Power angle control of UPQC to compensate load reactive power and voltage sag /swells

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Abstract—this paper presents a new concept of optimal utilization of a unified power quality conditioner (UPQC).To perform simultaneous of 1) voltage sag/swell compensation and 2) load reactive power control sharing with the shunt inverter by controlled of the series inverter. Where the active power control approach is used to compensate voltage sag/swell and is embedded with theory of power angle control (PAC) of UPQC to coordinate the load reactive power between two inverters. The named as UPQC-S(S for complex power) is deal with series inverter simultaneously delivers active and notations analyses, to extend the PAC approach for UPQC-S, are presented in this paper. Also Mat lab/Simulink based simulation results are discussed to support the developed concept. Finally the proposed concept is validated with a digital signal processor-based experimental study.

Index Terms- UPQC, UPQC-S, UPF, PAC

I.   INTRODUCTION

With the increase in the complexion of the powerdistribution system and the loads, it is very possible thatseveral kinds of power quality disturbances are in adistribution system or a power load simultaneously, and it istherefore important to introduce UPQC (Unified PowerQuality Conditioner). UPQC is the emerging device ofCustom Power, which combines the functions of seriesvoltage compensator, shunts current compensator andenergy storage device. Multiple power quality regulationfunctions are implemented in [1-5] UPQC simultaneously, with ahigher performance ratio.WITH the increasing application of nonlinear loads, the appearance of power quality problems is inevitable. Many of harmonic sources are single-phase loads, such ascomputers, fluorescent compact lamps, copiers, printers and other home and office electronic equipments. In addition to this the power-factor of the loads are generally poor. On the other hand modern equipments of domestic and commercial uses are very sensitive to power quality problems. In the past, the solutions to mitigate these identified power quality problems were through using conventional passive filters. But their limitations such as, fixed compensation, resonance with the source impedance and the difficulty in tuning time dependence of filter parameters have ignited the need of active and hybrid filters.

In UPQC-P approach, series APF injects a voltage in-phase with the source voltage, while in case of   UPQC-Q,   a quadrature voltage is injected through series APF to mitigate the voltage sag. In case of UPQC-VA$_{min}$voltage is injected at a certain angle by the series APF to keep an overall VA rating of the UPQC minimum. Among these approaches a UPQC-P requires a minimum magnitude of required voltage injection, while UPQC-Q requires a maximum voltage injection for the mitigation of same voltage sag. In all these three approaches, series APF injects voltage for the mitigation of voltage based distortions, while the shunt APF mitigates the current based distortions and maintain the DC link voltage and the overall power balance in the distribution system.
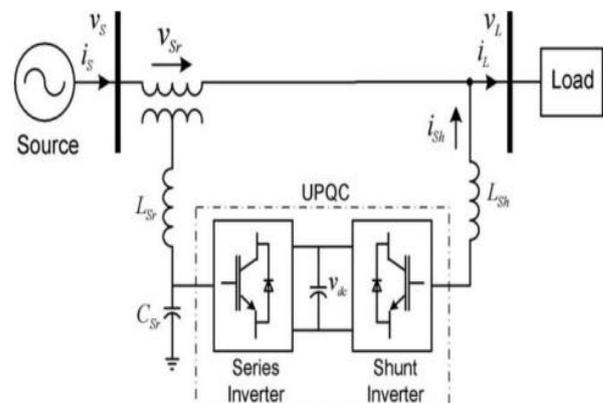

Fig.1. Unified power quality conditioner (UPQC) system configuration.

At the distribution level, UPQC is a most attractive solution to compensate several major power quality problems. The general block diagram representation of a UPQC-based system is shown in Fig. 1. It basically consists of two voltage source inverters connected back to back using a common dc bus capacitor. Three significant control approaches for UPQC can be found to control the sag on the system: 1) active power control approach in which an in-phase voltage is injected through series inverter, popularly known as UPQC-P

2) Reactive power control approach in which a quadrature voltage is injected [9], [10] known as UPQC-Q; and

3) a minimum VA loading approach in which a series voltage is injected at a certain angle, in this paper called as UPQC-VA$_{min}$.

In a minimum VA loading approach, the series inverter voltage is injected at an optimal angle with respect to the source current. Besides the series inverter injection, the current drawn by the shunt inverter, to maintain the dc link voltage and the overall power balance in the network, plays an important role in determining the overall UPQC VA loading.

II.   FUNDAMENTAL OF DIFFERENT APROACHES
A. UPQC-P

The phase representation of UPQC-P is shown in Fig.2.In this approach the series APF injects a voltage in-phase with the source voltage, while the shunt APF compensates for the required reactive power of the load.

Fig.2. Phasor representation of UPQC-P

B. UPQC-Q

The phasor representation of UPQC-Q approach is shown in Fig.3. In this approach the required injected voltage by the series APF is injected at an angle 90° with respect of the source voltage as shown in Fig 3.

Fig.3. Phasor representation of UPQC-Q

C. UPQC-VA$_{min}$

In case of UPQC-VA$_{min}$the required injected voltage by series APF is injected at a certain angle $\emptyset_{srmin}$with respect to sourcevoltage such that the overall rating of the UPQC is minimum. The phasor representation ofUPQC-VA$_{min}$ inapproach is shown in Fig.4.

Fig.4. Phasor representation of UPQC-VA$_{min}$

As we know some of the authors proposed so many techniques as we summarized the as a literature survey. Liu et al [6] have proposed an approach by which a singlephase system can be represented directly in α-β frame without using any transformation matrix.

The approach of using an imaginary variable is further extended by Zhang et al [2] to represent the single-phase system in d-q frame.In this indirect control, the reference current signal for the source current is generated using DC

component in current.By indirect controlling the shunt APF of single-phase UPQC the source supplies the fundamental active part of the load current, while the load harmonics and the reactive power requirements of the load should be supported by shunt APF of UPQC.

III. PROPOSED SYSTEM

This modified approach is utilized to compensate voltage sag/swell while sharing the load reactive power between two inverters. Since the series inverter of UPQC in this case delivers both active and reactive powers, it is given the name UPQCS (S for complex power.

1) The series inverter of UPQC-S is utilized for simultaneous voltage sag/swell compensation and load reactive power compensation in coordination with shunt inverter.

2) In UPQC-S, the available VA loading is utilized to its maximum capacity during all the working conditions contrary to UPQC-VAmin where prime focus is to minimize the VA loading of UPQC during voltage sag condition.

3) The concept of UPQC-S covers voltage sag as well as swell scenario.

The UPFC is a combination of a static compensator and static series compensation. It acts as a shunt compensating and a phase shifting device simultaneously.
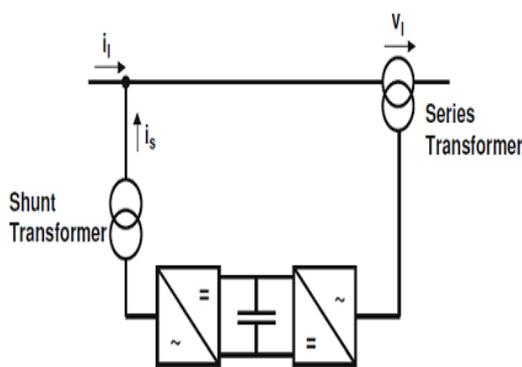
Fig.2.Principle configuration of an UPFC

The UPFC consists of a shunt and a series transformer, which are connected via two voltage source converters with a common DC-capacitor. The DC-circuit allows the active power exchange between shunt and series transformer to control the phase shift of the series voltage.

The series converter needs to be protected with a Thyristor bridge.

A. FUNDAMENTALS OF PAC CONCEPT

The phasor representation of the PAC approach under a rated steady-state condition is shown in Fig.3. According to this theory, a vector with proper magnitude $\overrightarrow{V_{sr}}$ and phase angle ϕ_{sr} when injected through series inverter gives a power angle δ boost between the source VSand 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 , denoted as angle β.
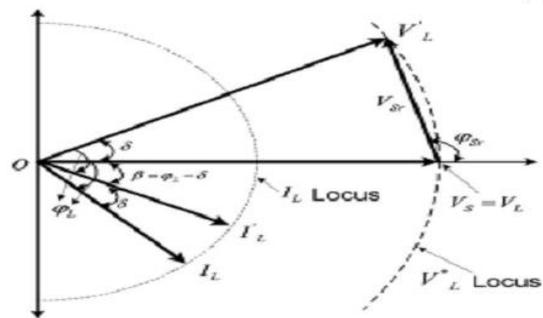

Fig.3. Concept of PAC of UPQC

The voltage sag on a system can be compensated through active power control and reactive power control methods. Fig.4 shows the phasor representations for voltage sag compensation using active power control as in UPQC-P [see Fig. 4(a)] and reactive power control as in UPQC-Q [see Fig. 4(b)]. Fig. 4(c) and (d) shows the compensationcapability of UPQC-P and UPQC-Q to compensate a swell on the system.
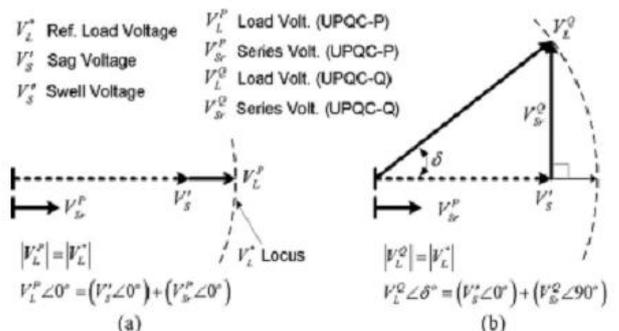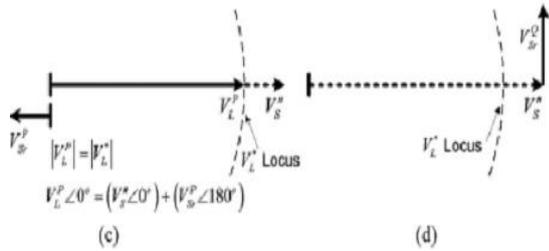
Fig. 4 Voltage sag and swell compensation using UPQC-P and UPQC-Q: phasor representation. (a) Voltage Sag (UPQC-P). (b) Voltage Sag (UPQC-Q). (c) Voltage Swell (UPQC-P). (d) Voltage Swell (UPQC-Q).

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.

PAC Approach under Voltage SAG Condition

Let us represent a vector $\overrightarrow{V_{Sr1}}$ responsible to compensate the load reactive power utilizing PAC concept and vector $\overrightarrow{V_{Sr2}}$ responsible to compensate the sag on the system using active power control approach.
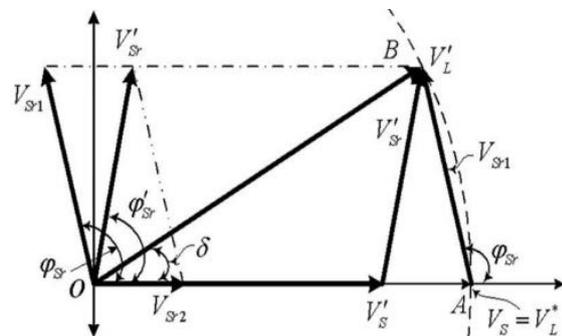
Fig.5 Phasor representation of proposed UPQC-S approach under voltage sag condition

Thus, for simultaneous compensation, as noticed from Fig.5, the series inverter should now supply a component which would be the vector sum of $\overrightarrow{V_{Sr1}}$ and $\overrightarrow{V_{Sr2}}$. This resultant series inverter voltage $\overrightarrow{V'_{sr}}$ will maintain the load voltage magnitude at a desired level such that the drop in source voltage will not appear across the load terminal.

B. Series Inverter Parameter Estimation under Voltage Sag

Fig. 6 shows the detailed phasor diagram to determine the magnitude and phase of series injection voltage.
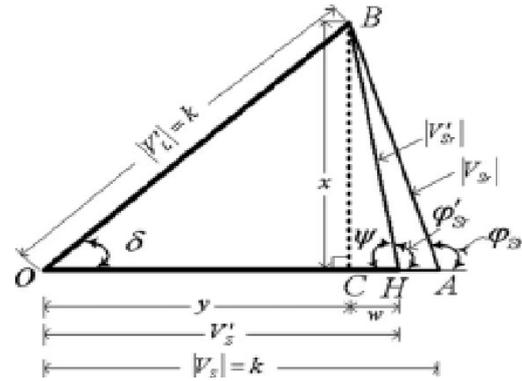

Fig. 6 phasor diagram to estimate the series inverter parameters for the proposed UPQC-S approach under voltage sag condition.

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

C. Shunt Inverter Parameter Estimation under Voltage Sag

The phasor diagram based on different currents is represented in Fig. 7.The current ISh represents the required current if the shunt inverter is used alone to compensate the total load reactive power demand.
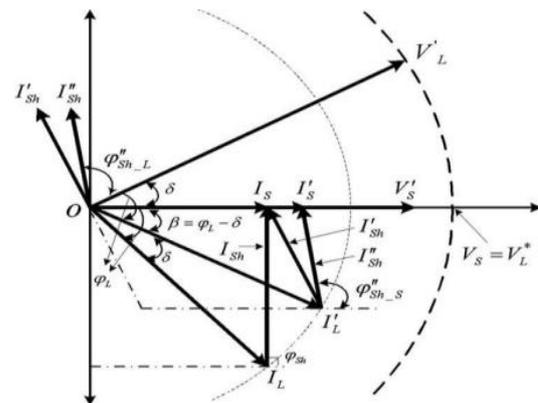

Fig. 7. Current-based phasor representation of the proposed UPQC-S approach under voltage sag condition.

**PAC Approach under Voltage SWELL Condition**

The phasor representation for PAC of UPQC-S during a voltage swell on the system is shown in Fig. 8.

Fig 8. Phasor representation of the proposed UPQC-S approach under voltage Swell condition.

IV. SIMULATION RESULTS

Figure 9 gives the Simulink diagram of proposed method.

Fig. 10 Simulation results: performance of the proposed UPQCS approach under voltage sags and swells conditions

(a) Supply voltage

(b) Load voltage

(c) Self-supporting dc bus voltage

(d) Enlarged power angle δ relation between supply and load voltages during steady-state condition.

(e) Supply current.

Fig. 11. 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.
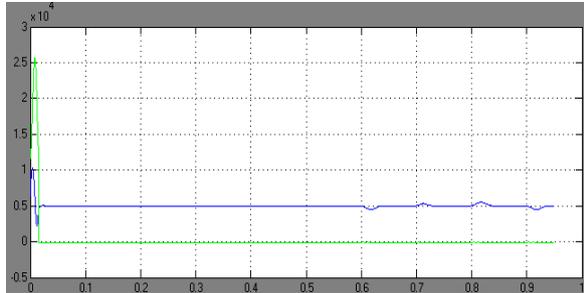
(a) Source P and Q
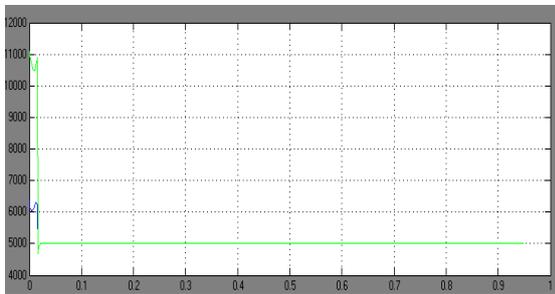
(b) Series inverter P and Q.
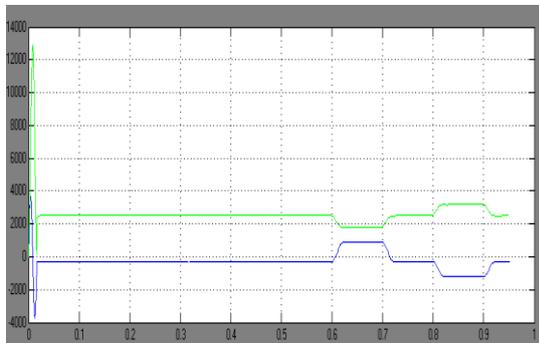
(c) Shunt inverter P and Q.

V. CONCLUSIONS

The objectives laid down have been successfully realized through software implementation in MATLAB/SIMULINK. PAC concept suggests that with proper control of series inverter voltage the series inverter successfully supports part of the load reactive power demand, and thus reduces the required VA rating of the shunt inverter.The reactive power flow control utilizing shunt and series inverters is also done in a unified power flow controller (UPFC).

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