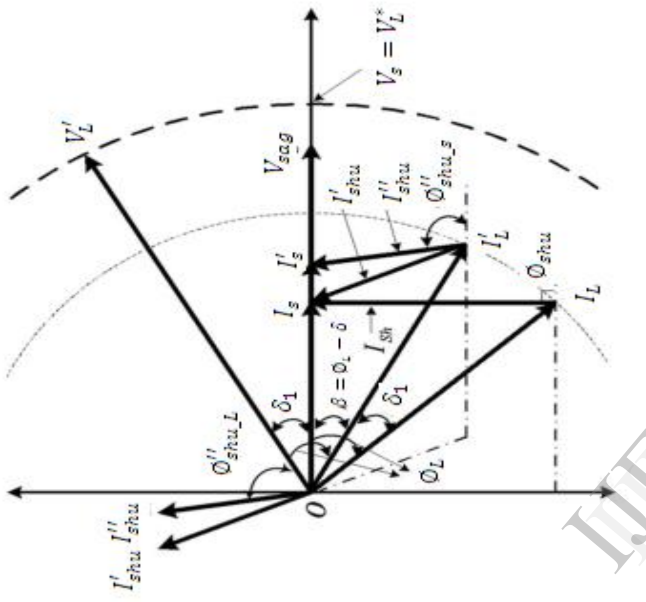

Fig. 6. Current-based vector representation of the combined APC and PAC approach under voltage sag condition.

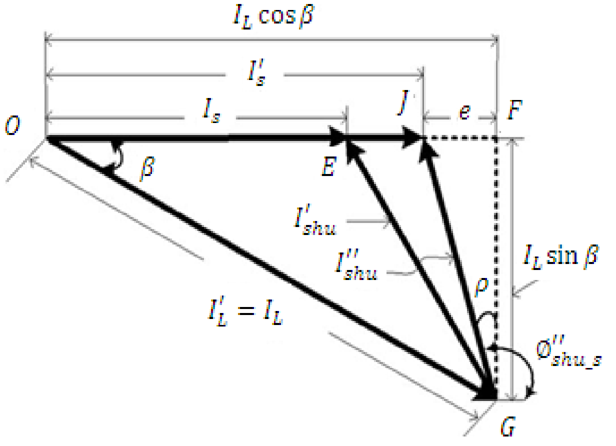

Fig. 7. Vector representation diagram to estimate the shunt inverter parameters for the combined APC and PAC approach under voltage sag condition

To support the active power required during voltage sag condition, the source delivers the extra source current. Therefore,

$$I'_s = a_1.I_L.\cos \varnothing_L \qquad (18)$$

In ΔGFJ (see Fig. 7)

$$I''_{shu} = \sqrt{\left(I'_L.\sin\beta\right)^2 + \left(I'_L(\cos\beta - a_1\cos\varnothing_L)\right)^2} \qquad (19)$$

$$I''_{shu} = I'_L.\sqrt{1 + a_1^2\sin^2\psi_L - 2a_1\cos\beta\cos\varnothing_L} \qquad (20)$$

$$\rho = \tan^{-1}\left(\frac{\cos\beta - a_1.\cos\varnothing_L}{\sin\beta}\right) \qquad (21)$$

$$\angle\varnothing''_{shu\ L} = \rho + 90^0 \qquad (22)$$

$$\angle\varnothing''_{shu\ L} = \rho + 90^0 - \delta \qquad (23)$$

Equations (20) and (23) give the required magnitude and phase angle of a shunt inverter compensating current.

V. VOLTAGE SWELL COMPENATION BY THE COMBINATION OF OF ACTIVE POWER AND POWER CONTROL APPORACH

The vector representation of APC and PAC of UPQC during a voltage swell on the system is shown in below Fig8.

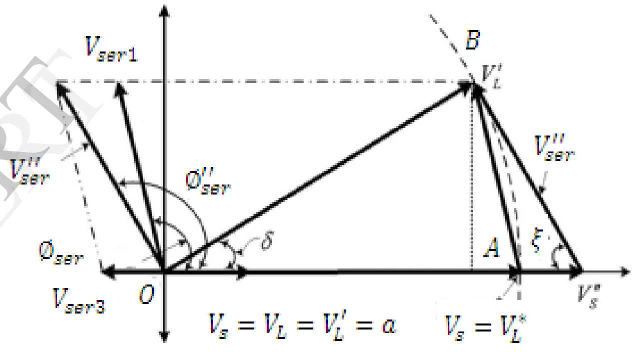

Fig. 8. Vector representation of the combined APC and PAC approach under voltage swell condition.

Let us represent a vector V_{Ser3} responsible to compensate the swell on the system using active power control approach. For simultaneous compensation, the series inverter should supply the V_{Ser1} component to support the load reactive power and V_{Ser3} to compensate the swell on the system. The resultant series injected voltage V''_{Ser} would maintain the load voltage magnitude at a desired level while supporting the load reactive power.

For voltage swell compensation using active power control approach

$$V_{ser3} = V_L^* - V''_s \qquad (24)$$

$$V_{ser3}\angle 180^0 = V_L^*\angle 0^0 - V''_s\angle 180^0 \qquad (25)$$

For simultaneous load reactive power and voltage swell compensations

$$V''_{ser} = V_{ser1} + V_{ser3} \qquad (26)$$

$$V''_{ser}\angle\varnothing''_{ser} = V_{ser1}\angle V_{ser1} + V_{ser3}\angle 180^0. \qquad (27)$$

For series inverter (see Fig. 8)

$$\left|V''_{ser}\right| = a.\sqrt{1 + a_0^2 - 2.a_0.\cos\delta 1} \quad (28)$$

$$\angle \mathrm{CLB} = \angle\xi = \tan^{-1}\left(\frac{\sin\delta 1}{a_0 - \cos\delta 1}\right) \quad (29)$$

$$\angle\varnothing''_{ser} = 180^0 - \angle\xi \quad (30)$$

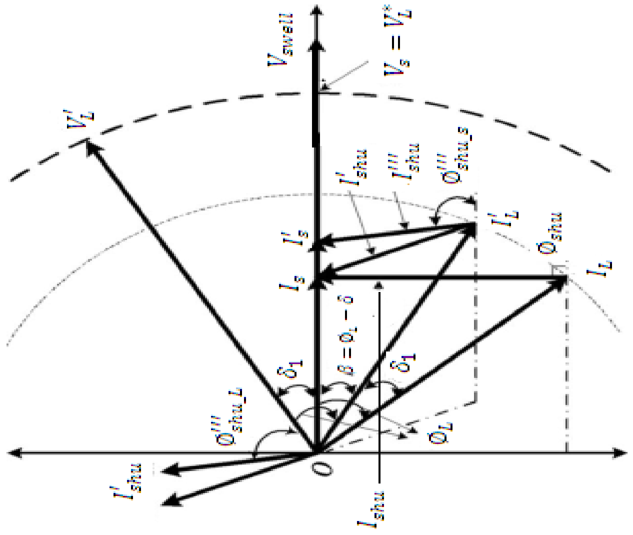

Fig. 9. Current-based vector representation of the combined APC and PAC approach under voltage swell condition.

The above Figure 9 shows the vector representation of different currents under voltage swell condition utilizing the active power control and power angle control approach.

The important equations are given here.

For shunt inverter (see Fig. 9)

$$I'''_{shu} = I'_L\sqrt{1 + a_1^2 cos^2\varnothing_L - 2a_1\cos\beta\cos\varnothing_L;} \quad (31)$$

$$\tau = \tan^{-1}\left(\frac{\cos\beta - a_1\cos\varnothing_L}{\sin\beta}\right) \quad (32)$$

$$\angle\varnothing'''_{sh\ L} = (\angle\tau + 90^0) - \delta 1 \quad (33)$$

It can be noted that the equations for voltage sag and swell compensation utilizing the PAC of UPQC-S are identical. However, the value of factor a_f will be negative for voltage sag and positive for voltage swell; hence, the value of factors a_1 and a_0 will be different for voltage sag and swell conditions, giving different magnitude and phase angles for series and shunt inverter parameters.

VI. ACTIVE–REACTIVE POWER FLOW THROUGH UPQC BY APC AND PAC

The active and reactive powers flow per phase through the UPQC during the voltage sag/swell by combination of APC and PAC approach is estimated as follows

A. Series Inverter of UPQC-S

For active power

$$P'_{ser} = V'_{ser}.I'_s.\cos\varnothing'_{ser} \quad (34)$$

From Fig. 5

$$P'_{ser} = V'_{ser}.I'_s.\cos(180^0 - \varnothing) \quad (35)$$

$$P'_{ser} = V'_{ser}.I'_s.(-\cos\varnothing) \quad (36)$$

$$P'_{ser} = -V'_{ser}.I'_s.\left(\frac{w}{V'_{ser}}\right) \quad (37)$$

$$P'_{ser} = -I'_s.a.(a_0 - \cos\delta 1) \quad (38)$$

The increase *I'S* or decrease *IS"* in the source current magnitudes during the voltage sag or swell condition, respectively, is represented as

$$I'_s = I''_s = a_1.I_L.\cos\varnothing_L \quad (39)$$

Therefore,

$$P_{ser,PAC} = P'_{ser} = -a.(a_1 - \cos\delta 1).(P_L) \quad (40)$$

$$P_L = a.I_L.\cos\varnothing_L$$

For reactive power

$$Q'_{ser} = V'_{ser}.I'_s.\sin\varnothing'_{ser} \quad . \ (41)$$

From Fig. 5

$$Q'_{ser} = V'_{ser}.I'_s.\sin(180^0 - \varnothing) \quad (42)$$

$$Q'_{ser} = V'_{ser}.I'_s.\sin\psi \quad (43)$$

$$Q'_{ser} = V'_{ser}.I'_s.\left(\frac{x}{V'_{ser}}\right) \quad (44)$$

Therefore,

$$Q_{ser,PAC} = Q'_{ser} = a_1.\sin\delta 1.P_L \quad (45)$$

Using (42) and (47), the active and reactive power flow through series inverter of UPQC-S during voltage sag/swell condition can be calculated.

C. *Shunt Inverter of UPQC-S*

The active and reactive power handled by the shunt inverter as seen from the source side is determined as follows.

For active power

$$P'_{shu} = V'_s.I''_{shu}.\cos\varnothing''_{shu\_s} \quad (46)$$

From Fig. 7

$$P'_{shu} = a_0.a.I''_{shu}.(-\sin\rho) \quad (47)$$

$$P'_{shu} = -a_0.a.I''_{shu}.\left(\frac{e}{I''_{shu}}\right) \quad (48)$$

$$P_{shu\_PAC} = -\frac{(a.I_L)(\cos\beta - a_1\cos\varnothing_L)}{a_1} \quad (49)$$

For reactive power

$$Q'_{shu} = V'_s.I''_{shu}.\sin\psi''_{shu\_s}. \quad (50)$$

From Fig. 7

$$Q'_{shu} = a_0.a.I''_{shu}.\cos\rho \quad (51)$$

$$Q'_{shu,PAC} = \left(\frac{(a.I_L).(\sin\beta)}{a_1}\right) \quad (52)$$

Using (51) and (54), the active and reactive power flow through shunt inverter of UPQC-S during voltage sag/swell condition can be calculated and utilized to determine the overall UPQC-SVA loading.

VII. UPQC-S CONTROLLER

In this paper, the generation of reference signals for series inverter and shunt inverter are 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 (45) and (52). 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.

The instantaneous load angle δ is determined by p-q theory shown in figure below 10a.

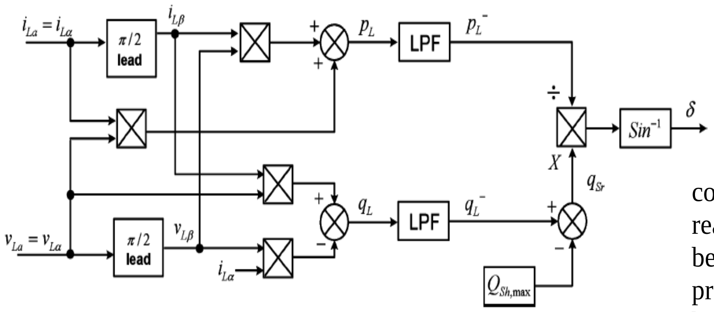

Fig. 10a. Instantaneous δ determination

The control block diagram for series inverter operation is shown in Fig. 10b.

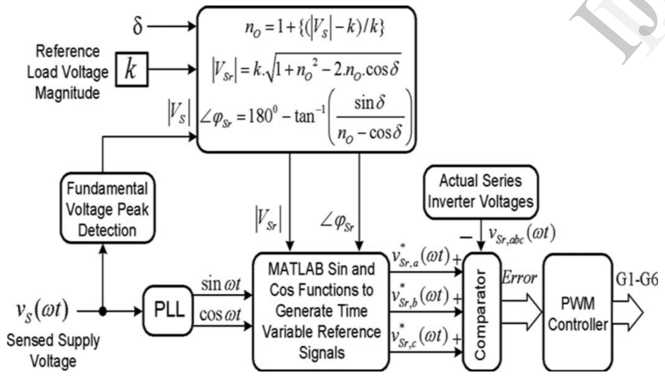

Fig. 10b. Reference voltage signal generation for the series inverter of the
Proposed UPQC-S approach.

The control diagram for the shunt inverter operation shown in figure below 10c.

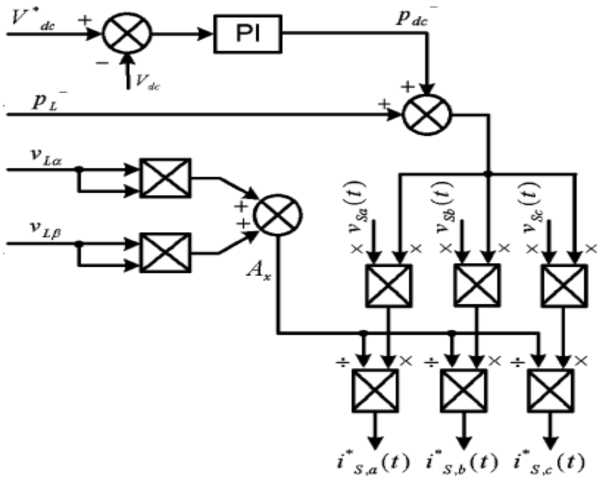

Fig. 10c. Reference voltage signal generation for the shunt inverter of the
Proposed UPQC-S approach

VIII. SIMULATION RESULTS

The performance of the proposed APC and PAC approach to control of UPQC for compensation of simultaneous load reactive power and voltage sag/swell in the power system has been evaluated by simulation. To analyze the performance of proposed control approach of UPQC, the source is assumed to be pure sinusoidal. The supply voltage which is available at UPQC terminal is considered as three phase, 50 Hz, 415 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 Fig. 11. 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 15° is maintained between the resultant load and actual source voltages. The series inverter shares reactive power demanded by the load. Thus, the reactive power support from the shunt inverter is

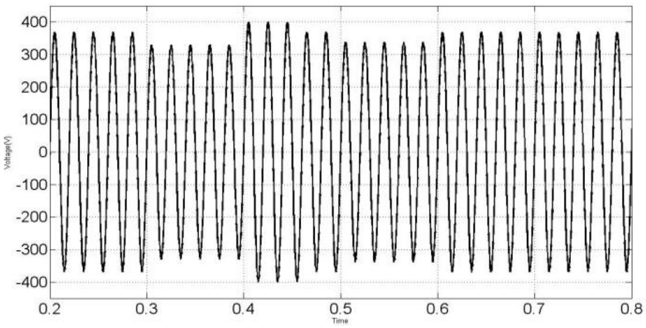

Fig. 11(a) Source Voltage

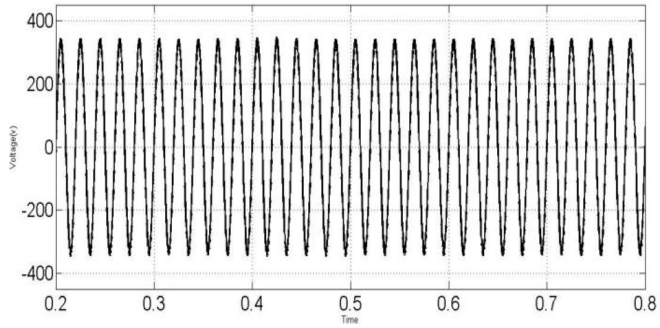

Fig. 11(b) Load Voltage

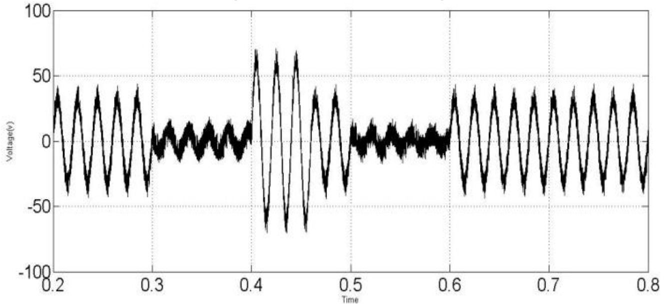

Fig. 11(c) Series Voltage

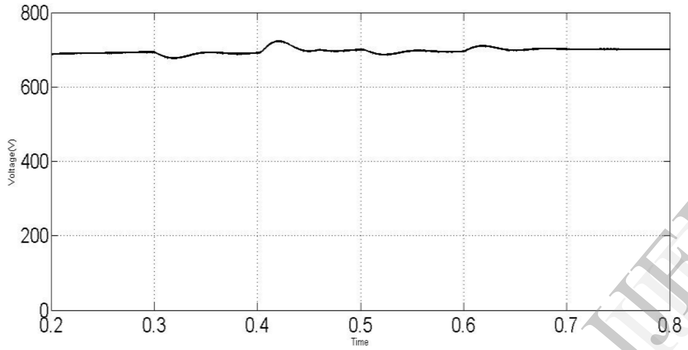

Fig. 11(d) Self-supporting dc bus Voltage

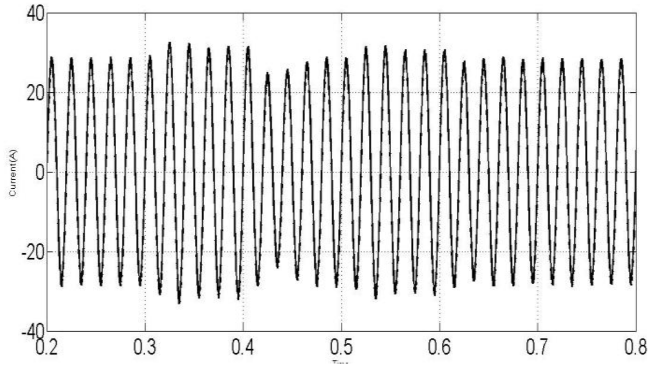

Fig. 11(e) Source Current

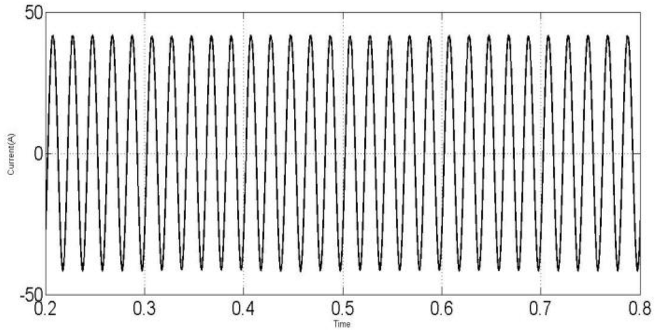

Fig. 11(f) Load Current

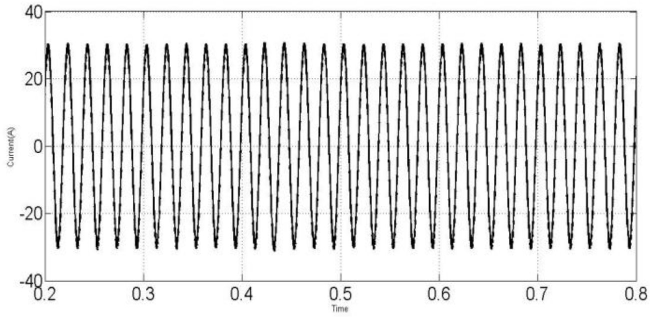

Fig. 11(g) shunt current

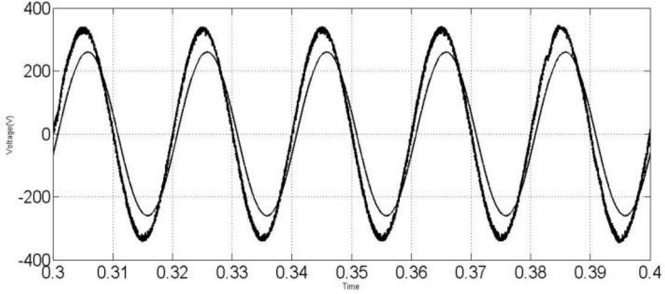

Fig. 11(h) Self-supporting dc bus Voltage

Fig. 11. Simulation results: Performance of the proposed UPQC-S approach under voltage sag and swell condition.

VIII. SIMULATION RESULTS

The performance of the proposed APC and PAC approach to control of UPQC for compensation of simultaneous load reactive power and voltage sag/swell in the power system has been evaluated by simulation. To analyze the performance of proposed control approach of UPQC, the source is assumed to be pure sinusoidal. The supply voltage which is available at UPQC terminal is considered as three phase, 50 Hz, 415 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 Fig. 11. Before time t_1 the UPQC-S system is working under steady state condition, compensating the load reactive power using both the inverters. A power angle δ of 15° is maintained between the resultant load and actual source voltages. The series inverter shares reactive power demanded by the load. Thus, the reactive power support from the shunt inverter is reduced from 15KVAR by utilizing the concept of PAC. In other words, the shunt inverter rating is reduced the total load kilovolt ampere rating. At time $t1 = 0.3$s, a sag of 20% is introduced on the system (sag last till time $t = 0.4$ s). A swell of 20% is imposed on the system for a duration of $t2 = 0.4–0.5$s. Between the time period $t = 0.5$ s and $t = 0.6$ s, the system is again in sag of 20%. The active and reactive power flows through the source, load, and UPQC are given in Fig. 12. The distinct features of the proposed UPQC-S approach are outlined as follows.

1) From Fig. 11(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. During the sag/swell compensation, as viewed from Fig. 11(f), to maintain the appropriate active power balance in the network, the source current increases during
the voltage sag and reduces during swell condition.
2) As illustrated by enlarged results, the power angle δ between the source and load voltages during the steady state
voltage sag [see Fig. 11(h)] maintained◦.

3) The UPQC-S controller maintains a self-supporting dc link voltage between two inverters [see Fig. 11(d)].

4) From Fig. 12(c) and (d), the reactive power supplied by the series inverter during the voltage sag condition increases due to the increased source current. As load reactive power demand is constant, the reactive power supplied by the shunt inverter reduces accordingly. On the other hand, during the voltage swell condition, the reactive power shared by the series inverter reduces and the shunt inverter increases. The reduction and increment in the shunt compensating current magnitude, as seen from Fig. 11(h), also confirm the aforementioned fact. Although the reactive power shared by the series and shunt inverters is varied, the sum of their reactive powers always equals the reactive power demanded by the load.

Thus, the aforementioned simulation study illustrates that with PAC of UPQC-S, the series inverter can compensate the load reactive power and voltage sag/swell simultaneously. The shunt inverter helps the series inverter to achieve the desired performance by maintaining a constant self-supporting dc bus. The significant advantage of UPQC-S over general UPQC applications is that the shunt inverter rating can be reduced due to reactive power sharing of both the inverters

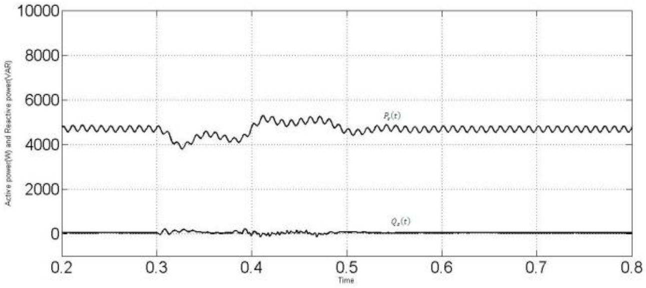

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Fig. 12.(a) Source P and Q

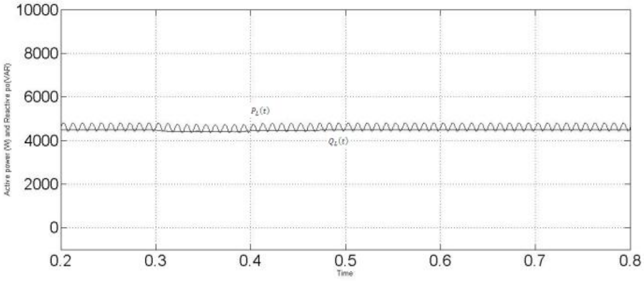

Fig. 12.(b) Load P and Q

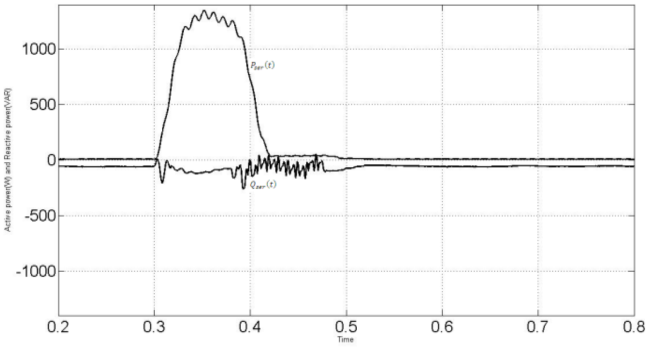

Fig. 12.(c) Series inverter P and Q

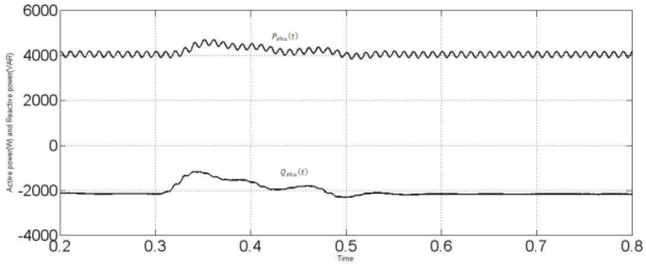

Fig. 12.(d) Shunt inverter P and Q

Fig. 12. Simulation results: active and reactive power flow through source, load, shunt, and series inverter utilizing proposed UPQC-S approach under voltage sag and swell conditions.

X. CONCLUSION

In this paper, a 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 and experimental studies demonstrate the effectiveness of the proposed concept of simultaneous voltage sag/swell and load reactive power sharing feature of series part of UPQC-S. The significant advantages of UPQC-S over general UPQC applications are: 1) the multi-function 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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