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Review of Novel Control Strategies for UPQC

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Abstract: Active filters have been known as the best tools for harmonic mitigation as well as reactive power compensation. They were developed since 1983, when one of the first prototypes based on instantaneous power theory was reported. Many configurations such as shunt, series, hybrid (a combination of shunt and series active filters) and unified power quality conditioner (UPQC, a combination of series and shunt active filters) have been introduced and improved. With the emergence of fast computing devices, control strategies for UPQC are continually changing aiming at near perfect compensation. Considerable attention is paid to the reference voltage/current estimation and control strategies. In this study, several techniques are discussed and compared in terms of performance and implementation.

Key words: Power quality, active power filter, harmonic compensation, UPQC, control strategy, voltage control, current control

INTRODUCTION

Over the past five decades, the increase of non-liner loads, such as diodes or thyristor rectifiers and cycloconverters draw non-sinusoidal currents into the power system, thus contributing to the degradation of power quality in utility or industrial power systems. Power electronics loads (nonlinear loads) inject harmonic currents into the ac system and increase overall reactive power demanded by the equivalent load. On the other hand, development in digital electronics communications and in process control has increased the number of sensitive loads that require ideal sinusoidal supply voltages for their proper operation (Sabin and Subdaram, 1996; Akagi, 1996; Man-Chung, 2000). Notably, voltage distortion or voltage harmonics in the power systems have been serious (Akagi, 1996) and the regulation of voltage imbalance and the compensation of harmonics become more and more important. Lots of power electronics circuits for power quality conditioning have been developed of all these topologies. Active Power Filter (APF), SVC and ASVC are very popular (Gyugyi, 1988; Juan *et al*., 1995). Active Power Filters are used in industrial and commercial sectors for over 2 decades. Different topologies and control strategies have been proposed and practiced in the past (Singh *et al*., 1999; Ei-Habrouk *et al*., 2000a, b; Grady *et al*., 1990). The common goal of all these strategies is to improve dynamic response of the controller in order to obtain better compensation. Due to advancement of microelectronics and Digital Signal Processing (DSP) systems, implementation of new control techniques are becoming feasible which were not possible in the past. Thus effectiveness of the control strategies has been enhanced considerably.

This study presents a review of novel control techniques for UPQC.

Considerable attention is paid to the reference voltage/current estimation and control strategies. Several techniques are discussed and compared in terms of performance and implementation.

COMPENSATION STRATEGY

The general configuration of UPQC is shown in Fig. 1. The UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance. With ideal compensation, the voltage at PCC is the fundamental positive sequence sinusoidal voltage of the power source side (Lee *et al*., 2004).

The currents of the source are sinusoidal and their phase angles are the same as the fundamental voltage in

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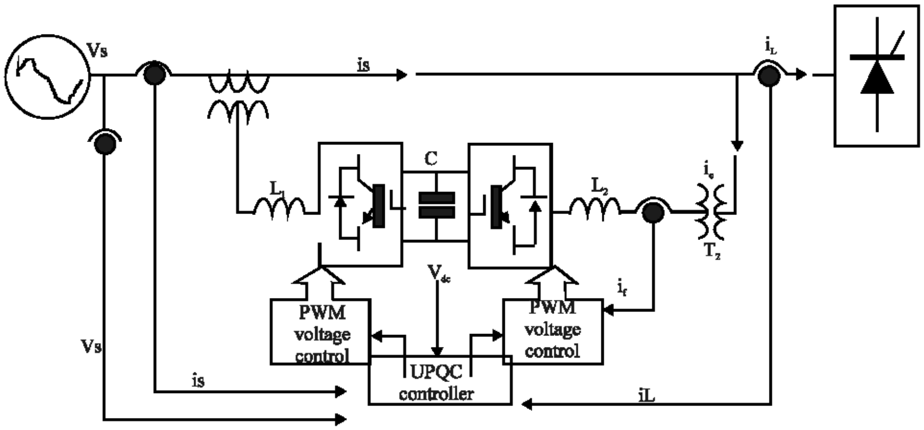

Fig. 1: General configuration of the UPQC

phase, respectively. In another words, with the function of the UPQC, the load is equal to a resistance. As the UPQC is a combination of series and shunt active filters, two active filters have different functions. The series active filter suppresses and isolates voltage-based distortions and the shunt active filter cancels current-based distortions. At the same time, it compensates reactive current of the load and improves power factor (Fujita and Akagi, 1998). The voltage-type PWM inverters are preferred to current-type inverters because of their better efficiency and dynamics (Singh *et al*., 1999; Ei-Habrouk *et al*., 2000a, b;Grady *et al*., 1990; Lee *et al*., 2004; Fujita and Akagi, 1998; Peng, 2001). There are many control methods to determine the reference value of the voltage and the current.

CONTROL STRATEGY

Control strategy plays a vital role in the overall performance of the power conditioner. Rapid detection of disturbance signal with high accuracy, fast processing of the reference signal and high dynamic response of the controller are the prime requirements for desired compensation. This control is realized using discrete analog and digital devices or advanced programmable devices, such as single-chip micro-computers, DSPs, etc.

Generation of appropriate switching pattern or gating signal with reference to command compensating signal determines the control strategy of the UPQC. Since derivation of reference signal from the measured distorted signal plays the main role, many theories and techniques were proposed or practiced over the years. These are either in frequency domain or in time domain. Different modifications of the power theories have been made for calculating the reference variables.

There are large number techniques and theories available. Among these are:

p-q-r instantaneous power theory: This method provides an analysis and control algorithm for a three-phase four-wire Unified Power Quality Conditioner (UPQC) based on p-q-r instantaneous power theory (Fan Ng *et al*., 2004). The p-q-r theory transforms a three-phase four-wire voltage space vector into a single dc voltage and the corresponding currents into a dc based active power p-axis component and two imaginary power components, q-axis and r-axis (Kim and Akagi, 1999; Kim *et al*., 2002a, b).

If there are harmonics and negative sequence exists in the voltage, the calculated reference current is not sinusoidal. In this method an extra q-axis component is used to add to the original current compensation strategy based on p-q-r theory to maintain a sinusoidal current waveform under distorted voltage. With p-q-r theory, a control block model of an integration feedback of dc power is used to maintain the average dc power to be zero. The analysis of the effect of sampling and quantization error on detection of dc storage voltage, minimization of looping active power and loss power in the UPQC system and the consideration of power flow at the source side can be completed in the future work (Fan Ng, 2004).

An extended method based on instantaneous reactive power theory in a rotating reference frame: The instantaneous reactive power theory based on rotating reference frame is presented in Kim and Akagi (1997a, b), Peng *et al.* (1998), Peng and Lai (1996) and Akagi *et al.* (1999) for three-phase four-wire systems for reactive power compensation and neutral current elimination. An extended method is used for extracting the compensating signals to suppress the harmonics and to correct the power factor. Also, a new dc voltage control loop is used that can be used in the presence of no integer harmonics and flicker voltages at the point of active filter connection. The active filter can improve power quality of highly and randomly varying loads in three-phase three-wire power systems with unbalanced voltages. In this method a three-phase electric arc furnace model with highly varying erratic currents was employed as the load. The results verify the efficiency of this method (Esfandiari *et al.*, 2004).

Two control scheme models based on two different kinds of voltage compensation strategy: In this method SHI (shunt inverter) control scheme remains the same in the both schemes (Malabika *et al.*, 2006). Two control schemes have been analyzed based on the different voltage compensation schemes of the SEI (Basu, 2003). The two control schemes are termed as UPQC-Q and UPQC-P. UPQC-Q has the advantage of VAr sharing between the two compensators. The SEI, while injecting voltage to mitigate the supply voltage sag, shares a part of load reactive power and does not consume any active power. But at higher load power factor (>0.9), the loading requirement of UPQC-Q is quite high due to excessive high SHI rating. The SHI rating of the UPQC-Q increases at a higher rate to compensate the effective leading input power factor created by quadrature voltage injection. This shifts the load voltage angle, seen from the utility side. Therefore, for higher power factor loads UPQC-P rating would be substantially lower than that of UPQC-Q. Also UPQC-Q cannot compensate unbalanced voltage sag. But for applications where VAr demand is very high UPQC-Q could be a potential control scheme for action, as it can effectively reduce the input power factor angle seen from the utility side (Basu *et al.*, 2002). The SEI control scheme of UPQC-P is based on d-q-o component analysis. UPQC-P can mitigate the supply voltage unbalance problem also besides voltage sag as the individual modulating signals can vary in phase because they would be directly derived from the d-q-o component analysis. Under balanced voltage sag condition, the load voltage angle after compensation is not altered. Therefore, the SHI of the UPQC-P does not require compensating any additional VAr created due to SEI control action.

Comparative loading analysis has brought useful insight in finding the typical application of the two different control schemes.

Switching controller method: In this method six single-phase H- bridge inverters are used in the structure of UPQC connected to a common dc storage capacitor. Of these six inverters three of them are used for series voltage insertion and the other three are used for shunt current injection. The UPQC current and voltage references are generated based on Fourier series extraction of fundamental sequence components using half cycle running (moving) averaging. They also propose a Linear Quadratic Regulator (LQR) based switching controller scheme that tracks a reference using the proposed compensator (Arindam and Gerard, 2001). This method is suitable for both utilities and customers having sensitive loads. From the utility standpoint, it can make the current drawn balanced sinusoidal. To accomplish this, the voltage at the point of common coupling must be of similar nature and also must contain the same amount of harmonics as the source. From the customer point of view, the UPQC can provide balanced voltages to their equipment that are sensitive to voltage dips. At the same time, the UPQC also filters out the current harmonics of the load. Therefore, the operation of UPQC is ideal from both viewpoints.

Direct-detection method: A number of methods proposed where the instantaneous active and non-active powers are calculated directly from the a-b-c phase voltages and line currents (Monteiro *et al.*, 2003; Peng *et al.*, 2003). It eliminates the need for complicated $\alpha\beta$ coordinate transformation, thus reducing the computation volume and improving the detection speed. However, this method requires low pass filter like$\alpha\beta$ transformation.

In method proposed in (Bbjszczak, 1995), the exact sinusoidal waveform of the voltage is stored in the memory (EPROM).

A microcomputer system reads the voltage values sequentially from the EPROM and compares it with the measured waveform and gives the reference values instantaneously. This method does not require calculation of an active current or voltage component and in this way a delay in compensator response is avoided.

Synchronous'd-q' reference-fame based algorithm: This algorithm relies on the Parks transformation Park (1929) and Kim and Akagi (1999) where three-phase voltage and current signals are transformed to a synchronously rotating frame. The active and reactive components of the system are represented by the direct and quadrate component, respectively. In this approach, fundamental quantities become d-c quantities (Bhattacharya *et al.*, 1991) which can be separated easily through filtering. To implement the synchronous reference frame some kind of synchronizing system (PLL) should be used. The system is very stable since the controller deals mainly with the d-c quantities. The computation is instantaneous but incurs time delays in filtering the d-c quantities. This method is applicable only for three-phase systems. The modified synchronous reference frame, named as 'instantaneous id-iq method' is also proposed (Soares *et al.*, 1997). This method is similar to synchronous reference frame method except that the transformation angle is obtained from the voltage αβ components. The speed referential is no longer constant but it varies instantaneously depending on the waveform of the three-phase voltage system. In this method, no synchronizing circuit is needed.

Feedback control strategy based on state space average model: The Series Power Quality Compensator (SPQC) can mitigate voltage disturbances in forms of voltage sags, voltage swells and voltage harmonics. The VSIs can inject appropriate voltage to counteract voltage disturbances and the rectifier can keep the voltage across the dc-link capacitor to be a desired voltage and keep the input power factor to be unity. The performance of the SPQC greatly depends on the control strategies.

- The disadvantage of the existing open-loop control strategy for the VSIs lies in that there is an error in compensation (Ron *et al*., 2001). Due to the existence the inductance and the resistance of the series filter and the series transformer, there is error existing inevitably. As is analyzed in (Hui *et al*., 2004), the error is greatly related to the supply current.
- The feedback control strategy can minimize the error. Designing the feedback gain according to the parameters of the series transformer and low pass filter and using the source current as the feedback signal to track the error related to the supply current, we can minimize the error.
- The shunt rectifier has a good performance in regulating the voltage cross the dc-link capacitor and keeping the input power factor unity (Mahinda *et al*., 2002; Zhaoan *et al*., 2001). If the capacity of the filter is increased, its functions can be expanded to compensating the current harmonics of the load and to supply reactive power to the load. In this way, the rectifier can be considered to be a shunt active power filter and the SPQC can be expanded to be a united power quality compensator (UPQC) (Peng, 2001).

Optimal control strategy based on phasor analysis: In the fundamental of UPQC, series compensator (sc) has been modeled as an ideal voltage source and the phasor synchronous link converter var compensate or (slcvc) has been modeled as in ideal current source.

A comprehensive control technique has been designed based on the VA loading of the two compensators, such that minimum VA loading of the two compensators is ensured. This has been achieved by pre-calculating a suitable angle of injection voltage for the series compensator. This also minimizes the operational losses of the UPQC. An optimal control design for minimum VA loading of a UPQC has been described in (Malabika *et al*., 2004).

Control algorithm based on wavelet transform: This control algorithm is used to drive the UPQC to obtain the optimum performance for current harmonics mitigation and voltage sag compensation. Some obtained results in (Elandy *et al*., 2001) are given to prove the practicability of using wavelet as a good tool for current disturbance extraction for the shunt part of UPQC and the manner it could be used to detect the reduction in voltage and generate control signal to drive the series filters to boost up the voltage to tolerable level (Farrukh, 1995).

Control of UPQC based on mathematical modeling (by applying moving time window method): The UPQC considered in this method is a multifunction power conditioner which can be used to compensate for various voltage disturbances of the power supply, to correct any voltage fluctuation and to prevent the harmonic load current from entering the power system. The direct compensation control method used in the series active filter and the moving window current calculation method used in the shunt active filter make the UPQC response very quickly to any sudden voltage change (Vilathgamuwa *et al*., 1998).

The control technique used in the shunt active filter not only keeps the voltage of the dc bus capacitor within a certain range but also causes the capacitor charging current to be obtained from the active component of the supply current. Under normal operating conditions, this capacitor charging current will be minimal (Joachim, 1994). The experimental results in (Vilathgamuwa *et al*., 1998) have shown that this method is feasible although further work is needed to optimize the parameters of the UPQC.

Fuzzy control algorithm: Two types of the current control techniques are proposed in (Singh *et al*., 1998) for the shunt inverter, one with direct current control, another with indirect current control. The strategy for current control of the series inverter remains the same in both of them. Both the inverters of the UPQC are operated in current control mode employing PWM control technique. With a view to have a self regulated dc bus, the cycle to cycle energy balance is maintained by employing a suitable closed loop control of the dc bus of the UPQC. The dc link voltage is sensed at a regular interval of 60° (time period of interrupt signal) and v_{dc} is compared with its reference counterpart v^*_{dc}. The error signal so obtained is processed in fuzzy PI controller. It is claimed (Dixon *et al*., 1997; Wang and Lia, 1992) that the fuzzy logic control yields the results which are superior to those obtained with the conventional controllers such as PI, SMC, PID, etc. The experimental results show the effectiveness of indirect current control technique towards the elimination of switching ripples from the supply current.

Control method based on H8: This method is based on H8 standard control of matching system that is used to design the H8 optimal controller of power quality. By analyzing the radical reasons of coupling effect between UPQC series unit and shunt unit, a simple and practical coordinated control strategy for UPQC series unit and shunt unit has been obtained in (Peng *et al*., 2006), i.e., by introducing corresponding voltage corrective link directly to UPQC series unit and shunt unit, respectively and by suitable mode of PWM in addition, the coupling effect between its series unit and shunt unit is eliminated fully. Therefore, the complex degree of the whole UPQC control system is simplified greatly. Combined with a waveform tracking control method based on H8 model matching technology about power quality (Li *et al*., 2004), the coordinated control between UPQC series unit and shunt unit is implemented through this strategy. The experimental results in (Peng *et al*., 2006) indicate that the method can eliminate the steady-state phase shift and amplitude attenuation of the voltage tracking compensation of series unit and the current tracking compensation of shunt unit for UPQC. Finally, the unified power quality multi-function control of UPQC is achieved. By application of a UPQC, the distribution network will become an ideal pure power source with high reliability and premium quality for power customer and those customers with pollution source will become qualified customers to the distribution system.

Adaptive defection technique: This method is based on adaptive interference canceling theory. Taking undistorted voltage signal as the reference and distorted current signal as the primary input, it can effectively extract the sum of total harmonics and reactive component present in the current signal. Operating in closed-loop, it maintains suitable operating state by continuously self-studying and self-adjusting from start to end (Karimi *et al*., 2003; Shiguo and Zheneheng, 1995). This method is useful in places where there are possibilities of suffering measurement accuracy due to noise or parameter variations.

But the implementation of this method is rather complex where DSP or microcontroller/microprocessor is preferable.

CONCLUSION

Most of the proposed or practiced control strategies for power quality conditioners have been reviewed with regard to performance and implementation. This work reveals that there has been a significant increase in interest of UPQC and associated control methods. This could be attributed to the availability of suitable power-switching devices at affordable price as well as new generation of fast computing devices (microcontroller and DSP) at low cost.

Each technique has its advantages and disadvantages. In case of reference signal calculation under balanced and sinusoidal voltage, all the methods give similar results. But under non-sinusoidal and unbalanced conditions, all the methods give different results (Marques, 1998). The direct detection method is the most attractive one, as it drives sinusoidal and balanced currents on the source and is insensitive to voltage perturbations. The control method based on *H8* avoids the transformation like park transformation which needs too much module to realize. This method offers better performance and has been found to be promising but the application of this method is complex. Selection of any technique depends on load characteristics; accuracy required and ease of implementation.

Although control strategies of UPQC have advanced greatly, still more work needs to be done to maintain near perfect power quality as more and more sensitive as well as complex loads are coming into the electric power networks.

REFERENCES

Akagi, H., 1996. New trends in active filters for power conditioning. IEEE. Trans. Ind. Applicat., 32 (6): 1312-1322.

Akagi, H., S. Ogasawara and H. Kim, 1999. The Theory of Instantaneous Power in Three-Phase Four-Wire Systems: A Comprehensive Approach. IEEE. Conf. Rec. 34th IAS Ann. Meeting, 1: 431-439.

Arindam Ghosh and Gerard Ledwich, 2001. A Unified Power Quality Conditioner (UPQC) for simultaneous voltage and current compensation, On a leave of absence from Indian Institute of Technology, Kanpur, India.

Basu, M., 2003. Some Investigations on Unified Power Quality Conditioner, Ph.D.Dissertation, Department of Electrical Engineering, IIT-Kanpur, India.

Basu, M., S.P. Das and G.K. Dubey, 2002. Performance study of UPQC-Q for load compensation and voltage sag mitigation, in: IEEE. Iecon 02, Sevilla, Spain, pp: 698-703.

Bbjszczak, G., 1995. Direct method for voltage distortion compensation in power networks by series converter filter. IEEE. Proc. Elec. Power Applications, 142 (5): 308-312.

Bhattacharya, S., D.M. Divan and B. Banerjee, 1991. Synchronous frame harmonics isolator using active series filter. Eur. Power Electron. Conf. 4th EPE., 9: 330-335.

Dixon, J., Cotardoj and Moran, 1997. DC link fuzzy control for an active power filter, sensing the line current only. IEEE-PESC, pp: 1109-1114.

El-Habrouk, M., M.K. Darwish and P. Mehta, 2000. A survey of active filters and reactive power compensation techniques; 8th Intl Conf on Power Electronics and varible Speed Drives. IEEE. Conf. Publ. 475: 7-12.

El-Habrouk, M., M.K. Darwish and P. Mehta, 2000. Active power filters: A review. IEE Proc. Elec. Power Applications, 147 (5): 403-413.

Elnady, A., A. Goauda and M.M.A. Salama, 2001. Unified power quality conditioner with a novel control algorithm based on wavelet transform, Electrical and Computer Engineering. Can. Conf., 2: 1041-1045.

Esfandiari, A., M. Parniani and H. Mokhtari, 2004. A New Control Strategy of Shunt Active Filters for Power Quality Improvement of Highly and Randomly Varying Loads, 2: 1297-1302.

Fan Ng, Man-Chung and Wong Ying-Duo Ha, 2004. Analysis and Control of UPQC and its DC-Link Power by Use of p-q-r Instantaneous Power Theory, power electronics systems and application. First Int. Conf., 9 (11): 43-45.

Farrukh Kamron, 1995. Combined deadbeat control of series-parallel converter combination used as a universal power filter. IEEE. PESC., pp: 196-201.

Fujita, H. and H. Akagi, 1998. The unified power quality conditioner. The integration of series and shunt-activefilters. IEEE. Trans. Power Elec., 13 (2): 315-322.

Grady, W.M., M.J. Samotyj and A.H. Noyola, 1990. Survey of active power line Conditioning methodologies. IEEE. Trans. Power Delivery, 5 (3): 1536-1542.

Gyugyi, L.G., Power electronics in electric utilities, static VAR compensators. Proc. IEEE., 876 (4): 483-494.

Hui Yan, Jun Li, Guoqing Tang and Qian Chen, 2004. Study of series power quality compensator with feedback control strategy for inverters. IEEE. Int. Conf. Elec. Utility Deregulation (DRPT), Hong Kong.

Joachim Holtz and Bernd Beyer, 1994. Fast current trajectory tracking control based on synchronous optimal puse width modulation. IEEE. IAS Ann. Meeting, pp: 734-741.

Juan, W. Dixon, Jaime J. Garcia and Luis Moran, 1995. Control System for Three-phase Power Filter which simultaneously Compensates Power Factor and Unbalanced Loads. IEEE. Trans. Industrial Elec., 42 (6): 636-641.

Karimi, H., M. Karimi-Ghartemani, M. Reza Iravani and A.R. Bakhshai, 2003. An adaptive filter for synchronous extraction of harmonics and distortions. IEEE. Trans. Power Delivery, 18 (4): 1350-1356.

Kim, H. and H. Akagi, 1997. The Instantaneous Power Theory Based on Mapping Matrices in Three-Phase Four-Wire Systems. Proc. Power Conversion Conf. Nagaoka, 1: 361-366.

Kim, H. and H. Akagi, 1999. The Instantaneous Power Theory on the Rotating p-q-r Reference Frames. IEEE International Conference on Power Electronics Drive System PEDS, Hong Kong.

Kim, H., F. Blaabjerg and B. Bak-Jensen, 2002. Spectral Analysis of instantaneous powers in single-phase and three-phase systems with use of p-q-r theory. IEEE. Trans. Power Elec., 17: 711-720.

Kim, H., F. Blaabjerg, B. Bak-Jensen and Jaeho Choi, 2002. Instantaneous power compensation in three-phase systems by using p-q-r theory. IEEE Transaction Power Electronics, Vol. 17, No. 5.

Kim, H.S. and U. Akagi, 1990. The instantaneous power theory on the rotating p-q-r reference frames, Power Electronics and Drive Systems. PEDS apos; 99. Proc. IEEE. Int. Conf., 1: 422-427.

Lee, G.M., D.C. Lee and J.K. Seok, 2004. Control of series active power filter compensating for source voltage unbalance and current harmonics. IEEE. Trans. Industrial Elec., 51 (1): 132-139.

Li Peng, Li Heming, Wei Bing and Yang Yihan. 2004. A Novel Control Method of Power Quality Waveform Tracking Compensation Based on H-Infinity Model Matching Technology. International Conference on Power System Technology, Singapore.

Mahinda Vilathgamuwa, A.A.D. Ranjith Perera and S.S. Choi, 2002. Performance Improvement of the Dynamic Voltage Restorer With Closed-Loop Load Voltage and Current-Mode Control. IEEE. Trans. Power Elec., 17: 824-834.

Malabika Basu, Michael Farrell, Michael F. Conlon, Kevin Gaughan and Eugene Coyle, 2004. Optimal control strategy of UPQC for minimum operational losses. Universities Power Eng. Conf., 1: 246-250.

Malabika Basu, Shyama P. Das and Gopal K. Dubey, 2006. Comparative evaluation of two models of UPQC for suitable interface to enhance power quality. Elsevier B.V.

Man-Chung Wong, Ying-Duo Han and Liang-Bing Zhao, 2000. Study of distribution system unified conditioner (DS-UniCon), Power Electronics and Motion Control Conference, Proceedings. PIEMC. The Third Int., 3 (15): 18.

Marques, G.D., 1998. A comparison of active power filter control methods in unbalanced and non-sinusoidal conditions. In: Proc. Iecon, 1: 44-449.

Monteiro, L.F.C., M. Aredes and J.A. Moor Neto, 2003. A control strategy for unified power quality conditioner. In IEEE. Int. Symp. Industrial Elec. ISIE, 3 (1): 391-396.

Park, Two-reaction, R.H., 1929. Theory of synchronous machines generalized method of analysis-part. IEEE. Trans., 48: 716-726.

Peng Li, Qian Bai and Gengyin Li, 2006. Coordinated Control Strategy for UPQC and Its Verification. Power Engineering Society General Meeting, IEEE.

Peng LI, Yi han Yang, Zhenguo Ma and Heming Li, 2003. The study and simulation verifying of the controlling signal detecting method about UPQC. In: Proc. 6th Int. Conf. Elec. Machines Sys. ICEMS., 2: 657-660.

Peng, F.Z. and J. Lai, 1996. Generalized Instantaneous Reactive Power Theory for Three-Phase Power Systems. IEEE. Trans. Instrumentation and Measurement, 45 (1): 293-297.

Peng, F.Z., 2001. Harmonic Sources and Filtering Approaches. IEEE Industry Applications Magazine, pp: 18-25.

Peng, F.Z., G.w. Ott and D.J. Adams, 1998. Harmonic and Reactive Power Compensation Based on the Generalized Instantaneous Reactive Power Theory for Three-Phase Four-Wire Systems. IEEE. Trans. Power Elec., 13 (6): 1174-1181.

Ron Cao. Jianfeng Zhao, Weiwei Shi, Ping Jiang and Guoqing Tang, 2001. Series power quality compensator for voltage sags, swells, harmonics and unbalance. In 2001 Transmission and Distribution Conference and Exposition, pp: 543-547.

Sabin, D. and A. Sundaram, 1996. Quality enhances reliability. IEEE. Spectrum, 33 (2): 34-41.

Shiguo Luo and Zheneheng Hou, 1995. An adaptive detecting method for harmonic and reactive currents, IEEE. Trans. Industrial Elec., 42 (1): 85-89.

Singh, B., B. Kamal AL-Haddad and Ambrish Chandra, 1999. A Review of Active Filters for Power Quality Improvement. IEEE. Trans. Industrial Elec., 46 (5): 960-971.

Singh, B.N., Ambrish Chandra, Kamal Al-haddad and Bhim Singh, 1998. Fuzzy control algorithm for universal active filter, power quality, Hyderabad, India, pp: 73-80.

Soares, V., P. Verdelho and C.D. Marques, 1997. Actlive power filter control circuit based on instantaneous active and reactive current id-iq method. Power Elec. Specialists Conf. PESC., 97: 1096-1101.

Vilathgamuwa, M., Y.H. Zhang and S.S. Choi, 1998. Modelling, analysis and control of unified power quality conditioner ,international conference on harmonics and quality of power. Proc. 8th Int. Conf., 2: 1035-040.

Wang, H.G.C. and S.C. Lia, 1992. A Stability approach to fuzzy control design for nonlinear system. Fuzzy Set Sys., 48: 279-286.

Zhaoan Wang, Qun Wang, Weizheng Yao and Jinjun Liu, 2001. A series active power filter adopting hybrid control approach. IEEE. Trans. Power Elec., 16: 301-310.