Ahmet Teke1,*, Mehmet Tümay1

J. Electrical Systems 7-1 (2011): 122-130

Regular paper

Unified Power Quality Conditioner: A Literature Survey

Journal of Electrical Systems

Widespread applications of power electronic based loads in industry have increased the importance and application of power quality studies. Decrease in the cost of power electronic devices, fast switching characteristics of converters and improvements in the efficiency of both power converters and energy storage components have increased the applicability of new technological solutions such as Custom Power (CP) and Flexible AC Transmission Systems (FACTS) Devices. Unified Power Quality Conditioner (UPQC, a combination of series and shunt power filters) is one of the CP devices and compensates voltage and current quality problems. UPQC has become very popular in recent years both in low voltage and medium voltage applications. In this study, a comprehensive review on circuit topologies and control algorithms of UPQC studies is presented. The drawbacks and advantages of each presented techniques are also presented. The study also helps the researchers to select the optimum control strategies and power circuit configuration for UPQC applications.

Keywords: Unified Power Quality Conditioner, Power Quality, Literature Review, Custom Power.

1. Introduction

Power quality issues are becoming more and more significant in these days because of the increasing number of power electronic devices that behave as nonlinear loads. A wide diversity of solutions to power quality problems is available for both the distribution network operator and the end user [1]. The power processing at source, load and for reactive and harmonic compensation by means of power electronic devices is becoming more prevalent due to the vast advantages offered by them. The shunt active power filter (APF) is usually connected across the loads to compensate for all current related problems such as the reactive power compensation, power factor improvement, current harmonic compensation and load unbalance compensation, whereas the series active power filter is connected in a series with a line through series transformer. It acts as controlled voltage source and can compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc [2]. UPQC is a Custom Power Device and consists of combined series active power filter that compensates voltage harmonics, voltage unbalance, voltage flicker, voltage sag/swell and shunt active power filter that compensates current harmonics, current unbalance and reactive current as shown in Figure 1, [3].

UPQC is also known as universal power quality conditioning system, the universal active power line conditioner and universal active filter [4-5]. UPQC system can be divided into two sections: The control unit and the power circuit. Control unit includes disturbance detection, reference signal generation, gate signal generation and voltage/current measurements. Power circuit consists of two voltage source converters, standby and system protection system, harmonic filters and injection transformers.

The findings of the comprehensive literature survey summarize the available studies related with control unit and power circuit of the UPQC. Therefore, the paper is organized into the following sections: The power circuit configurations are presented in Section 2. The control unit of UPQC is examined in Section 3. Section 4 includes field applications of UPQC and future trends. Finally, the conclusions of this study are given.

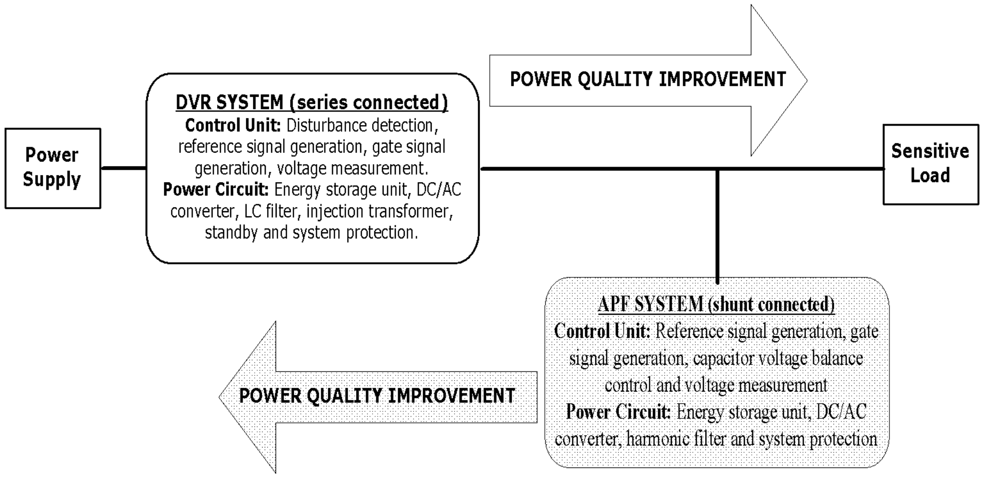

Figure 1. Basic representation of UPQC

2. Power Circuit of UPQC

UPQC is a combination of a shunt (Active Power Filter, APF) and a series compensator (Dynamic Voltage Restorer, DVR) connected together via a common dc link capacitor, which facilitates the sharing of the active power. Each compensator consists of IGBT inverters, which can be operated in current or voltage controlled mode. Depending upon the location of the shunt compensator with respect to series compensator, the UPQC model could be named as Right Shunt-UPQC or Left Shunt-UPQC. Typically the active power generated in one unit is consumed in the other unit maintaining the energy balance Overall characteristics of the Right Shunt-UPQC are superior to those of the left shunt-UPQC [6]. Basic topologies of UPQC are shown in Figure 2.

The paper has been mainly focused on the circuit topologies and control algorithms of UPQC and a number of topologies have been reviewed. UPQC can be used for medium voltage and low voltage applications. In case of low power applications, it is not convenient to install an UPQC, since the DVR spends most of its time in standby mode [7]. UPQC is generally designed as 3-phase 3-wire (3P3W) systems [8]. 3-phase 4-wire (3P4W) system is also realized from (3P3W) system where the neutral of series transformer used in series part UPQC is considered as the fourth wire for 3P4W system [9]. There are also single phase UPQC systems [10]. Various topologies such as H bridge topology [11], multilevel topology [12-13], single-phase UPQC with two half-bridge converters [10] and single-phase UPQC with three legs [10] are the examined for UPQC applications. A new topology consists of the DC/DC converter and the super-capacitor is presented in [14]. Series and parallel units do not have a common DC link (OPEN UPQC) in [15]. Advanced renewable generation based distributed power generation system is developed in [16]. UPQC is connected between two independent feeders to regulate bus voltage of one of feeders while regulating voltage across a sensitive load in the other feeder in [17]. A new configuration named multiconverter unified power-quality conditioner (MC-UPQC) for simultaneous compensation of voltage and current in adjacent feeders has been proposed in [18]. Compared to a conventional UPQC, MC-UPQC topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell and interruption in two-feeder systems.

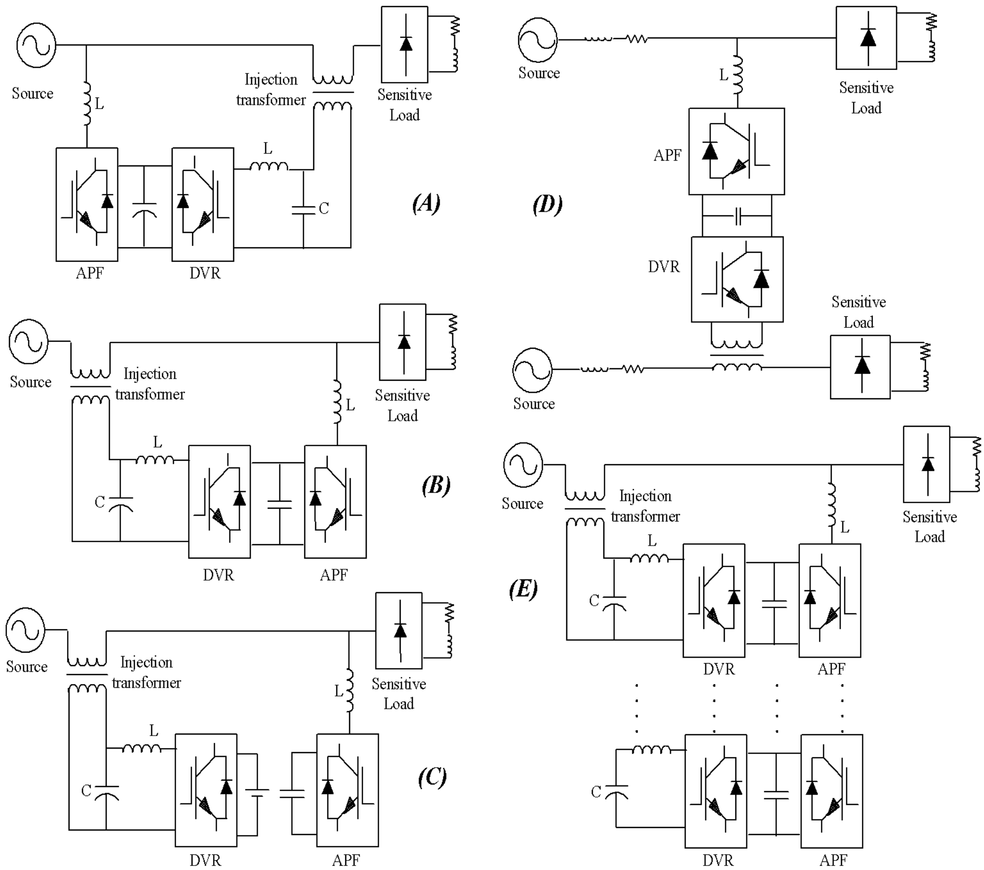

Figure 2. Power circuit topologies: (a) Left Shunt-UPQC, (b) Right Shunt-UPQC (c) OPEN UPQC, (d) Interline UPQC and (e) Multilevel UPQC

The protection of a UPQC against voltage surges and short circuit conditions to prevent its malfunction or destruction is discussed in [19]. The power circuit of UPQC generally consists of common energy storage unit, DC/AC converter, LC filter and injection transformer.

2.1 Energy Storage Unit

DC link (energy storage unit) supplies required power for compensation of load voltage during voltage sag/swell or current harmonics. UPQC generally consists of two voltage sourced inverters (series and shunt) using IGBT which operate from a common DC link storage capacitor [20]. DC link (DC-DC converter) connected to the battery energy storage system is used in [21]. Voltage interruption can also be eliminated by the use of a UPQC with distributed generation [22]. Split capacitor topology is used in [4]. Photovoltaic generation as well as the functions of a unified power quality conditioner is presented in [23].

2.2 DC/AC Inverter

Inverter circuits convert DC power to AC power. Types of inverter are voltage source (fed) inverter (VSI) and current source (fed) inverter [24]. VSIs are preferred for both shunt and series sides [20]. The series converters are generally composed of 6 bridge VSI [25] and rarely composed of three single-phase H bridge VSIs [11]. Shunt converters are generally composed of 6 bridge VSIs for three phase [26]. There are also some studies using 6 bridge inverters for series converter [8] and three single phase H bridge inverters for shunt converter [11]. Current source inverters are preferred for both shunt and series sides in [27].

2.3 LC filter

The effect of harmonics generated by the inverter can be minimized using inverter side and line side filtering [28-29]. Inverter side filtering scheme has the advantage of being closer to harmonic source thus high order harmonic currents are prevented to penetrate into series injection transformer but this scheme has the disadvantages of causing voltage drop and phase angle shift in the fundamental component of the inverter output. In line side filtering scheme, harmonic currents penetrate into series injection transformer but voltage drops and phase shift problems do not disturb the system. Inverter side LC filtering is generally preferred for both series sides [30] and inverter side L filtering is generally preferred for shunt side [31]. Inverter side C filtering is preferred for shunt side in [17]. UPQC incorporating an LCL filter is presented in [32].

2.4 Injection Transformer

Series converter of UPQC is most of time in standby mode and conduction losses will account for the bulk of converter losses during the operation [33]. In this mode, the series injection transformer works like a secondary shorted current transformer using bypass switches delivering utility power directly to the load. UPQC without injection transformer has been designed and reported in [34]. A novel configuration of UPQC which can be connected to the distribution system without series injection transformers is presented in [35].

3. Control Unit

The control unit is the most important part of the UPQC system. 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 [36]. As shown from Figure 3, the main considerations for the control system of a UPQC include:

- Series inverter control: Sag/swell detection, voltage reference generation, voltage injection strategies and methods for generating of gating signals.
- Shunt inverter control: Current reference generation, methods for generating of gating signals and capacitor voltage control.

3.1 Sag/Swell Detection

Voltage sag/swell must be detected fast and corrected with a minimum of false operations for 3 phase systems. Monitoring of $\sqrt{V_d^2 + V_q^2}$ or V_d in a vector controller is the simplest type of sag/swell detection, which will return the state of supply at any instant in time and hence, detect whether or not sag has occurred [37-38]. The sag/swell detection methods for series inverter side are root mean square method, Fast Fourier Transform (FFT) method [39], Peak Sequence Analysis (PSA) method [40], Synchronous frame (dq) detection method [41], analogical method of perturbation detection for voltage [42].

3.2 Reference Signal Generation

To generate reference signals for shunt converter, p-q-r instantaneous reactive power theory (IRPT) is generally preferred for reference current calculation [43]. An extended method based on IRPT in a rotating reference frame is used to suppress the harmonics and to correct the power factor. Adaptive detection technique is evaluated in [44] that minimizes the affects of noise or parameter variations. Besides, sinusoidal template vector algorithm [45], DC link voltage, neuron based [46] and proportional-integral (PI) controller method [30] and fuzzy control [47] are used. To generate reference signals for series converter unit; vector template generation method [48], adaptive detection [49], dq transform [50], using peak detector and averaging method [51], using band pass filter and positive sequence calculation [52] and FIR filter [53] are used. To generate reference signals for both series and shunt converter simultaneously; linear quadratic regulator [54], unit vector template generation method [48], positive sequence component method [55], wavelet transform [41], multi variable regulator based with Kalman filters [56], Artificial Intelligence Based [22], neural network [34], Pole shift control [57], least squares algorithm [58] and abc-dq transform method [59] are employed.

The overall power balance of the UPQC is maintained through the DC-link capacitor [60]. DC voltage control can be fulfilled by the traditional DC voltage feedback control or the composite control [8], PI control [30]. UPQC implemented in [61] uses a control circuit without reference calculation. The control of the UPQC can be implemented using DSP [62], FPGA or combination of them with passive circuits.

3.3 Generating of gating signals

The outputs of controller process are the control signals that are used in generation of switching signals of the inverter. To generate gating signals for only shunt converter, hysteresis controller [30] and predictive current regulation current controller [63] are employed. To generate gating signals for only series converter; sinusoidal pulse width modulation (PWM) [30] and hysteresis controller [64] methods are employed. Space vector PWM in [65], fuzzy hysteresis in [3] and sinusoidal PWM strategy in [66] are preferred for both series and shunt side inverter signal generation, respectively.

4. UPQC in Service and Future Trends

Digital controller based UPQC has been developed for a laboratory prototype in some of the studies [2], [30], [62], [67]. As a large scale structure, a 250kVA UPQC is developed at Centre for the Development of Advanced Computing (C-DAC), Trivandrum, India and is under field trial at the centre [68]. Hykon Group Company installs IGBT based UPQC in the range of 10kVA to 250kVA connected to a low voltage level [69].

Most of the proposed or practiced control strategies for power quality conditioners have been reviewed with regard to performance and implementation. The research 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, DSP, FPGA) at low cost [36]. However, deregulation of electricity market may contribute to rising penetration level of distributed generation (DG) from renewable energy sources (wind, solar, biomass, etc.) in the near future. This can lead to an increase in the number of UPQC studies based on DG [70].

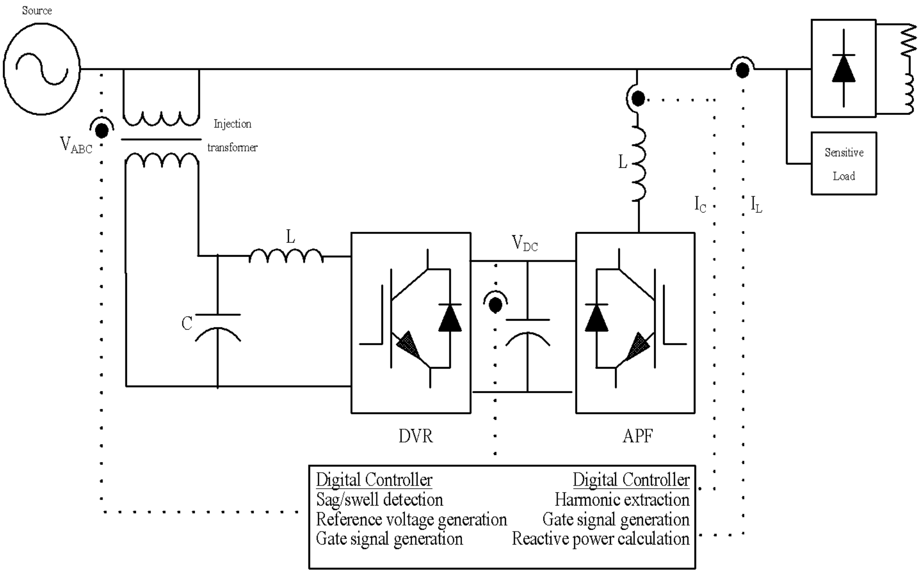

Figure 3. Control unit of UPQC with a specified power circuit topology

5. Conclusions

Unified Power Quality Conditioner can mitigate the some types of power quality disturbances such as voltage sags/swells, voltage harmonics, unbalances, current harmonics and poor power factor. These disturbances can cause misoperation of highly automated systems, malfunction of sensitive loads which increases the economical cost of fault, decrease of system efficiency and increase of the power losses and overheat transformers. UPQC can be very effective solution such a high technology industrial plants or the group of customers having sensitive loads in Custom Power Park.

The paper has been mainly concentrated on the converter topologies and the control algorithms. A number of UPQC topologies have been reviewed. With this study, the findings about UPQC studies in the literature and the application notes of UPQCs in service are presented and thus the trends of UPQC through the years are clearly observed

Acknowledgment

The authors gratefully acknowledge Electrical, Electronics and Informatics Research Group of the Scientific and Technical Research Council of Turkey (Project No: EEEAG-106E188) for full financial support.

References

[1] J. A. Muoz, J. R. Espinoza, I.A. Rubilar, L.A. Moran, P.E Melin, "A modular approach for integrating harmonic cancellation in a multi-cell based UPQC," *Industrial Electronics, IECON 34th Annual Conference of IEEE*, 2008, 3178-3183.

[2] V. Khadkikar, 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 Transactions on Power Delivery, 23, 2008, 2522-2534.

[3] F. Mekri, M. A. Machmoum,, N.A. Mazari, B. Iren, "A fuzzy hysteresis voltage and current control of an unified power quality conditioner," *Industrial Electronics, IECON 34th Annual Conference of IEEE*, 2008, 2684-2689.
[4] M. Aredes,; K. Heumann,; E.H. Watanabe, "An universal active power line conditioner," IEEE Transactions on Power Delivery, 13, 1998, 545-551.
[5] C. B. Jacobina, W. R. N. Santos, A. C. Oliveira, E. R. C. da Silva, E. C. dos Santos, "Single phase universal active filter without transformer," *Applied Power Electronics Conference, APEC, IEEE*, 2007, 698-703.
[6] A. Ghosh, G. Ledwich, *Power Quality Enhancement Using Custom Power Devices*, Springer, Power Electronics and Power Systems Series: 2002.
[7] R. A. Mastromauro, M. Liserre, A. D. Aquila, "Single-phase grid connected photovoltaic systems with power quality conditioner functionality," Proceedings of EPE, 2007, 1-11.
[8] H. Xinming, L. Jinjun, Z. Hui, "A unified compensator design based on instantaneous energy equilibrium model for the DC link voltage control of UPQC," *Applied Power Electr. Conf. and Exposition, 24 Annual IEEE*, 2009, 1577-1582.
[9] V. Khadkikar, A. Chandra, "A novel structure for three-phase four-wire distribution system utilizing unified power quality conditioner (UPQC)," IEEE Transactions on Industry Applications, 45, 2009, 1897-1902.
[10] A. Nasiri, A. Emadi, Grainger, "Different topologies for single-phase unified power quality conditioners," *Industry Applications Conference, 38th IAS Annual Meeting. Conference Record*, 2, 2003, 976-981 vol.2.
[11] A. Ghosh, A.K. Jindal, A.A, Joshi, "Unified power quality conditioner for voltage regulation of critical load bus," *Power Engineering Society General Meeting, IEEE*, 1, 2004, 471-476.
[12] L. M. Tolbert, F. Z. Peng and T. G. Habetler, "A multilevel converter-based universal power conditioner," IEEE Trans. on Industry Applications, 36, 2000, 596-603.
[13] J.A. Munoz, J.R. Espinoza, L.A. Moran, C.R. Baier, "Design of a modular upqc configuration integrating a components economical analysis," IEEE Transactions on Power Delivery, 24, 2009, 1763-1772.
[14] B. M. Han, B. Bae, "Unified power quality conditioner with super capacitor for energy storage," European Trans. on Electrical Power, 18, 2007, 327-343.
[15] M. Brenna, R. F. Tironi, "A new proposal for power quality and custom power improvement OPEN UPQC," IEEE Transactions on Power Delivery, 2009, 24, 2107-2116.
[16] S. Chakraborty, M.G. Simoes, "Experimental evaluation of active filtering in a single-phase high-frequency ac microgrid" IEEE Transactions on energy conversion, 24, 2009, 673-682.
[17] A.K.; Jindal, A.; Ghosh, A.; Joshi, "Interline unified power quality conditioner," Power Delivery, IEEE Transactions on 22, 2007, 364-372.
[18] H.R. Mohammadi, A.Y. Varjani, H. Mokhtari, "Multiconverter unified power-quality conditioning system: MC-UPQC," IEEE Transactions on Power Delivery, 24, 2009, 1679-1686.
[19] B. S. Chae, W. C. Lee, T.K. Lee, D. S. Hyun, "A fault protection scheme for unified power quality conditioners," *Power Electronics and Drive Systems, Proceedings., 4th IEEE International Conference on*, 1, 2001, 66-71, vol.1.
[20] M. Hosseini, H.A. Shayanfar and M. F. Firuzabad, "Modeling of unified power quality conditioner (UPQC) in distribution systems load flow," Elsevier Energy Conversion and Management 50, 2009, 1578-1585.
[21] M.; Davari, S.M.; Aleemran, H.; Nafisi, I.; Salabeigi, G.B., Gharehpetian, "Modeling the combination of UPQC and photovoltaic arrays with Multi-Input Single-Output DC-DC converter," *Industrial Technology, IEEE Int. Conference*, 2009, 1-6.
[22] M. George, "Artificial intelligence based three-phase unified power quality conditioner," Journal of Computer Science 3 (7), 2007, 465-477.
[23] M. C. Cavalcanti, G. M. D. Souza Azevedo, B. A. Amaral, F. A. Santos Neves, "Unified power quality conditioner in a grid-connected photovoltaic system," EPQU Journal, 2006, 12, Issue 2.
[24] J.G., Nielsen, M., Newman, H., Nielsen and F., Blaahjergl, "Control and testing of a dynamic voltage restorer (DVR) at medium voltage level," IEEE Transactions on Power Delivery, 19(3), 2003, 1248-1253.
[25] A. E. León, J. A. Solsona, C. Busada, H. Chiacchiarini and M. I. Valla, "High-performance control of a three-phase voltage-source converter including feed forward compensation of the estimated load Current," Energy Conversion and Management 50, Issue 8, 2009, 2000-2008.
[26] M.; Forghani, S.; Afsharnia, "Online wavelet transform based control strategy for UPQC control system," Power Delivery, IEEE Transactions on, 22, Issue 1, 2007, 481-491.
[27] K. Vadirajacharya, P. Agarwal, H.O. Gupta, "Performance evaluation of CSI based unified power quality conditioner using artificial neural network," International Journal of Power Electronics, 1, 2008, No.1 17-32.
[28] S.S. Choi, B.H. Li, D.M. Vilathgamuwa, "A comparative study of inverter- and line-side filtering schemes in the dynamic voltage restorer," *Power Engineering Society Winter Meeting, IEEE,* 4, 2000, 2967-2972 vol.4.
[29] M.J.; Newman, D.G.; Holmes, J.G.; Nielsen, F.; Blaabjerg, "A dynamic voltage restorer (DVR) with selective harmonic compensation at medium voltage level," Industry Applications, IEEE Transactions on, 41, 2005, 1744-1753.
[30] M. Basu, S.P. Das, G.K. Dubey, "Investigation on the performance of UPQC-Q for voltage sag," IET Gener. Transm. Distrib., 2, 2008, 414-423.

[31] A. J. Laxmi, G. T. Ram Das, K. Uma Rao, Rayudu, K. D, "Comparison of PI and ANN control strategies of unified shunt series compensator" *Power India Conference, IEEE,* 2006, 7.
[32] I.; Axente, M.; Basu, Conlon, M.F. "A control approach for UPQC connected to weak supply point," *Universities Power Engineering Conference, 42nd International,* 2007, 619-623.
[33] P. Daehler, R. Affolter, "Requirements and solutions for dynamic voltage restorer, a case study," *Proc. IEEE Power Eng. Soc. Meeting 4,* 2000, 2881-2885.
[34] L. H. Tey, P. L. So and Y. C. Chu, "Neural network-controlled unified power quality conditioner for system harmonics compensation," *Asia Pacific IEEE/PES Trans. and Distr. Conf. and Exhibition,* vol. 2, 2002, 1038-1043.
[35] B. Han, B. Bae, S. Baek, G. Jang, "New configuration of UPQC for medium-voltage application," Power Delivery, IEEE Trans. on, 21, 2006, 1438-1444.
[36] R. Rezaeipour and A. Kazemi, "Review of novel control strategies for UPQC," Int. Journal of Electrical and Power Engineering, 2, 2008, 241-247.
[37] P. Tai Cheng; J. M. Chen; Chia-Lung Ni; "Design of a state-feedback controller for series voltage-sag compensators," Industry Applications, IEEE Transactions on, 45, 2009, 260-267.
[38] C., Fitzer, M., Barnes and P.Green, "Voltage sag detection technique for a dynamic voltage restorer," IEEE Trans. on Industry Applications, 40, 2004, 203-212.
[39] D.O. Kisck, V., Navrapescu, "Single phase unified power quality conditioner with optimum voltage angle injection for minimum VA requirement," *Power Electronics Specialists Conference, IEEE,* 2007, 574-579.
[40] W. Srisongkram, W. Subsinggha, P. Boonchiam, "Voltage sag detection method in power distribution systems for power quality issues," *Power System Research Center,* 2009.
[41] A., Elnady, A., Goauda, M.M.A., Salama, "Unified power quality conditioner with a novel control algorithm based on wavelet transform," *Electrical and Computer Engineering, Canadian Conference on,* 2, 2001, 1041-1045.
[42] [42] M.S. Khoor, M. Machmoum, "Simplified analogical control of a unified power quality conditioner," *Power Electronics Specialists Conference, IEEE 36th,* 2005, 2565-2570.
[43] H.; Fujita, H.; Akagi, "The unified power quality conditioner: the integration of series and shunt-active filters," Power Electronics, IEEE Transactions on, 13, Issue 2, 1998, 315-322.
[44] H. Karimi, M. K. Ghartemani, M. R. Iravani, A.R. Bakhshai, "An adaptive filter for synchronous extraction of harmonics and distortions," Power Delivery, IEEE Transactions on, 18, Issue: 4, 2003, 1350-1356.
[45] H. Djeghloud, H. Benalla, A. Bentounsi, "Supply current and load voltage distortions suppression using the unified power quality conditioner," Systems, Signals and Devices, IEEE SSD, 5th International Multi-Conference, 2008.
[46] V. G. Kinhal, P. Agarwal, H. O. Gupta, "Performance investigation of neural-network based unified power quality conditioner," IEEE Transactions on Power Delivery, 26, 2011, 431-437.
[47] B. N. Singh, H. Chandra, K. Al-Haddad and B. Singh, "Fuzzy control algorithm for universal active filter," *Power Quality conference 98*, 1998, 73-80.
[48] V. Khadkikar, A. Chandra, A.O. Barry, T.D. Nguyen, "Application of UPQC to protect a sensitive load on a polluted distribution network," *Power Engineering Society General Meeting, IEEE*, 2006, 6.
[49] Y. Rong, C. Li, Q. Ding, "An adaptive harmonic detection and a novel current control strategy for unified power quality conditioner," Simulation Modelling Practice and Theory, Vol. 17, 2009, 955-966.
[50] P. Zhu; X. Li; Y. Kang; J. Chen; "A novel control scheme in 2-phase unified power quality conditioner, *Industrial Electronics Society," The 29th Annual Conference of the IEEE*, 2, 2003, 1617-1622.
[51] A. Esfandiari, M. Parniani, H. Mokhtari, "Mitigation of electric arc furnace disturbances using the unified power quality conditioner," *Industrial Electronics Society, 30th Annual Conference of IEEE*, 2, 2004, 1469-1474.
[52] M. T. Haque, T. Ise, S.H. Hosseini, "A novel control strategy for unified power quality conditioner (UPQC)," *Power Electronics Specialists Conference*, IEEE 33rd Annual Publication, 1, 2002, 94-98.
[53] Y. Chen, X. Zha , J. Wang, H. Liu, J. Sun, H. Tang, "Unified power quality conditioner (UPQC): the theory, modeling and application," *Power System Technology, Proceedings. International Conference*, 3, 2000, 1329-1333.
[54] L. H. Tey, So, P.L. Chu, Y.C., "Unified power quality conditioner for improving power quality using ANN with hysteresis control," *Power System Technology, International Conference*, 2, 2004, 1441-1446.
[55] P. Jaime, P. Salmeron, J. R. Vazquez, F. Alcantara, "Series-parallel configuration of active power filters for VAr and harmonic compensation," *Industrial Electronics Society, IEEE 28th Annual Conference*, 4, 2002, 2945-2950.
[56] K. H. Kwan, P.L. So, Y.C. Chu, "Unified power quality conditioner for improving power quality using MVR with kalman filters," *Power Engineering Conference, The 7th International*, 2, 2005, 980-985.
[57] A. Kumar Jindal, A. Ghosh, A. Joshi, "*The protection of sensitive loads from interharmonic currents using shunt series active filters*," Electric Power Systems Research, 2005, 187-196.
[58] I. Kamwa and R. Grondin, "Fast adaptive schemes for tracking voltage, phasor and local frequency in power transmission and distribution technique," IEEE Trans. Power Del., 7, no. 2, 1992, 789-795.

[59] W. C. Lee; D. M. Lee; T. K. Lee, "New control scheme for a unified power-quality compensator-q with minimum active power injection," Power Delivery, IEEE Transactions on, 25, 2010, 1068-1076.

[60] N.G. Jayanti, M. Basu, M.F. Conlon, K. Gaughan, "Rating requirements of the unified power quality conditioner to integrate the fixedspeed induction generator-type wind generation to the grid," Renewable Power Generation, IET, 3, Issue: 2, 2009, 133-143.

[61] G. Chen, Y. Chen, L. F. Sanchez and K. M. Smedley, "Unified power quality conditioner for distribution system without reference calculations," *4th Int. Power Electronics and Motion Control Conf.*, 3, 2004, 1201-1206.

[62] I. Axente, M. Basu, J N. Ganesh, M. F. Conlon, K. Gaughan, "A 12 kVA DSP controlled laboratory prototype UPQC capable of mitigating unbalance in source voltage and load current," IEEE Transactions on, Power Electronics, 2010.

[63] M.J. Newman, D.G. Holmes, "A universal custom power conditioner with selective harmonic voltage compensation," *IECON 02, Industrial Electronics Society, IEEE 28th Annual Conference*, 2, 2002, 1261-1266.

[64] V. Khadkikar, P. Agarwal, A. Chandra, A.O. Barry, T.D. Nguyen, "A simple new control technique for unified power quality conditioner (UPQC)," *Harmonics and Quality of Power, 11th International Conference on*, 2004, 289-293.

[65] P. Zhu Li, X. Kang, Y. Chen, "Control scheme for a universal power quality manager in a two-phase synchronous rotating frame," Generation, Transmission and Distribution, IEE Proceedings, 151, Issue: 5, 590-596, 2004.

[66] M. Victor Moreno, P. Alberto, L. Marco, Antonio Dell' Aquila, "Unified power quality conditioner (UPQC) with voltage dips and over-voltages compensation capability," *International Conference on Renewable Energies and Power Quality*, 2008.

[67] Y.Y. Kolhatkar, S.P. Das, "Experimental investigation of a single-phase UPQC with minimum VA loading," *IEEE Trans. on Power Delivery*, 22, 2007, pp. 373-380.

[68] R. S. Kumar, P. Ganesan, "250kVA Unified power quality controller," TENCON IEEE Region 10 Conference, pp. 1-4, 2006.

[69] T. Juha, "Series active power filter in power conditioning," Tampere University of Technology, *Laboratory of Power Electronics*, 2009, pp.179.

[70] B. Malabika, P. S. Das, K. G. Dubey, "Comparative evaluation of two models of UPQC for suitable interface to enhance power quality," *Electric Power Systems Research*, 2007, pp. 821-830.