VOLTAGE SAG/SWELL AND LOAD REACTIVE POWER COMPENSATION USING UPQC

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ABSTRACT

This paper explains the new method of optimal utilization of 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 coordinate the load reactive power between the two inverters.

Keywords: PAC, UPFC, UPQC

I.INTRODUCTION

The power quality problems are mainly seen in power distribution systems. The main source for increased current and voltage harmonics is large use of nonlinear loads. The use of renewable energy sources in power system is imposing new challenges to the power industries. To maintain power quality regulations at distribution levels, UPQC is the solution. The basic block diagram of UPQC is as shown in fig.1.

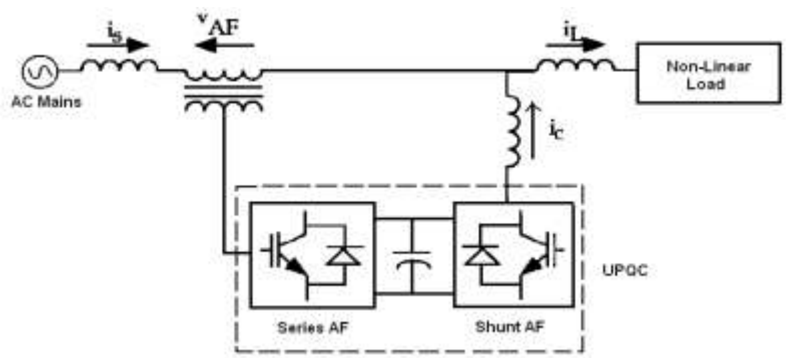


Fig.1 Unified Power Quality Conditioner

The block diagram consists of two voltage source inverter connected back to back using a common DC link capacitor. The main power quality problems on the system are voltage sag/swell. This problem can be compensated using a series active filter, dynamic voltage restorer, UPQC, etc. Among these the UPQC is having a better sag/swell compensation capability. The sag on the system can be controlled by three different approaches namely: 1) active power control approach; 2) reactive power control approach; and 3) a minimum VA loading approach. In this paper UPQC-VAmin approach is used. In a minimum VA loading approach, the series inverter voltage is injected at an optimal angle with respect to the source current. By using PAC concept, a part of load reactive power demand is also supported with proper control of series inverter voltage thereby reducing the required VA rating of shunt inverter. The reactive power flow control can also be done with UPFC. A UPFC is utilized in a power transmission system whereas a UPQC is used in power distribution system to perform the shunt and series compensation simultaneously. The modified approach of UPFC is UPQC; in this compensation of voltage sag/swell is done by sharing the load reactive power between two inverters.

II.PROPOSED PROJECT

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

2) The prime focus is to minimize the VA loading of UPQC during voltage sag condition by using the available VA loading to its maximum capacity.

2.1 Voltage SAG/SWELL compensation using UPQC-P and UPQC-Q

V_L^*-Ref. load voltage, V_L^P- load voltage(UPQC-P), V_L^Q –load voltage(UPQC-Q), V_{Sr}^P –Series voltage(UPQC-P), V_{Sr}^Q -Series voltage (UPQC-Q), $V_S{'}$-sag voltage, $V_S{''}$-swell voltage

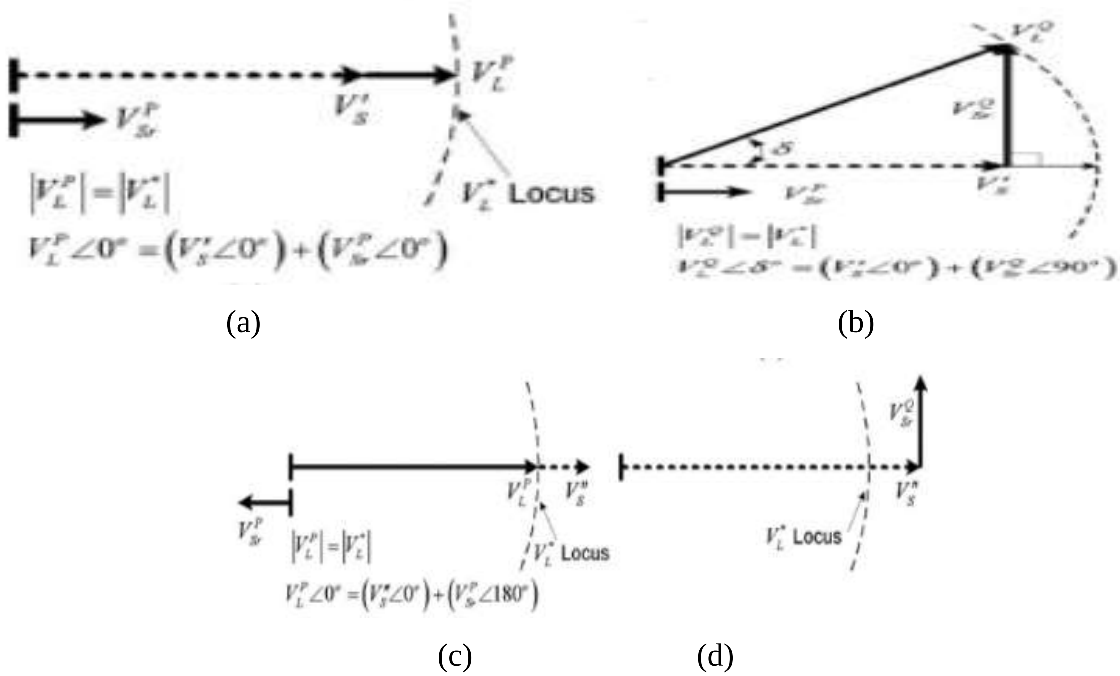


Fig.2. (a) Voltage Sag (UPQC-P). (b) Voltage Sag (UPQC-Q). (c) Voltage Swell (UPQC-P). (d) Voltage Swell (UPQC-Q).

Fig.2(a & b)shows the phasor representations for voltage sag compensation using active power control as in UPQC-P and reactive power control as in UPQC-Q.Fig.2 (c & d) shows the compensation capability of UPQC-P and UPQC-Q to compensate a swell on the system.

2.2 PAC Approach under Voltage SAG Condition

(a) Series Inverter Parameter Estimation under Voltage Sag

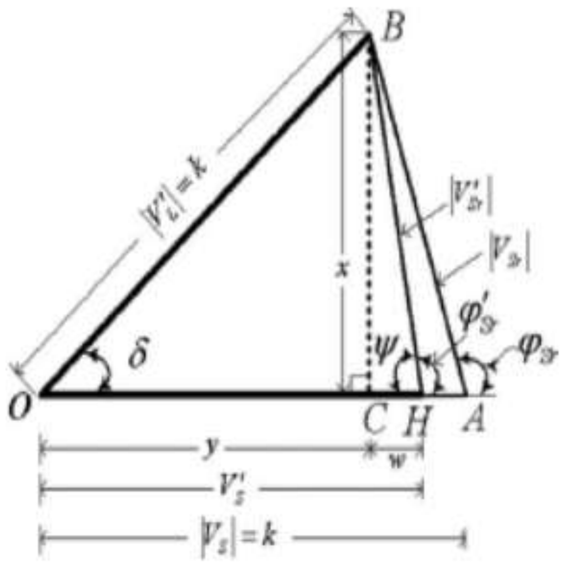


Fig.3 Phasor diagram to determine the series inverter parameters for the UPQC-Sunder voltage sag condition.

In this section, the required series inverter parameters to get simultaneous load reactive power and voltage sag compensations are computed. The fig.3 shows calculation of the magnitude and phase of series injection voltage.

The voltage fluctuation factor kf is given by,

$$k_f = \frac{V_S - V_L^*}{V_L^*} \quad (1)$$

Equation (1) represents sag condition under PAC

$$k_f = \frac{V_S' - V_L'}{V_L^*} = \frac{V_S' - k}{k} \quad (2)$$

Let us define

$$1 + k_f = n_o \quad (3)$$

To compute the magnitude of V_{Sr} from ΔCHB in Fig. 3

$$w = l(ch) = n_o k - y \quad (4)$$

$$|V_{Sr}'| = k\sqrt{(1 + n_o^2 - 2n_o \cos\delta)} \quad (5)$$

To compute the phase of

$\angle CHB = \angle \Psi = \tan^{-1}\frac{z}{w} = \tan^{-1}\left(\frac{\sin\delta}{n_o - \cos\delta}\right)$ (6)

$\angle \Psi'_{Sr} = 180^0 - \angle \Psi$(7)

Equation (5) & (7), give the required magnitude and phase of series inverter voltage of UPQC-S.

b) Shunt Inverter Parameter Estimation under Voltage Sag

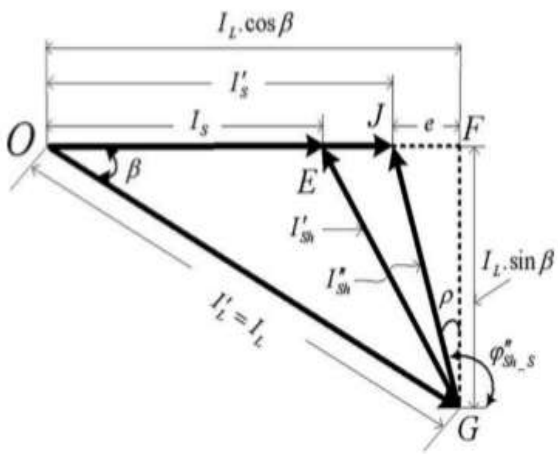


Fig.4. Phasor Diagram to Determine the Shunt Inverter Parameters

The above fig shows the phasor diagram to determine the shunt inverter injected current magnitude and its phase angle. The source delivers the extra current, to give the active power required during voltage sag condition.

During voltage sag

$I'_S = \frac{I_L}{1+k_f}\cos\Psi_L$(8)

$\frac{1}{1+k_f} = k_0$ (9)

Therefore,

$I'_s = k_o I_L \cos\Psi_l$(10)

$I''_{sh} = \sqrt{(I'_L \sin\beta)^2 + \left(I'_L(\cos\beta - k_o\cos\Psi_l)\right)^2}$(11)

$I''_{Sh} = I'_L\sqrt{1 + k_o^2\cos^2\Psi_L - 2k_o\cos\beta\cos\Psi_L}$(12)

$\rho = \tan^{-1}\left(\frac{\cos\beta - k_o\cos\Psi_L}{\sin\beta}\right)$(13)

$\angle\Psi''_{Sh\_S} = \angle\rho + 90^0$(14)

$\angle\Psi''_{Sh\_l} = (\angle\rho + 90^0) - \delta$(15)

Equation (12) & (15) give the required magnitude and phase angle of a shunt inverter.

c) Voltage SWELL Condition using PAC Approach

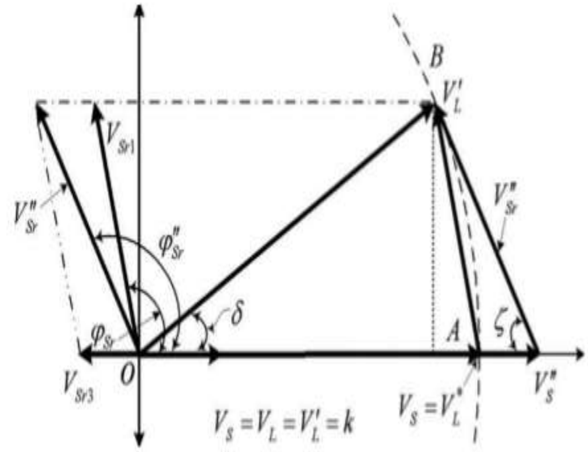


Fig.5. Phasor representation for PAC of UPQC-S during a voltage swells on the system.

For voltage swell compensation using active power control approach

$$\overrightarrow{V_{Sr3}} = \overrightarrow{V_L^*} - \overrightarrow{V_S^*} \quad (16)$$

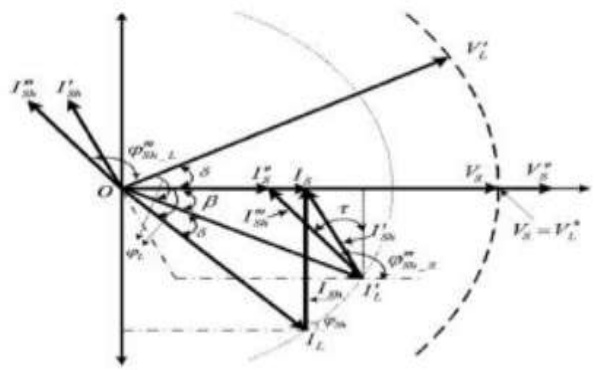


Fig.6. Phasor representation for different currents under PAC of UPQC-S under a voltage swells condition.

Under voltage swell condition.

$$V_{Sr3}\angle 180^0 = V_L^*\angle 0^0 - V_S^*\angle 180^0 \quad (17)$$

For simultaneous load reactive power and voltage swell compensations

$$\overrightarrow{V_{Sr}^*} = \overrightarrow{V_{Sr1}} + \overrightarrow{V_{Sr3}} \quad (18)$$

For series inverter

$$|V_{Sr}^*| = k\sqrt{1 + n_0^2 - 2n_o \cos\delta} \quad (19)$$

$$\angle CLB = \angle\xi = \tan^{-1}\left(\frac{\sin\delta}{n_o - \cos\delta}\right) \quad (20)$$

$$\angle\Psi_{sr}^* = 180^0 - \angle\xi \quad (21)$$

$I_{sh}^{''} = I_L^{'}\sqrt{1 + k_o^2 \cos^2 \Psi_L - 2k_o \cos\beta \cos\Psi_L}$ (22)

$\zeta = \tan^{-1}\left(\frac{\cos\beta - k_o \cos\Psi_L}{\sin\beta}\right)$ (23)

$\angle\Psi_{Sh\_L}^{''} = (\angle\zeta + 90^0) - \delta$ (24)

Equation (12) & (15) sag, (22) & (24) for voltage swell compensation utilizing the PAC of UPQC are similar.

d) Active–Reactive power flow through UPQC

(i) Series Inverter of UPQC-S

For active power

$P_{Sr}^{'} = V_{Sr}^{'} I_S^{'} \cos\Psi_{Sr}^{'}$ (25)

The increase or decrease in the source current magnitudes during the voltage sag or swell condition, is represented by-

$I_s^{'} = I_s^{''} = k_o I_L \cos\Psi_L$ (26)

Therefore,

$P_{sr,PAC} = P_{sr}^{'} = -k_o(n_o - \cos\delta)(P_L)$ (27)

For reactive power

$Q_{sr}^{'} = V_{sr}^{'} \sin\Psi_{sr}^{'}$ (28)

Therefore,

$Q_{sr,PAC} = Q_{Sr}^{'} = k_o(\sin\delta)(P_L)$ (29)

Equation (27) & (29) are used to determine the active and reactive power flow through series inverter of UPQC-S during voltage sag/swell.

(ii) Shunt Inverter of UPQC

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

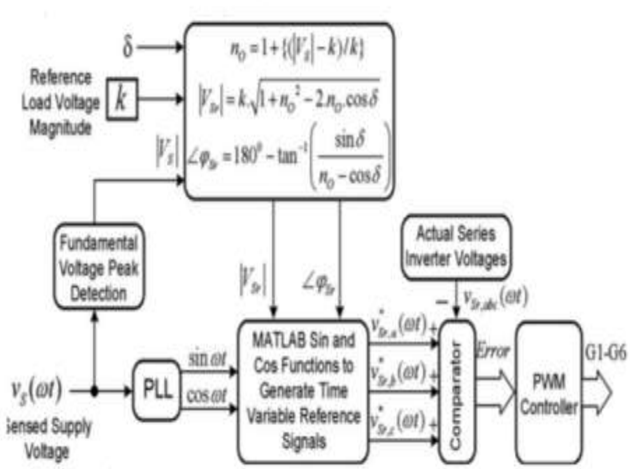


Fig.7. Reference voltage signal generation for the series inverter

For active power,

$P'_{sh} = V'_s I''_{sh} \cos \Psi''_{Sh_s}$ (30)

$P'_{sh} = n_o k I''_{Sh} (-\sin \rho)$ (31)

$P_{Sh,PAC} = -\frac{(kI_L)(\cos \beta - k_o \cos \Psi_L)}{k_o}$ (32)

For reactive power

$Q'_{sh} = V'_{sh} I''_{Sh} \sin \Psi''_{Sh\_s}$ (33)

$Q'_{sh} = n_o k I''_{sh} \cos \rho$ (34)

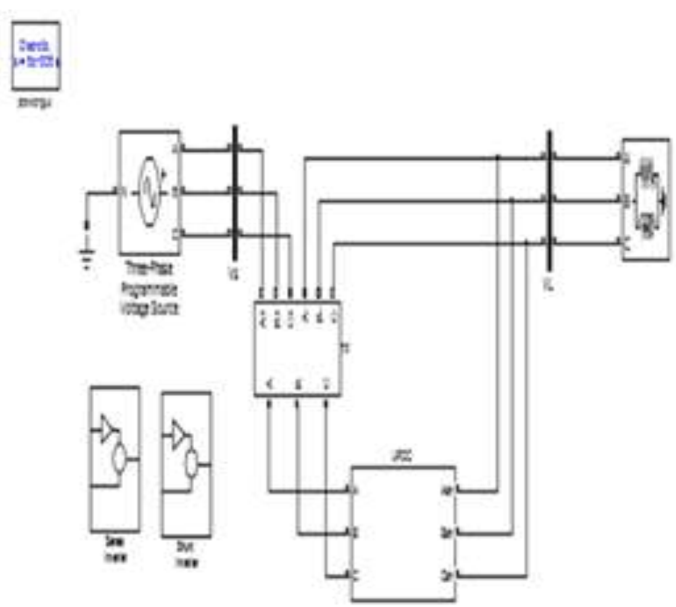
$Q_{Sh,PAC} = \frac{(kI_L)(\sin \beta)}{k_o}$ (35)

Equation (32) & (35) are used to calculate the active and reactive power flow through shunt inverter of UPQC-S during voltage sag/swell condition and also to determine the overall UPQC VA loading.

(Iii) UPQC Controller

The power angle δ is maintained at constant value under different operating conditions. Thus, the reactive power shared by the series inverter and by the shunt inverter changes as per the equations.

III.MATLAB CIRCUITS



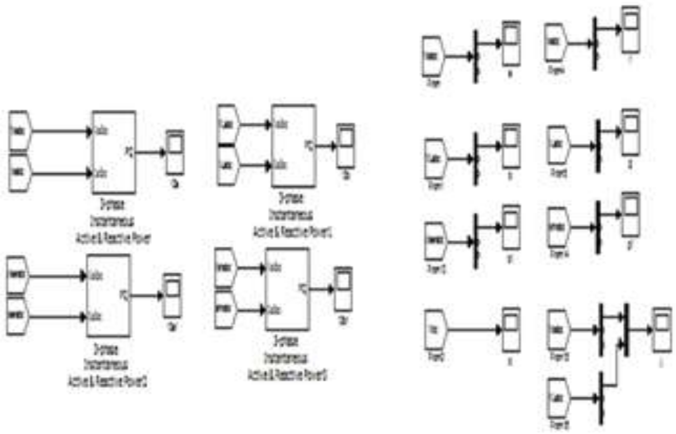


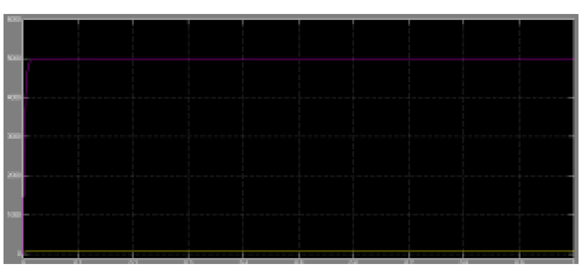
Fig.8. Simulink Diagram of Proposed Method

IV.RESULTS

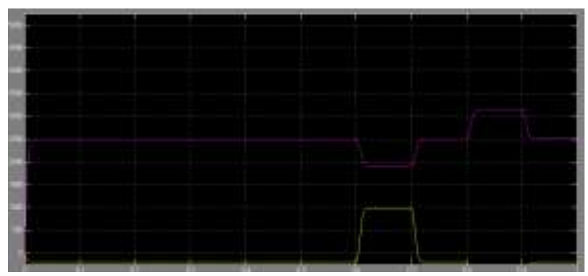
Following fig.9 shows the Performance of the proposed UPQC approach under voltage sags and swells conditions.

a) Source P & Q

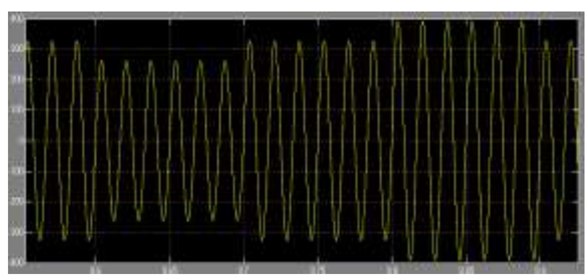
b) Series Inverter P and Q



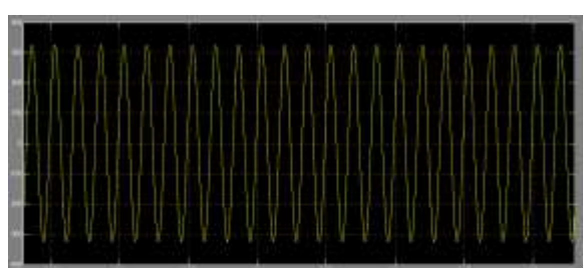
c) Load P and Q



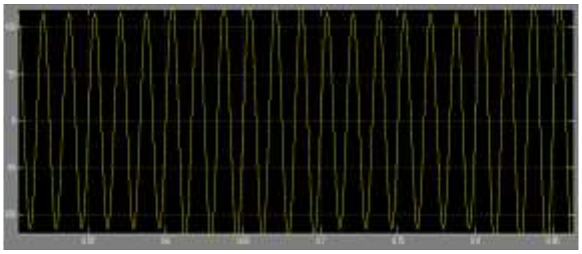
d) Shunt Inverter P and Q



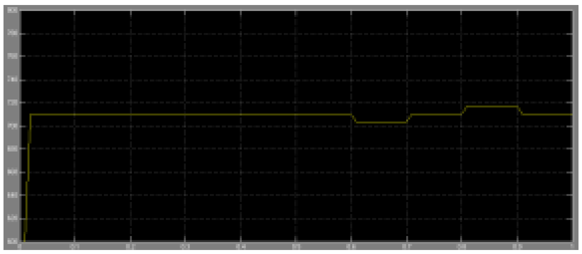
e) Supply Voltage



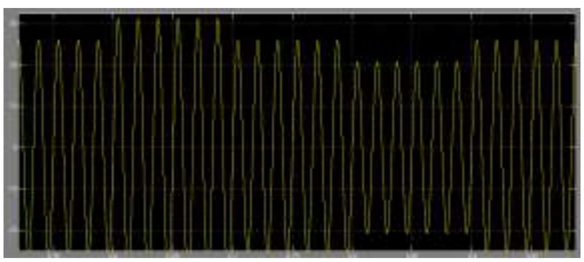
f) Load Voltage



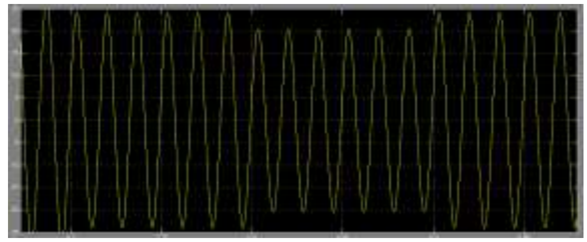
g) Series inverter injected voltage



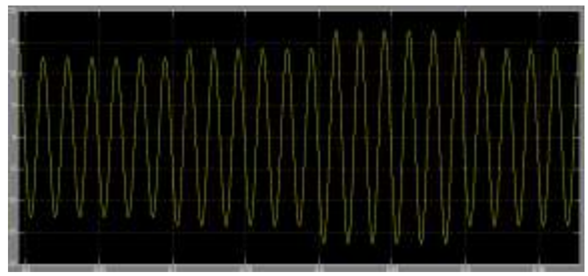
h) Self-supporting dc bus voltage



i) Supply current



j) Load Current



k) Shunt inverter injected current

REFERENCES

[1] Hirofumi Akagi, Trends in Active Power Line Conditioners, IEEE Tran. Power Electronics, vol. 9, no.3, May 1994, pp. 263-268.

[2] Janko Nastran, Rafael Cajhen, Matija Seliger, and Peter Jereb, Active Power Filter for Nonlinear AC Loads, IEEE Trans. Power Electronics, vol.9, no.1, Jan. 1994, pp. 92-96.

[3] E. Destobbeleer and L.Protin, On the Detection of Load Active Currents for Active Filter Control, IEEE Trans. Power Electronics, vol. 11, no.6, Nov. 1996, pp. 768-775.

[4] Mauricio Aredes, Jorgen Hafner, and Klemens Hermann, Three-Phase Four-Wire Shunt Active Filter Control Strategies, IEEE Trans. Power Electronics, vol.12, no.2, Mar. 1997, pp. 311-318.

[5] Hideaki Fujita and Hirofumi Akagi, the Unified Power Quality Conditioner: The Integration of Series- and Shunt-Active Filters, IEEE Tran. Power Electronics, vol. 13, no.2, Mar. 1998, pp.315-322.

[6] Fang Zheng Peng, George W. Ott Jr., and Donald J. Adams, Harmonic and Reactive Power Compensation Based on the Generalized Instantaneous Reactive Power Theory for Three-Phase Four-Wire Systems, IEEE Trans, Power Electronics, vol.13, no.6, Nov. 1998, pp. 1174-1181.

[7] Kishore Chatterjee, B.G. Fernandes, and Gopal K.Dubey, An Instantaneous Reactiv Volt Ampere Compensator and Harmonic Suppressor System, IEEE Trans. Power Electronics, vol. 14, no.2, Mar.1999, pp. 381-392.

[8] Po-Tai Cheng, Subhashish Bhattacharya, and Deepak D. Divan, Line Harmonics Reduction in High-Power Systems Using Square-Wave Inverters-Based Dominant Harmonic Active Filter, IEEE Trans. Power Electronics, vol. 14, no.2, Mar. 1999, pp. 265-272.

[9] Shyh-Jier Huang and Jinn-Chang Wu, A Control Algorithm for Three-Phase Three-Wired Active Power Filters Under Nonideal Main Voltages, IEEE Trans. Power Electronics, vol. 14, no. 4, Jul. 1999, pp. 753-760.

[10] Ambrish Chandra, Bhim Singh, B.N.Singh, and Kamal Al-Haddad, An Improved Control Algorithm of Shunt Active Filter for Voltage Regulation, Harmonic Elimination, Power-factor Correction, and Balancing of Nonlinear loads, IEEE Trans. Power Electronics, vol. 15, no.3, May 2000, pp. 495-507.

[11] Moleykutty George, Modeling and simulation of a current controlled three-phase shunt active power filter using MATLAB/PSB, AIUB Journal of Science and Engineering, vol. 3, no.1, Aug. 2004 issue, pp. 11-18.

[12] M. George, C.L. Seen, Modeling and control of zero-sequence current of parallel three-phase converters using Matlab/power system blockset, IEEE Power Systems Conf. and Exp. 2004, PSCE 2004, vol. 3, pp. 1440-1443.

[13] Hyosung Kim, Sang-Joon Lee, and Seung-Ki Sul, A calculation for the compensation voltages in dynamic voltage restorers by use of PQR power theory, 19th Annual IEEE Applied Power Electronics Conf. and Expo. 2004, APEC '04, vol. 1, pp. 573-579.

[14] J. G. Nielsen, M. Newman, H. Nielsen, and F. Blaabjerg, Control and testing of a dynamic voltage restorer (DVR) at medium voltage level, IEEE Trans. on Power Electronics, vol. 19, issue 3, May 2004, pp. 806-813.

[15] E. K. K. Sng, S. S. Choi, and D. M. Vilathgamuwa, Analysis of series compensation and DC-link voltage controls of a transformer less self-charging dynamic voltage restorer, IEEE Trans. Power Delivery, vol. 19, issue 3, Jul. 2004, pp. 1511-1518.

[16] M. J. Newman, D. G. Holmes, J. G. Nielsen and F. Blaabjerg, A dynamic voltage restorer (DVR) with selective harmonic compensation at medium voltage level, IEEE Trans. Ind. Application, vol. 41, issue 6, Nov.-Dec. 2005, pp. 1744-1753.