

## APPLICATION OF UTILIZING SERIES INVERTER BY SIMULTANEOUS VOLTAGE SAG/SWELL AND LOAD REACTIVE POWER COMPENSATION

Haritha inavolu<sup>1</sup>, Venkateswara Reddy <sup>2</sup>,Swathi Chenna<sup>3</sup>, Durga Bhavani<sup>4</sup>, Usha Rani<sup>5</sup>.

<sup>1</sup>Assistant professor, EEE, VIKAS College of Engineering, Andhra Pradesh, India,

<sup>2</sup>Associative professor, EEE, VIKAS College of Engineering, Andhra Pradesh, India,

<sup>3</sup>Student, EEE, VIKAS College of Engineering, Andhra Pradesh, India,

<sup>4</sup>Student, EEE, VIKAS College of Engineering, Andhra Pradesh, India,

<sup>5</sup>Student, EEE, VIKAS College of Engineering, Andhra Pradesh, India

### Abstract

This project introduces a new concept of optimal utilization 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. The active power control approach is used to compensate voltage sag/swell and is integrated with theory of power angle control (PAC) of UPQC to co ordinate 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 powers). A detailed mathematical analysis, to extend the PAC approach for UPQC-S, is presented in this project. MATLAB/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:** Active power filter (APF), power angle control (PAC), power quality, reactive power compensation, unified power quality conditioner (UPQC), voltage sag and swell compensation

\*\*\*

### I. INTRODUCTION

The modern power distribution system is becoming highly vulnerable to the different power quality problems. The extensive use of nonlinear loads is further contributing to increased current and voltage harmonics issues.

Furthermore, the penetration level of mall/large-scale renewable energy systems based on wind energy, solar energy, fuel cell, etc., installed at distribution as well as transmission levels is increasing significantly. This integration of renewable energy sources in a power system is further imposing new challenges to the electrical power industry to accommodate these newly emerging distributed generation systems. To maintain the controlled power quality regulations, some kind of compensation at all the power levels is becoming a common practice. 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.

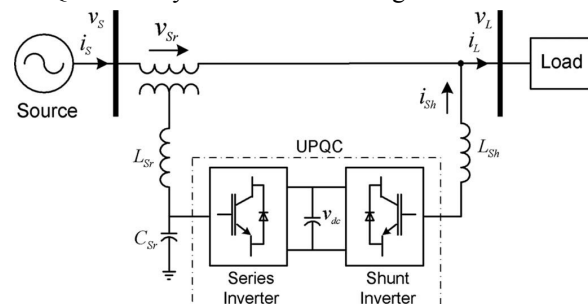


Fig. 1. Unified power quality conditioner (UPQC) system configuration.

It basically consists of two voltage source inverters connected back to back using a common dc bus capacitor. This paper deals with a novel concept of optimal utilization of a UPQC. The voltage sag/swell on the system is one of the most important power quality problems. The voltage sag/swell can be

effectively compensated using a dynamic voltage restorer, series active filter, UPQC, etc. Among the available power quality enhancement devices, the UPQC has better sag/swell compensation capability. Three significant control approaches for UPQC can be found to control the sag on the system active power control approach in which an in-phase voltage is injected through series inverter, popularly known as UPQC-P reactive power control approach in which a quadrature voltage is injected known as UPQC-Q and a minimum VA loading approach in which a series voltage is injected at a certain angle, in this paper called as UPQC-VAmin. Among the aforementioned three approaches, the quadrature voltage injection requires a maximum series injection voltage, whereas the in-phase voltage injection requires the minimum voltage injection magnitude. 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. The reported paper on UPQC-VAmin is concentrated on the optimal VA load of the series inverter of UPQC especially during voltage sag condition. Since an out of phase component is required to be injected for voltage swell compensation, the suggested VA loading in UPQC-VAmin determined on basis of voltage sag, may not be at optimal value. A detailed investigation on VA loading in UPQC-VAmin considering both voltage sag and swell scenarios is essential. In the paper, the authors have proposed a concept of power angle control (PAC) of UPQC. The 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. Most importantly, this coordinated reactive power sharing feature is achieved during normal steady-state condition without affecting the resultant load voltage magnitude. The optimal angle of series voltage injection in UPQC-VAmin is computed using lookup table or particle swarm optimization technique. These iterative methods mostly rely on the online load power factor angle estimation, and thus may result into tedious and slower estimation of optimal angle. On the other hand, the PAC of PQC concept determines the series injection angle by estimating the power angle  $\delta$ . The angle  $\delta$  is computed in adaptive way by computing the instantaneous load active/reactive power and thus, ensures fast and accurate estimation. Similar to PAC of UPQC, the reactive power flow control utilizing shunt and series

inverters is also done in a unified power flow controller (UPFC). A UPFC is utilized in a power transmission system whereas a UPQC is employed in a power distribution system to perform the shunt and series compensation simultaneously. The power transmission systems are generally operated in balanced and distortion-free environment, contrary to power distribution systems that may contain dc component, distortion, and unbalance. The primary objective of a UPFC is to control the flow of power at fundamental frequency. Also, while performing this power flow control in UPFC the transmission network voltage may not be maintained at the rated value. However, in PAC of UPQC the load side voltage is strictly regulated at rated value while performing load

reactive power sharing by shunt and series inverters. In this paper, the concept of PAC of UPQC is further expanded for voltage sag and swell conditions. 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). The key contributions of this paper are outlined as follows.

- 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.

In this paper, a detailed mathematical formulation of PAC for UPQC-S is carried out. The feasibility and effectiveness of the proposed UPQC-S approach are validated by simulation as well as experimental results.

## 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. 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. The phasor representation of the PAC approach under a rated steady-state condition is shown in Fig. 2.

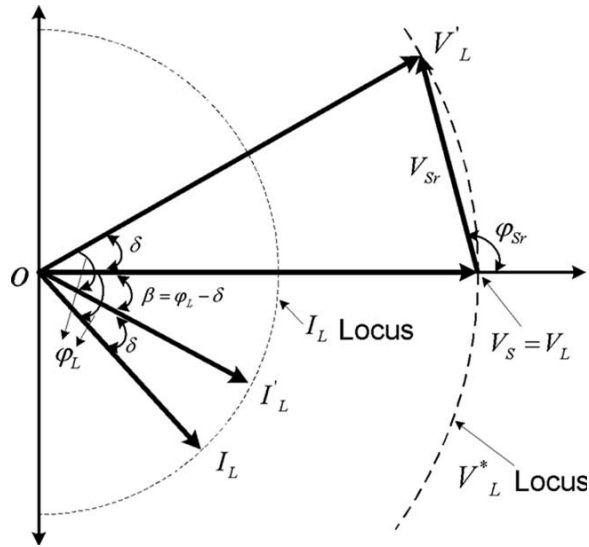


Fig. 2. Concept of PAC of UPQC.

According to this theory, a vector  $V_{Sr}$  with proper magnitude  $V_{Sr}$  and phase angle  $\phi_{Sr}$  when injected through series inverter gives a power angle  $\delta$  boost between the source  $V_S$  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  $\beta$ . 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.

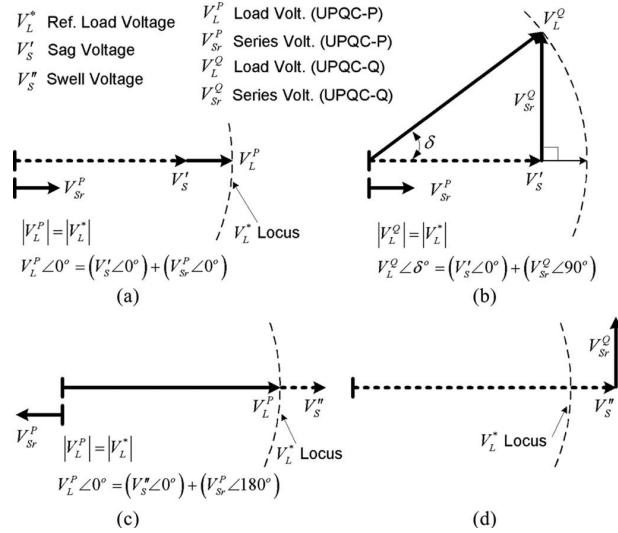


Fig. 3. Voltage sag and swell compensation using UPQC-P and UPQC-Q: phasor representation. (a) Voltage Sag (UPQC-P). (b) Voltage Sag (UPQC-Q). (c) Voltage Swell (UPQC-P). (d) Voltage Swell (UPQC-Q).

### III. VOLTAGE SAG/SWELL COMPENSATION UTILIZING UPQC-P AND UPQC-Q

The voltage sag on a system can be compensated through active power control and reactive power control, methods. Fig. 3 shows the phasor representations for voltage sag compensation using active power control as in UPQC-P [see Fig. 3(a)] and reactive power control as in UPQC-Q [see Fig. 3(b)]. Fig. 3(c) and (d) shows the compensation capability of UPQC-P and UPQC-Q to compensate a swell on the system.

For a voltage swell compensation using UPQC-Q [see Fig. 3(d)], the quadrature component injected by series inverter does not intersect with the rated voltage locus. Thus, the UPQC-Q approach is limited to compensate the sag on the system. However, the UPQC-P approach can effectively compensate both voltage sag and swell on the system. Furthermore, to compensate an equal percentage of sag, the UPQC-Q requires larger magnitude of series injection voltage than the UPQC-P ( $V_{Sr}^Q > V_{Sr}^P$ ). Interestingly, UPQC-Q 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 UPQC-Q cannot be controlled to vary the load reactive power support. Additionally, the phase shift in UPQC-Q is valid only during the voltage sag condition. Therefore, in this paper, PAC concept is integrated with active power control approach to achieve

simultaneous voltage sag/swell compensation and the load reactive power support utilizing the series inverter of UPQC. This new approach in which the series inverter of UPQC performs dual functionality is named as UPQC-S. The significant advantages of UPQC-S over other approaches are given as follows.

1) The series inverter of UPQC-S can support both active power (for voltage sag/swell compensation) and reactive power (for load reactive power compensation) simultaneously and hence the name UPQC-S (S for complex power).

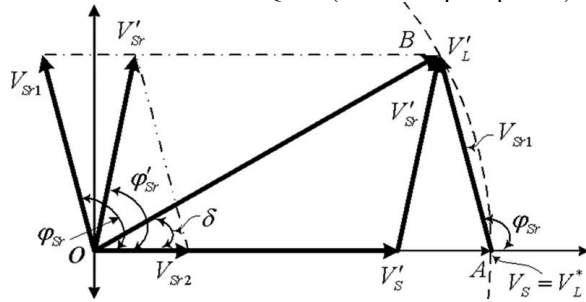


Fig. 3. Phasor representation of the proposed UPQC-S approach under voltage sag condition.

2) The available VA loading of UPQC is utilized to its maximum capacity and thus, compared to general UPQC operation for equal amount of sag compensation, the required rating of shunt inverter in UPQC-S will be smaller.

**IV. PAC APPROACH UNDER VOLTAGE SAG CONDITION**

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  $\delta$  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  $\delta$  between both the voltages. However, if the load on the system changes during the voltage sag condition, the PAC approach will give a different  $\delta$  angle. The increase or decrease in new  $\delta$  angle would depend on the increase or decrease in load reactive power, respectively.

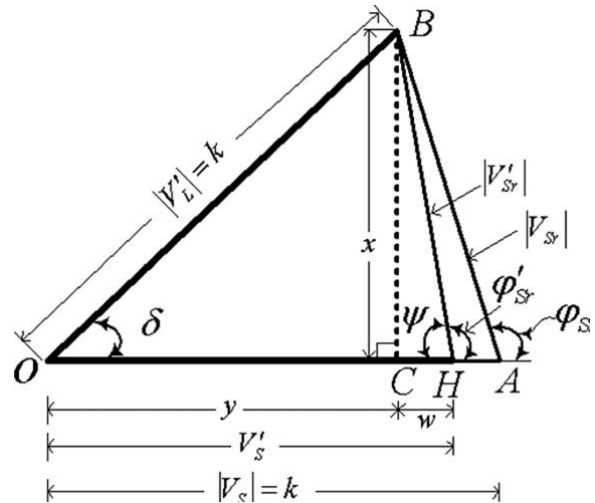


Fig. 4. Detailed phasor diagram to estimate the series inverter parameters for the proposed UPQC-S approach under voltage sag condition.

**V. 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. 6. Let us represent a vector  $V_{Sr3}$  responsible to compensate the swell on the system using active power control approach. For simultaneous compensation, the series inverter should supply the  $V_{Sr1}$  component to support the load reactive power and  $V_{Sr3}$  to compensate the swell on the system. The resultant series injected voltage  $V_{Sr}$  would maintain the load voltage magnitude at a desired level while supporting the load reactive power.

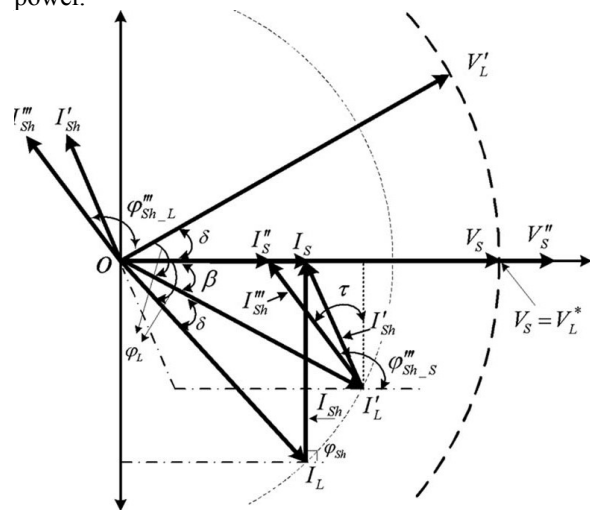


Fig. 5. Current-based phasor representation of the proposed UPQC-S approach under voltage swell condition.

## VI. ACTIVE-REACTIVE POWER FLOW THROUGH UPQC-S

The per-phase active and reactive powers flow through the UPQC-S during the voltage sag/swell is determined in this section. As the performance equations for series and shunt inverters are identical for both sag and swell conditions, only sag condition is considered to determine the equations for active and reactive power.

### 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.

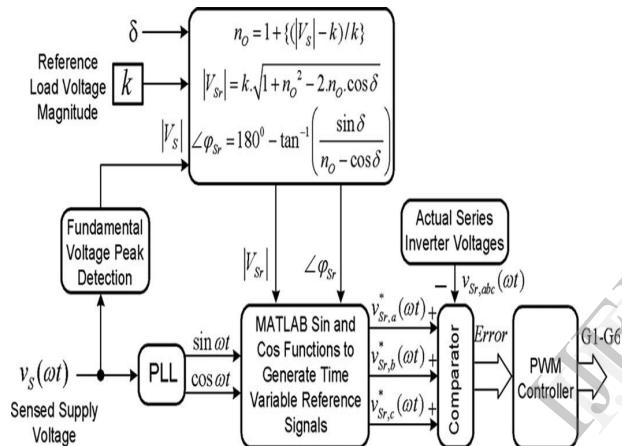


Fig.6. Reference voltage signal generation for the series inverter of the proposed UPQC-S approach.

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-S VA loading.

## VII. 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. 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  $\delta$  of  $21^\circ$  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 the concept of PAC. In other words, the shunt inverter rating is reduced by 25% of the total load kilovoltampere rating. At time  $t_1 = 0.6$  s, a sag of 20% is introduced on the 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 20% is imposed on the system for a duration of  $t_2 = 0.8-0.9$  s. The active and reactive power flows through the source, load, and UPQC are given in Fig.7. The distinct features of the proposed UPQC-S approach are outlined as follows. From Fig. 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 to maintain the appropriate active power balance in the network, the source current increases during the voltage sag and reduces during swell condition. As illustrated by enlarged results, the power angle  $\delta$  between the source and load voltages during the steady state, voltage sag, and voltage swell is maintained at  $21^\circ$ . The UPQC-S controller maintains a self-supporting dc link voltage between two inverters.

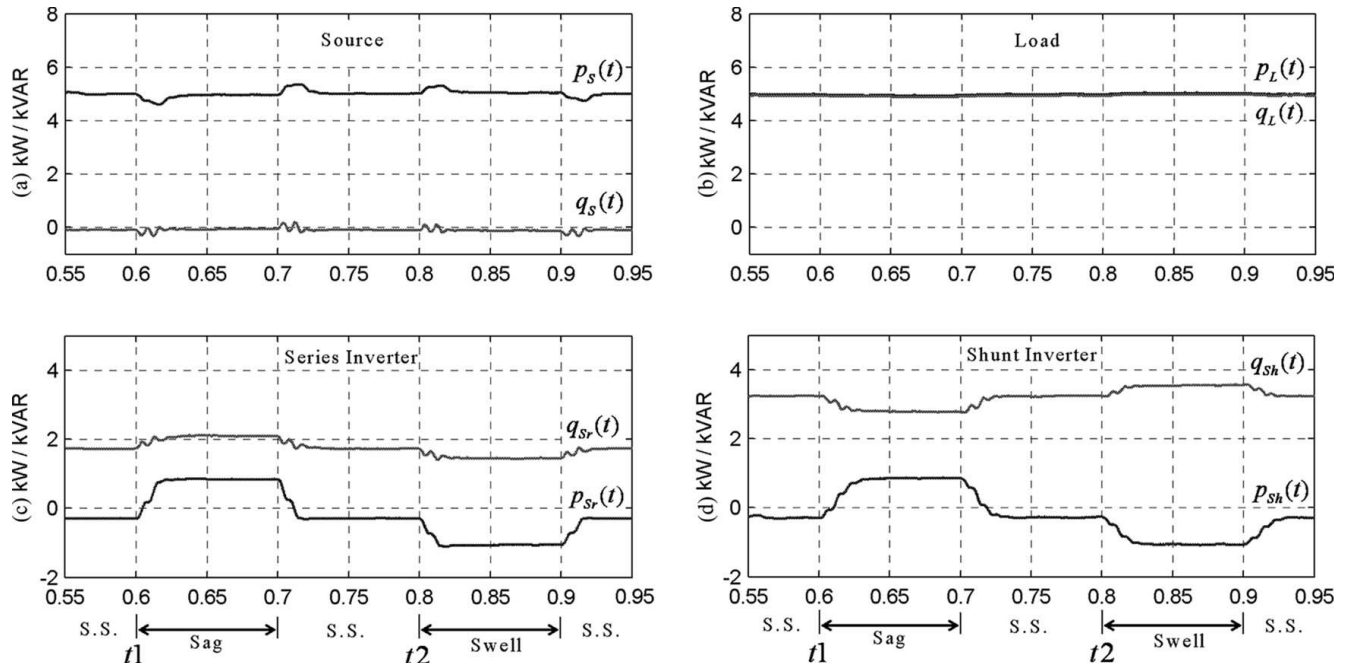


Fig. 12. Simulation results: active and reactive power flow through source, load, shunt, and series inverter utilizing proposed UPQC-S approach under voltage sag and swell conditions. (a) Source P and Q. (b) Load P and Q. (c) Series inverter P and Q. (d) Shunt inverter P and Q.

**TABLE I**  
LOSSES ASSOCIATED WITH UPQC UNDER  
DIFFERENT SCENARIOS

	Condition	$I_{Ss}$ (rms)	$I_{Sr}$ (rms)	$V_{Sr}$ (rms)	$\frac{P_{loss}}{P_{load}}$
Steady-State	(i) Without PAC approach and Series transformer SC	20.20 A	-	-	0.74 %
	(ii) Without PAC and Series inverter in operation	20.20 A	20.80 A	4.00 V	1.70 %
	(iii) With PAC approach	13.18 A	19.95 A	92.3 V	1.20 %
Voltage Sag	(i) Without PAC approach	20.90 A	26.05 A	48.4 V	2.60 %
	(ii) With PAC approach	11.90 A	25.05 A	89.4 V	1.82 %
Voltage Swell	(i) Without PAC approach	20.60 A	17.45 A	48.5 V	1.58 %
	(ii) With PAC approach	14.94 A	16.62 A	110.5 V	1.39 %

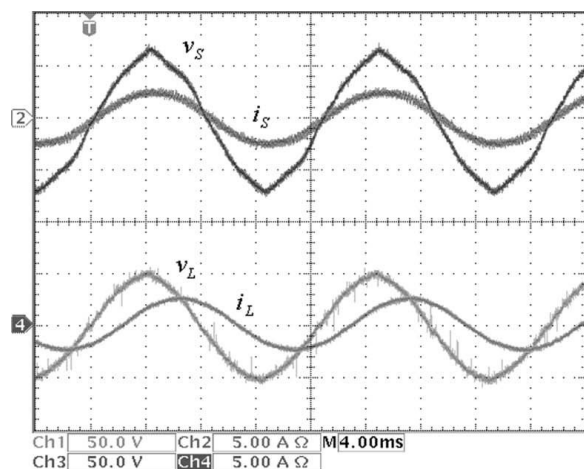
Table I gives the power losses associated with UPQC with and without PAC approach under different scenarios. The power loss is computed as the ratio of losses associated with UPQC to the total load power. The rms values of current flowing through shunt and series inverters and series injection voltage are also given in Table I. Initially, it is considered that the shunt inverter alone supports the load reactive power and the series inverter is assumed to be in OFF condition. The series injection transformer is also short circuited. This operating condition gives the losses in the shunt part of UPQC, which are found as 0.74% of the rated load power. In the second condition, the series inverter is turned on as well. The percent power losses, when both the inverters of UPQC are in operation, are noticed as 1.7%. Under this condition when UPQC is controlled as UPQC-S to support the load reactive power using both shunt and series inverters, controlled by the PAC approach, losses are observed as 1.2%. The power loss in the UPQC system with PAC approach thus is lower than the normal UPQC control. This is an interesting outcome of the PAC approach even when the series inverter

deals with both active and reactive powers due to  $\delta$  shift between source and load voltages. One may expect to increase the power loss with the UPQC-S system. The reduction in the power loss is mainly due to the reduction in the shunt inverter rms current from 20.20 A (without PAC approach) to 13.18 A (with PAC approach). Second, the current through the series inverter (which is almost equal to the source current) remains unchanged. Similarly from the Table I, the power losses utilizing the PAC approach, during voltage sag and swell conditions, are observed lower than those without PAC approach. This study thus suggests that the PAC approach may also help to reduce the power loss associated with UPQC system in addition to the previously discussed advantages.

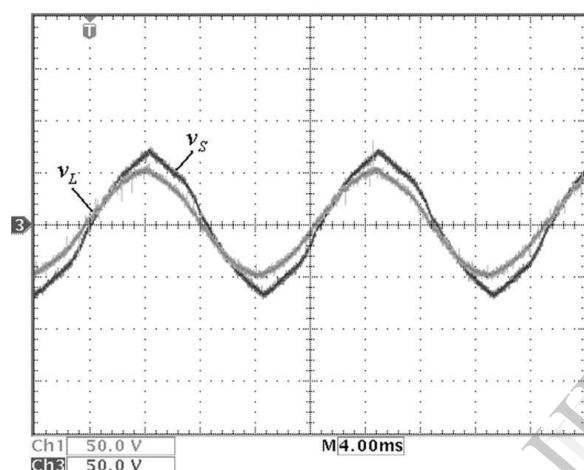
## VIII. CONCLUSION

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 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:

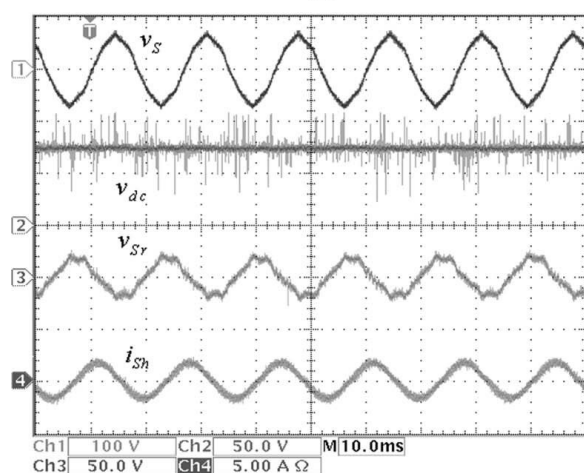
- 1) The multifunction ability of series inverter to compensate voltage variation (sag, swell, etc.) while supporting load reactive power
- 2) Better utilization of series inverter rating of UPQC; and
- 3) Reduction in the shunt inverter rating due to the reactive power sharing by both the inverters.



(a)



(b)



(c)

Fig. 16. Experimental results: performance of proposed UPQC-S approach under voltage swell condition (voltage swell = 22%,  $\delta = 10^\circ$ ). (a) Source and load  $v-i$  profiles. (b) Power angle  $\delta$  shift between resultant load and source voltages. (c) UPQC-S injected  $v-i$  and self-supporting dc bus profiles.

## ACKNOWLEDGEMENT

The satisfaction that accompanies the successful completion of this task would be put incomplete without the mention of the people who made it possible, whose constant guidance and encouragement crown all the efforts with success.

We avail this opportunity to express our deep sense of gratitude and hearty thanks to **N.Narsi Reddy**, Chairman & **N.Satya Narayana Reddy**, Vice president and correspondent of **VIKAS COLLEGE OF ENGINEERING & TECHNOLOGY**, Nunna for providing congenial atmosphere and encouragement.

We show gratitude to our honorable Principal **Dr.B.Ramana**, for having provided all the facilities and support.

We would like to thank **Mr. M. Venkateswara Reddy, M.E, (Ph.D)**, Associative Professor & Head of the department of Electrical and Electronics Engineering for his expert guidance and encouragement at various levels in my seminar.

We would like to express our heartfelt gratitude to our guide Ms. Inavolu Haritha (M.Tech), Assistant Professor, Department of Electrical and Electronics Engineering, Vikas College of Engineering and Technology. She has given me tremendous support in both technical and moral front. Without her support and encouragement to complete this report.

We express our deep sense of gratitude and thanks to the **Teaching and Non-Teaching Staff** at our college who stood with us during the seminar and helped us to make it a successful venture.

## REFERENCES

- [1] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, *Electrical Power Systems Quality*. New York: McGraw-Hill, 1996, p. 265.
- [2] C. Sankaran, *Power Quality*. Boca Raton, FL: CRC Press, 2002, p. 202.
- [3] R. A. Walling, R. Saint, R. C. Dugan, J. Burke, and L. A. Kojovic, "Summary of distributed resources impact on power delivery systems," *IEEE Trans. Power Del.*, vol. 23, no. 3, pp. 1636–1644, Jul. 2008.
- [4] L. Gyugyi, "Unified power-flow control concept for flexible AC transmission systems," *IEEE - C Gen. Trans. Distr.*, vol. 139, no. 4, pp. 323–331, Jul. 1992.



- [5] N. G. Hingorani and L. Gyugyi, *Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*. New York: IEEE Press, 2000, p. 432.
- [6] V. K. Sood, *HVDC and FACTS Controllers – Applications of Static Converters in Power Systems*. Boston, MA: Kluwer, 2004, p. 295.
- [7] A. Ghosh and G. Ledwich, *Power Quality Enhancement Using Custom Power Devices*. Boston, MA: Kluwer, 2002, p. 460.
- [8] B. Singh, K. Al-Haddad, and A. Chandra, “A review of active power filters for power quality improvement,” *IEEE Trans. Ind. Electron.*, vol. 45, no. 5, pp. 960–971, Oct. 1999.
- [9] M. El-Habrouk, M. K. Darwish, and P. Mehta, “Active power filters: A review,” *IEE Electr. Power Appl.*, vol. 147, no. 5, pp. 403–413, Sep. 2000.
- [10] Doncker, C. Meyer, R. W. De, W. L. Yun, and F. Blaabjerg, “Optimized control strategy for a medium-voltage DVR—Theoretical investigations and experimental results,” *IEEE Trans. Power Electron.*, vol. 23, no. 6, pp. 2746–2754, Nov. 2008.
- [11] C. N. Ho and H. S. Chung, “Implementation and performance evaluation of a fast dynamic control scheme for capacitor-supported interline DVR,” *IEEE Trans. Power Electron.*, vol. 25, no. 8, pp. 1975–1988, Aug. 2010.
- [12] Y. Chen, C. Lin, J. Chen, and P. Cheng, “An inrush mitigation technique of load transformers for the series voltage sag compensator,” *IEEE Trans. Power Electron.*, vol. 25, no. 8, pp. 2211–2221, Aug. 2010.
- [13] S. Subramanian and M. K. Mishra, “Interphase AC–AC topology for voltage sag supporter,” *IEEE Trans. Power Electron.*, vol. 25, no. 2, pp. 514–518, Feb. 2010.
- [14] H. Fujita and H. Akagi *IEEE Trans. Power Electron.*, vol. 13, no. 2, pp. 315–322, Mar. 1998.
- [15] V. Khadkikar and A. Chandra, “A new control philosophy for a unified power quality conditioner (UPQC) to coordinate load-reactive power demand between shunt and series inverters,” *IEEE Trans. Power Del.*, vol. 23, no. 4, pp. 2522–2534, Oct. 2008.
- [16] M. Vilathgamuwa, Z. H. Zhang, and S. S. Choi, “Modeling, analysis and control of unified power quality conditioner,” in *Proc. IEEE Harmon Quality Power*, Oct. 14–18, 1998, pp. 1035–1040.
- [17] M. Gon, H. Liu, H. Gu, and D. Xu, “Active voltage regulator based on novel synchronization method for unbalance and fluctuation compensation,” in *Proc. IEEE Ind. Electron. Soc (IECON)*, Nov. 5–8, 2002, pp. 1374–1379.
- [18] M. S. Koor and M. Machmoum, “Simplified analogical control of a unified power quality conditioner,” in *Proc. IEEE Power Electron. Spec. Conf. (PESC)*, Jun., 2005, pp. 2565–2570.
- [19] V. Khadkikar, A. Chandra, A. O. Barry, and T. D. Nguyen, “Analysis of power flow in UPQC during voltage sag and swell conditions for selection of device ratings,” in *Proc. IEEE Electr. Computer Eng. (CCECE)*, May 2006, pp. 867–872.
- [20] B. Han, B. Bae, H. Kim, and S. Baek, “Combined operation of unified power-quality conditioner with distributed generation,” *IEEE Trans. Power Del.*, vol. 21, no. 1, pp. 330–338, Jan. 2006.
- [21] H. R. Mohammadi, A. Y. Varjani, and H. Mokhtari, “Multiconverter unified power-quality conditioning system:MC-UPQC,” *IEEE Trans. Power Del.*, vol. 24, no. 3, pp. 1679–1686, Jul. 2009.
- [22] I. Axente, J. N. Ganesh, M. Basu, M. F. Conlon, and K. Gaughan, “A 12-kVA DSP-controlled laboratory prototype UPQC capable of mitigating unbalance in source voltage and load current,” *IEEE Trans. Power Electron.*, vol. 25, no. 6, pp. 1471–1479, Jun. 2010.
- [23] M. Basu, S. P. Das, and G. K. Dubey, “Investigation on the performance of UPQC-Q for voltage sag mitigation and power quality improvement at a critical load point,” *IET Generat., Transmiss. Distrib.*, vol. 2, no. 3, pp. 414–423, May 2008.
- [24] V. Khadkikar and A. Chandra, “A novel control approach for unified power quality conditioner Q without active power injection for voltage sag compensation,” in *Proc. IEEE Int. Conf. Ind. Technol. (ICIT)*, Dec. 15–17, 2006, pp. 779–784.
- [25] M. Yun, W. Lee, I. Suh, and D. Hyun, “A new control scheme of unified power quality compensator-Q with minimum power injection,” in *Proc. IEEE Ind. Electron. Soc. (IECON)*, Nov. 2–6, 2004, pp. 51–56.
- [26] Y. Y. Kolhatkar and S. P. Das, “Experimental investigation of a singlephase UPQC with minimum VA loading,” *IEEE Trans. Power Del.*, vol. 22, no. 1, pp. 373–380, Jan. 2007.
- [27] D. O. Kisck, V. Navrapescu, and M. Kisck, “Single-phase unified power quality conditioner with optimum voltage angle injection for minimum VA requirement,” in *Proc. IEEE Power Electron. Spec. Conf. (PESC)*, Jun. 17–21, 2007, pp. 574–579.
- [28] G. S. Kumar, P. H. Vardhana, B. K. Kumar, and M. K. Mishra, “Minimization of VA loading of unified power quality conditioner (UPQC),” in *Proc. IEEE Powereng*, Mar. 18–20, 2009, pp. 552–557



**Vinod Khadkikar** (S'06–M'09)

received the B.E. degree from the Government College of Engineering, Dr. B.A.M.U. University, Aurangabad, India, in 2000, the M.Tech. degree from the Indian Institute of Technology, New Delhi, India, in 2002, and the Ph.D. degree from the 'Ecole de Technologie Sup'erieure, Montr'eal, QC, Canada, in 2008, all in electrical engineering.

From December 2008 to March 2010, he was a Postdoctoral Fellow at the University of Western Ontario, London, ON, Canada. Since April 2010, he has been an Assistant Professor at Masdar Institute, Abu Dhabi, United Arab Emirates. From April 2010 to December 2010, he was a Visiting Faculty at the Massachusetts Institute of Technology, Cambridge, MA. His research interests include applications of power electronics in distribution systems and renewable energy resources, grid interconnection issues, power quality enhancement, and active power filters.



**Ambrish Chandra** (SM'99)

received the B.E. degree from the University of Roorkee (presently IIT), Roorkee, India, the M.Tech. degree from the Indian Institute of Technology, New Delhi, India, and the Ph.D. degree from the University of Calgary, Exshaw, AB, Canada, in 1977, 1980, and 1987, respectively. He was a Lecturer and later as a Reader at the University of Roorkee. Since 1994, he has been a Professor in the Department of Electrical Engineering, 'Ecole de Technologie Sup'erieure, Universit'e du Qu'ebec, Montr'eal, QC, Canada. His main research interests include power quality, active filters, static reactive power compensation, flexible ac transmission systems, power quality issues related with autonomous and grid connected renewable energy resources. Dr. Chandra is a Professional Engineer in the province of Qu'ebec, Canada

## BIOGRAPHIES

**Mr.M. Venkateswara Reddy M.E, (Ph.D)**, Associative Professor and Head of the Department of Electrical and Electronics Engineering in Vikas College of Engineering and Technology.

**Inavolu Haritha** is Assistant Professor of EEE in VIKAS College of Engineering and Technology Affiliated by JNTU Kakinada University. She received the B.Tech Electrical and Electronics Engineering from Paul Raj college of Engineering and Technology, and completed M.Tech in Mother Theresa Institute of Science and Technology. She was interested in Electrical Machines.

**CH.D.SWATHI** was born in 1992 in Vijayawada, Andhra Pradesh, India. I completed my intermediate in Narayana Jr College in 2009. I will be received my B.Tech degree in Electrical and Electronics Engineering from Vikas College of Engineering and Technology Affiliated by JNTU Kakinada University. I well knew the Power Electronics, and all other Electronics subjects.

**B.DURGA BHAVANI** was born in 1993 in Vijayawada, Andhra Pradesh, India. I will be received my B.Tech degree in Electrical and Electronics Engineering from Vikas College of Engineering and Technology Affiliated by JNTU Kakinada University. I well knew the Power Electronics, and all other Electronics subjects.

**P.USHA RANI** was born in 1993 in Vijayawada, Andhra Pradesh, India. I will be received my B.Tech degree in Electrical and Electronics Engineering from Vikas College of Engineering and Technology Affiliated by JNTU Kakinada University. I well knew the Power Electronics, and all other Electronics subjects.