UPQC System Configuration for Single Phase and Three Phase Network : A Review

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***Abstract* - This paper presents a literature review on the broad overview on the different possible UPQC system configurations for single-phase (two-wire) and three-phase (three-wire and four-wire) networks, different compensation approaches, and recent developments to enhance the electric power quality at distribution levels. Therefore, a list on the types of different UPQC configuration is developed and presented to highlight the distinguishing feature offered by a particular UPQC.**

Index Terms—Active power filter (APF), harmonic compensation, power quality, reactive power compensation, unified power quality conditioner (UPQC), voltage sag and swell compensation.

I. INTRODUCTION

IT has been always a challenge to maintain the quality of electric power within the acceptable limits [1]–[7]. The adverse effects of poor power quality are well discussed [1], [2], [5]–[7].Reliability of supply and power quality (PQ) are the two most important facts of any power delivery system today [1]. Not so long ago, the main concern of consumers of electricity was the continuity of supply. However nowadays, consumers want not only continuity of supply, but the quality of power is very important to them too. The power quality problems in distribution power systems are not new, but customer awareness of these problems has recently increased. For example, for many years interruptions shorter than several minutes were not considered as a cause of concern to most consumers.

Recently this has changed: more and more equipment is sensitive to very short duration events, and more and more customers (domestic as well as industrial) view short interruptions as a serious imperfection of the supply. The term active power filter (APF) is a widely used terminology in the area of electric power quality improvement [8]–[10]. APFs have made it possible to mitigate some of the major power quality problems effectively. Extensive and well-documented surveys on the APF technologies covering several aspects are provided in [8]–[10]. This paper focuses on a unified power quality condition (UPQC). The UPQC is one of the APF family members where shunt and series APF functionalities are integrated together to achieve superior control over several power quality problems simultaneously.

This review papers is broadly classified into five major groups based on 1) physical structure of the UPQC [7]–[18] and 2) method used to compensate sag/dip in the source voltage 3) type of converter (current or voltage source) 4) supply system (single-phase two-wire, three-phase three-wire and four-wire) and 5) recently developed new system configurations for single-phase and/or three-phase system. Therefore, this paper aims at developing an acronymic list to cover different UPQC aspects. All acronyms are identified, alphabetically, UPQC-D, UPQCDG, UPQC-I, UPQC-L, UPQC-MC, UPQC-R. Besides this, this paper also discusses the most significant control strategies/approaches/concepts that are utilized to control the UPQC.

II. UNIFIED POWER QUALITY CONDITIONER

The Unified Power Quality Conditioner is a custom power device that is employed in the distribution system to mitigate the disturbances that affect the performance of sensitive and/or critical load [19]. It is a type of hybrid APF and is the only versatile device which can mitigate several power quality problems related with voltage and current simultaneously therefore is multi functioning devices that compensate various voltage disturbances of the power supply, to correct voltage fluctuations and to prevent harmonic load current from entering the power system.

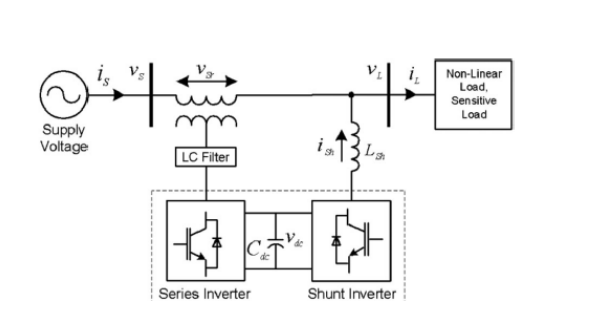

Fig. 1: UPQC general block diagram

The system configuration of a single-phase UPQC is shown in Fig. 1. Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. The shunt converter is connected in parallel to the load. It provides VAR support to the load and supply harmonic currents.

Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply [2]. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor. The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers

The main purpose of a UPQC is to compensate for supply voltage power quality issues, such as, sags, swells, unbalance, flicker, harmonics, and for load current power quality problems, such as, harmonics, unbalance, reactive current, and neutral current. The key components of this system are as follows.

1) Two inverters —one connected across the load which acts as a shunt APF and other connected in series with the line as that of series APF.
2) Shunt coupling inductor Lsh is used to interface the shunt inverter to the network. It also helps in smoothing the current wave shape. Sometimes an isolation transformer is utilized to electrically isolate the inverter from the network.
3) A common dc link that can be formed by using a capacitor or an inductor. In Fig. 1, the dc link is realized using a capacitor which interconnects the two inverters and also maintains a constant self-supporting dc bus voltage across it.
4) An LC filter that serves as a passive low-pass filter (LPF) and helps to eliminate high-frequency switching ripples on generated inverter output voltage.
5) Series injection transformer that is used to connect the series inverter in the network. A suitable turn ratio is often considered to reduce the voltage and current rating of series inverter.

In principle, UPQC is an integration of shunt and series APFs with a common self-supporting dc bus. The shunt inverter in UPQC is controlled in current control mode such that it delivers a current which is equal to the set value of the reference current as governed by the UPQC control algorithm [20]. Additionally, the shunt inverter plays an important role in achieving required performance from a UPQC system by maintaining the dc bus voltage at a set reference value. In order to cancel the harmonics generated by a nonlinear load, the shunt inverter should inject a current.

Similarly, the series inverter of UPQC is controlled in voltage control mode such that it generates a voltage and injects in series with line to achieve a sinusoidal, free from distortion and at the desired magnitude voltage at the load terminal. In the case of a voltage sag condition, actual source voltage will represent the difference between the reference load voltage and reduced supply voltage, i.e., the injected voltage by the series inverter to maintain voltage at the load terminal at reference value. In all the reference papers on UPQC, the shunt inverter is operated as controlled current source and the series inverter as controlled voltage source except [12] in which the operation of series and shunt inverters is interchanged. For enhancement of power now a day we use fuzzy logic controller or artificial neural network instead of PI controller.

III. UPQC CLASSIFICATION

In this section, the classification of UPQC is given. Fig. 2 shows a pictorial view for the classification of UPQC. The UPQC is classified in three main groups based on the physical structure.

- Converter topology
- Supply system
- System configuration.

A. Classification based on converter topology

In a UPQC, both shunt and series inverters share a common dc link. The shunt inverter is responsible to regulate this self-supporting dc link at a set reference value. The UPQC may be developed using a pulse width modulated (PWM) current source inverter (CSI) [9]–[11], [55] that shares a common energy storage inductor *L*dc to form the dc link. A voltage blocking diode connected in series with insulated gate bipolar transistor is required to realize this topology Fig. 3 shows single-line representation of a CSI-based UPQC system configuration. The dc current in the inductor is regulated such that the average input power is equal to the average output power plus the power losses in the UPQC. The CSI-based UPQC topology is not popular because of higher losses, cost, and the fact that it cannot be used in multilevel configurations. The second topology, a most common and popular converter topology for UPQC, consists of PWM VSI that shares a common energy storage capacitor *C*dc. Fig. 1 depicts single-line representation of a VSI-based UPQC system configuration. Almost all the reported work on the UPQC dominantly uses the VSI-based topology [12], [14]–[18]. The advantages offered by VSI topology over CSI include lighter in weight, no need of blocking diodes, cheaper, capability of multilevel operation, and flexible overall control.

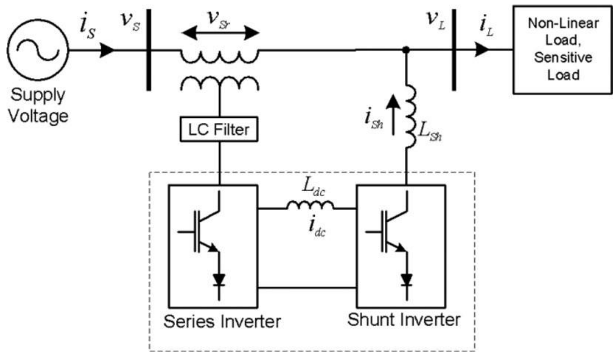

Fig. 3 CSI-based UPQC system configuration

B Classification based on Supply System:

The ac loads or equipments on the power system can be broadly divided into single-phase and three-phase, supplied by single-phase (two wire) or three-phase (three-wire or four-wire) source of power.

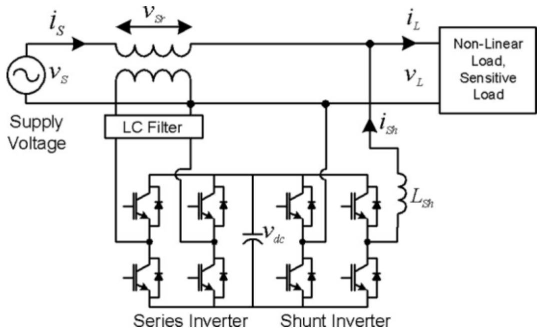

Fig. 4 UPQC: two H-bridge configuration (eight switches).

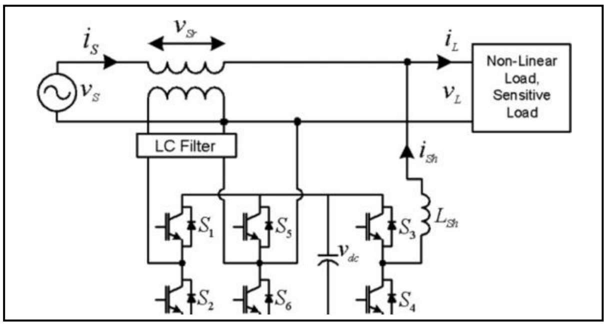

Fig. 5 UPQC: three-leg configuration (six switches).

The voltage-related power quality problems are similar for both single- and three-phase systems except an additional voltage unbalance compensation needed in the case of a three-phase system. For a single-phase system, the load reactive current and current harmonics are the major issues. In the case of three-phase three-wire (3P3W) system, one need to consider current unbalance apart from reactive and harmonics current. Furthermore, the three-phase four-wire (3P4W) system requires an additional neutral current compensation loop. Fig. 4 shows the most popular UPQC system configuration to compensate the power quality problems in single-phase two wire (1P2W) supply system consisting of two H-bridge inverters (total eight semiconductor switches) [11], [23], [37], [40], [41], [53]. It represents the VSI-based 1P2W UPQC topology. A CSI-based topology can also be realized for 1P2W UPQC, as given in [11]. Nasiri and Emadi introduced two additional reduced part configurations for single phase UPQC [40], namely, three-leg single-phase UPQC (total six semiconductor switches) shown in Fig. 5 and half-bridge single-phase UPQC (total four semiconductor switches) shown in Fig. 6. These topologies can be considered for low-cost low power applications. In a three-leg topology, the series inverter consists of switches S1 and S2 (leg one), whereas, switches S3 and S4 are for shunt inverter (leg two). The third leg, switches S5 and S6, is common for both the series and shunt inverters. The half-bridge topology consists of one leg each for shunt and series inverters. The reduced switching devices may affect the compensation performance of UPQC.

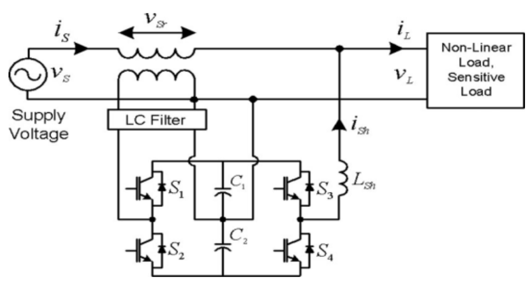

Fig. 6. UPQC: half-bridge configuration (four switches).

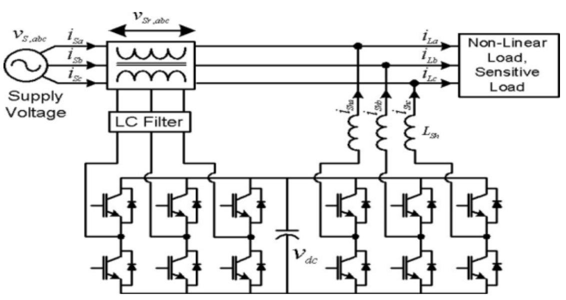

Fig. 7. 3P3W UPQC.

The two inverters can be connected with each other using a high-frequency transformer. Like bidirectional-isolated dc/dc converter, the power transfer between two inverters can be controlled by adjusting voltage phase shift between them. Several nonlinear loads, such as, adjustable speed drives fed from 3P3W, current regulator, frequency converters, arc welding machines, and arc furnace, impose combinations of previously listed power quality problems. A 3P3W VSI-based UPQC is depicted in Fig. 7. It is the most widely studied UPQC system configuration [12]–[15], [17]–[20], [22], [24], [26], [29], [32]–[34], [36], [38], [39], [42], [44]–[50], [52], [54], [56]. Apart from the three phase loads, many industrial plants often consist of combined loads, such as, a variety of single-phase loads and three-phase loads, supplied by 3P4W source. The presence of fourth wire, the neutral conductor, causes an excessive neutral current flow and, thus, demands additional compensation requirement.

3) Classification Based on the System Configuration: This section gives an overview on the different UPQC configurations

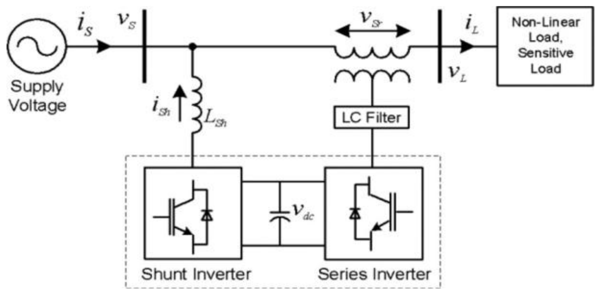

Fig. 8 UPQC-L system configuration.

1) Right and Left Shunt UPQC (UPQC-R and UPQC-L): Since the UPQC has two back-to-back connected inverters; it can be classified based on the placement of shunt inverter with respect to series inverter. The shunt inverter can be located either on the right (thus the name right shunt UPQC (UPQC-R)) [7]–[20], [22], [23], [25], [26], [28]–[40], [42], [44]–[56], [58] or left (hence the name left shunt UPQC (UPQC-L)) [7], [21], [24], [27], [41], [43], [57], side of the series inverter. Figs. 1 and 3–10 represent UPQC-R system configuration, while Fig. 11 shows UPQC-L configuration. Among two configurations, the UPQC-R is the most commonly used. In UPQC-R, the current(s) that flow through series transformer is(are)mostly sinusoidal irrespective to the nature of load current on the system(provided that the shunt inverter compensate current harmonics, reactive current, unbalance, etc., effectively). Thus, UPQC-R gives a better overall UPQC performance compare to UPQC-L.

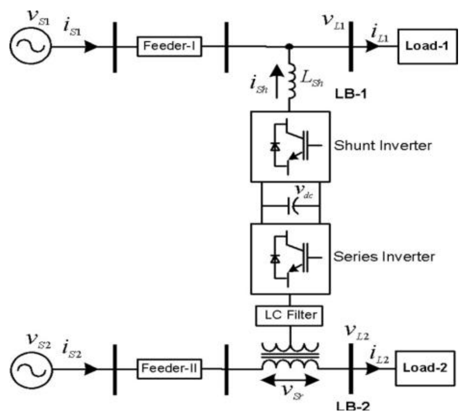

Fig. 9 UPQC-I system configuration.

2) Interline UPQC (UPQC-I): Fig. 10 depicts an interesting UPQC system configuration, suggested by Jindal *et al.* [38], where the two inverters of the UPQC are connected between two distribution feeders named as interline UPQC (UPQC-I). One of the inverters is connected in series with one of the feeders while the other inverter in shunt with second feeder. With such a configuration, the simultaneous regulation of both the feeder voltages can be achieved. Furthermore, the UPQC-I can control and manage the flow of real power between the two feeders. This configuration, however, has certain limitations and can be used for special cases. The current-related problems (such as harmonics and unbalance) could be effectively compensated only on the feeder in which the inverter is connected in shunt. Alternatively, the harmonics in the voltages can only be adequately mitigated in the series-inverter-connected feeder.

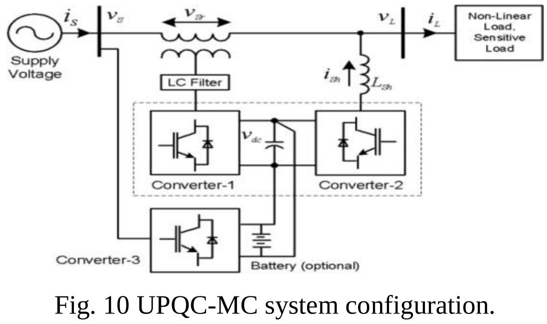

Fig. 10 UPQC-MC system configuration.

3) Multiconverter UPQC (UPQC-MC): Researchers have explored the possibilities for improving the system performance by considering additional third converter unit to support the dc bus [17], [19], [20]. To further enhance the system performance, the use of storage battery or super capacitor can be used as discussed in [17] and [66]. The third converter can be connected in different ways, for example, in parallel with the same feeder [17], [19], [42], [46] or in series/parallel with the adjacent feeder [15]. Graovac *et al*. [19] addressed this configuration as UPQS. Wong *et al*. [17] have named this configuration as DS-UniCon (distribution system unified conditioner), whereas, Mohammadi *et al.* [25] called this configuration as MC-UPQC (Multiconverter UPQC). In MC-UPQC, the third converter is connected in series with the adjacent feeder. Similar to UPQC-I, the MC-UPQC can be connected between two different feeders. In this paper, the configuration in which three converters are utilized to realize the UPQC system is termed as multiconverter UPQC (UPQC-MC). Fig. 10 shows a pictorial view of UPQC-MC.

4) Distributed Generators Integrated With UPQC (UPQCDG): Solar and wind energies are emerging as alternate sources of electricity. The UPQC can be integrated with one or several distributed generation (DG) systems [39], [33], [46], [8], [15]. The system configuration, thus, achieved is referred as UPQC-DG and is illustrated in Fig. 11. As shown, the output of DG system is connected to dc bus of the UPQC. The DG power UPQC to supply Fig. 11. UPQC-DG system configuration. to the loads connected to the PCC in addition to the voltage and current power quality problem compensation. Additionally, a battery can be connected to the dc bus, such that the excess DG generated power can be stored and used as backup can be regulated and managed through.

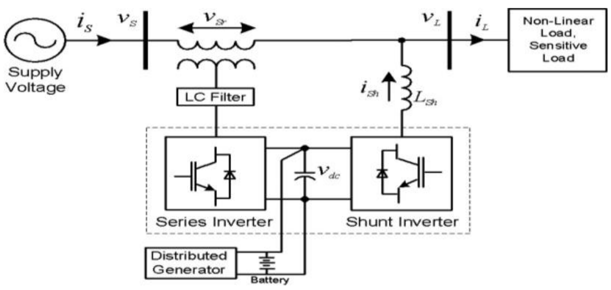

Fig. 11 UPQC-DG system configuration.

In the event of voltage interruption, the UPQC-DG system gives additional benefit by providing the power to the load (uninterruptible power supply operation). Furthermore, the DG power can be transferred in an interconnected mode (power to the gird and loads) or islanding mode (power to the specific loads) and so on. So far, several interesting UPQC system configurations are brought to the attention. Some of these configurations may impose limitations, interface issues, increase overall circuit complexity, and cost. These aspects need to be addressed adequately for practical viability of these configurations. Nevertheless, these topologies give alternative options to realize the UPQC-based system configuration in several ways.

IV. CONTROL TECHNIQUE FOR UPQC

Control strategy plays the most significant role in any power electronics based system. It is the control strategy which decides the behavior and desired operation of a particular system. The effectiveness of a UPQC system solely depends upon its control algorithm. The UPQC control strategy determines the reference signals (current and voltage) and, thus, decides the switching instants of inverter switches, such that the desired performance can be achieved. There are several control strategies/algorithm/techniques available in the existing literature those have successfully applied to UPQC systems. Frequency domain methods, such as, based on the fast Fourier transformer (FFT), are not popular due to large computation time and delay in calculating the FFT. Control methods for UPQC in the time domain are based on instantaneous derivation of compensating commands in the form of either voltage or current signals. There are a large number of control methods in the time domain.

V. CONTROL TECHNIQUE FOR UPQC

Technical literature on the APFs can be found since early 1970s [9]. However, the use of UPQC to enhance electric power system quality is reported since mid 1990s [11]. Among the various power quality enhancement devices, STATCOM and few others are commercially available [9], [17]–[18]. At the time of writing this paper, no commercial UPQC product was available in the market. A 250-kVA prototype developed at C-DAC, Thiruvananthapuram, India [55], is the most viable reported prototype. The technology to develop commercial UPQC system is available today; however, the overall cost and complexity of such a system still imposes some limitations. The capacity of small- and large-scale renewable energy systems based on wind energy, solar energy, etc., installed at distribution as well as transmission levels is increasing significantly. These newly emerging DG systems are imposing new challenges to electrical power industry to accommodate them without violating standard requirements (such as, IEEE 1547, IEEE 519). In terms of power quality, the excessive feeder voltage rise due to reverse power flow from DG system and power system stability is of significant importance. Moreover, most of the DG systems utilize power electronic converters as interfacing device to deliver the generated power to the grid. The switching operation of these systems is contributing as increased harmonic levels both in the grid voltages and currents [12]–[14]. The aforementioned power quality issues suggest potential applications of UPQC in renewable- energy based power systems. In this paper, several UPQC configurations and topologies have been discussed. Among these configurations, UPQC-DG could be the most interesting topology for a renewable-energy-based power system. This configuration can offer multifunctional options, namely, active power delivery from DG system to grid (normal DG operation), voltage and current-related power quality compensation (UPQC operation), and uninterruptible power supply operation. Commercial products have started to appear in the market to increase the renewable energy system connectivity by compensating some of these problems [52], [26]. As the penetration levels of DG system on the existing power system continue to increase, the utilization of active compensating technologies (such as, flexible ac transmission system devices and APFs) is expected to increase gradually.

VI. CONCLUSION

A comprehensive review on the UPQC to enhance the electric power quality at distribution level has been reported in this paper. Recent rapid interest in renewable energy generation, especially front-end inverter-based large-scale photovoltaic and wind system, is imposing new challenges to accommodate these sources into existing transmission/distribution system while keeping the power quality indices within acceptable limits. UPQC in this context could be useful to compensate both voltage- and current-related power quality problems simultaneously. Different aspects of UPQC and up to date developments in this area of research have been briefly addressed. An effort is made to categorize interesting features of the UPQC by organizing an acronymic list. These acronyms could be used to clearly identify particular application, utilization, configuration, and/or characteristic of the UPQC system under study. It is desirable that this review on UPQC will serve as a useful reference guide to the researchers working in the area of power quality enhancement utilizing APFs.

VII. REFERENCES

[1] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, *Electrical PowerSystems Quality*. New York: McGraw-Hill, 1996.

[2] C. Sankaran, *Power Quality*. Boca Raton, FL: CRC Press, 2002

[3] *IEEE Recommended Practices and Requirements for Harmonic Controlin Electrical Power Systems*, IEEE Standard 519-1992, 1992.

[4] *IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems*, IEEE Standard 1547-2003, 2003.

[5] N. G. Hingorani and L. Gyugyi, *Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*. New York: Institute of Electrical and Electronics Engineers, 2000.

[6] V. K. Sood, *HVDC and FACTS Controllers—Applications of Static Converters in Power Systems*. Boston, MA: Kluwer, 2004.

[7] A. Ghosh and G. Ledwich, *Power Quality Enhancement Using Custom Power Devices*. Boston, MA: Kluwer, 2002.

[8] H.Akagi, "Trends in active power line conditioners," *IEEE Trans. Power Electron.*, vol. 9, no. 3, pp. 263–268, May 1994

[9] .B. Singh, K. Al-Haddad, and A. Chandra, "A review of active filters for power quality improvement," *IEEE Trans. Ind. Electron.*, vol. 46, no. 5, pp. 960–971, Oct. 1999.

[10] 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.

[11] F. Kamran and T. G. Habetler, "Combined deadbeat control of a seriesparallel converter combination used as a universal power filter," in *Proc. Power Electron. Spec. Conf.*, Jun. 18–22, 1995, pp. 196–201.

[12] S. Muthu and J. M. S. Kim, "Steady-state operating characteristics ofunified active power filters," in *Proc. Appl. Power Electron. Conf.*, Feb.23–27, 1997, pp. 199–205

[13] H. Fujita and H. Akagi, "The unified power quality conditioner: The integrationof series and shunt-active filters," *IEEE Trans. Power Electron.*,vol. 13, no. 2, pp. 315–322, Mar. 1998.

[14] B. N. Singh, A. Chandra, K. Al-Haddad, and B. Singh, "Fuzzy controlalgorithm for universal active filter," in *Proc. Power Quality Conf.*, Oct.14–18, 1998, pp. 73–80.

[15] M. Aredes,K.Heumann, and E.H.Watanabe, "An universal active power line conditioner," *IEEE Trans. Power Del.*, vol. 13, no. 2, pp. 545–551, Apr. 1998.

[16] M. C. Wong, C. J. Zhan, Y. D. Han, and L. B. Zhao, "A unified approach for distribution system conditioning: Distribution system unified conditioner (DS-UniCon)," in *Proc. Power Eng.*

Soc. Winter Meet., Jan. 23–27, 2000, pp. 2757–2762.

[17] M. Hu and H. Chen, "Modeling and controlling of unified power quality conditioner," in *Proc. Adv. Power Syst. Control, Operation Manage.*,Oct. 30–Nov. 1, 2000, pp. 431–435.

[18] D. Graovac, V. Katic, and A. Rufer, "Power quality compensation using universal power quality conditioning system," *IEEE Power Eng. Rev.*, vol. 20, no. 12, pp. 58–60, Dec. 2000.

[19] Y. Chen, X. Zha, J. Wang, H. Liu, J. Sun, and H. Tang, "Unified power quality conditioner (UPQC): The theory, modeling and application," in *Proc. Int. Conf. Power Syst. Technol.*, 2000, pp. 1329–1333.

[20] S. Chen and G. Joos, "Rating issues of unified power quality conditioners for load bus voltage control in distribution systems," in *Proc. Power Eng. Soc. Winter Meet.*, 28 Jan.–1 Feb., 2001, pp. 944–949.

[21] S. Chen and G. Joos, "A unified series–parallel deadbeat control technique for an active power quality conditioner with full digital implementation," in *Proc. IEEE 36th Ind. Appl. Soc. Annu. Meet. Ind. Appl. Conf.*, 30 Sep.–4 Oct., 2001, pp. 172–178.

[22] M. Basu, S. P. Das, and G. K. Dubey, "Experimental investigation of performance of a single phase UPQC for voltage sensitive and nonlinear loads," in *Proc. 4th IEEE Int. Conf. Power Electron. Drive Syst.*, Oct. 22–25, 2001, pp. 218–222.

[23] A. Elnady, A. Goauda, and M. M. A. Salama, "Unified power quality conditioner with a novel control algorithm based on wavelet transform," in *Proc. Can. Conf. Electr. Comput. Eng.*, 2001, pp. 1041–1045.

[24] A. Elnady and M. M. A. Salama, "New functionalities of an adaptive unified power quality conditioner," in *Proc. Power Eng. Soc. Summer Meet.*, 2001, pp. 295–300.

[25] B. S. Chae, W. C. Lee, D. S. Hyun, and T. K. Lee, "An overcurrent protection scheme for series active compensators," in *Proc. 27th Annu. Conf. IEEE Ind. Electron. Soc.*, 2001, pp. 1509–1514.

[26] E. H. Watanabe and M. Aredes, "Power quality considerations on shunt/series current and voltage conditioners," in *Proc.10th Int. Conf. Harmonics Quality Power*, Oct. 6–9, 2002, pp. 595–600.

[27] A. Pievatolo, E. Tironi, I. Valade, and G. Ubezio, "UPQC reliability analysis," in *Proc. 10th Int. Conf. Harmonics Quality Power*, Oct. 6–9, 2002, pp. 390–397.

[28] P. Rodriguez, L. Sainz, and J. Bergas, "Synchronous double reference frame PLL applied to a unified power quality conditioner," in *Proc. 10th,Int. Conf. Harmonics Quality Power*, Oct. 6–9, 2002, pp. 614–619.

[29] J. Prieto, P. Salmeron, J. R. Vazquez, and J. Alcantara, "A series–parallel configuration of active power filters for VAr and harmonic compensation," in *Proc. IEEE 28th Annu. Conf. Ind. Electron. Soc.*, Nov. 5–8, 2002, pp. 2945–2950.

[30] A. Elnady, W. El-khattam, and M. M. A. Salama, "Mitigation of AC arc furnace voltage flicker using the unified power quality conditioner," in *Proc. Power Eng. Soc. Winter Meet.*, 2002, pp. 735–739.

[31] M. T. Haque, T. Ise, and S. H. Hosseini, "A novel control strategy for unified power quality conditioner (UPQC)," in *Proc. Power Electron. Spec. Conf.*, 2002, vol. 1, pp. 94–98.

[32] G. Jianjun, X. Dianguo, L. Hankui, and G. Maozhong, "Unified power quality conditioner (UPQC): The principle, control and application," in *Proc. Power Convers. Conf.*, 2002, pp. 80–85.

[33] L. H. Tey, P. L. So, and Y. C. Chu, "Neural network-controlled unified power quality conditioner for system harmonics compensation," in *Proc. IEEE/PES Transmiss. Distrib. Conf. Exhib.*, 2002, pp. 1038–1043.

[34] R. Faranda and I. Valade, "UPQC compensation strategy and design aimed at reducing losses," in *Proc. IEEE Int. Symp. Ind. Electron.*, 2002, pp. 1264–1270.

[35] L. F. C. Monteiro, M. Aredes, and J. A. Moor Neto, "A control strateg for unified power quality conditioner," in *Proc. Int. Symp. Ind. Electron.*, Jun. 9–11, 2003, pp. 391–396.

[36] M. Correa, S. Chakraborty, G. Simoes, and A. Farret, "A single phase high frequency ACmicrogrid with an unified power quality conditioner," in *Proc. IEEE Int. Symp. Ind. Electron.*, Jun. 9–11, 2003, pp. 956–962.

[37] J. Liu, Y. He, Y. Ye, and X. Wang, "An unified scheme and respective algorithms for the control of DC-linked double converters in an universal power quality controller," in *Proc. Power Electron. Spec. Conf.*, Jun. 15– 19, 2003, pp. 327–332.

[38] S. W. Park, I. Y. Chung, J. H. Choi, S. I. Moon, and J. E. Kim, "Control schemes of the inverter-interfaced multi-functional dispersed generation,"

in *Proc. Power Eng. Soc. Gen. Meet.*, Jul. 13–17, 2003, pp. 1924– 1929.

[39] A. Nasiri and A. Emadi, "Different topologies for single-phase unified power quality conditioners," in *Proc. 38th Int. Appl. Soc. Annu. Meet. Ind. Appl. Conf.*, Oct. 12–16, 2003, pp. 976–981.

[40] A. Ghosh, A. K. Jindal, and A. Joshi, "Inverter control using output feedback for power compensating devices," in *Proc. Convergent Technol. Conf.*, Oct. 15–17, 2003, pp. 48–52.

[41] P. Zhu, X. Li, Y. Kang, and J. Chen, "A novel control scheme in 2-phase unified power quality conditioner," in *Proc. 29th Annu. Conf. IEEE Ind. Electron. Soc.*, Nov. 2–6, 2003, pp. 16917–1622.

[42] A. Ghosh, A. K. Jindal, andA. Joshi, "Aunified power quality conditioner for voltage regulation of critical load bus," in *Proc. Power Eng. Soc. Gen. Meet.*, Jun. 6–10, 2004, pp. 471–476.

[43] Y. Cheng and L. Philippe, "Advanced control methods for the 3-phase unified power quality conditioner," in *Proc. Power Electron. Spec. Conf.*, Jun. 20–25, 2004, pp. 4263–4267.

[44] J. Tlusty and V. Valouch, "Effectiveness of unified power quality conditioner for flicker mitigation," in *Proc. 4th Int. Power Electron. Motion Control Conf.*, Aug. 14–16, 2004, pp. 902–907.

[45] V. Khadkikar, P. Agarwal, A. Chandra, A. Barry, and T. Nguyen, "A simple new control technique for unified power quality conditioner (UPQC)," in *Proc. 11th Int. Conf.Harmonics Quality Power*, Sep. 12–15, 2004, pp. 289–293.

[46] A. Esfandiari, M. Parniani, and H. Mokhtari, "Mitigation of electric arc furnace disturbances using the unified power quality conditioner," in *Proc. 30th Annu. Conf. Ind. Electron. Soc.*, Nov. 2–6, 2004, pp. 1469– 1474.

[47] C. A. Sepulveda, J. R. Espinoza, L. A. Moran, and R. Ortega, "Analysis and design of a linear control strategy for three-phase UPQCs," in *Proc. 30th Annu. Conf. IEEE Ind. Electron. Soc.*, Nov. 2–6, 2004, vol. 3, pp. 3060–3065.

[48] F. Ng, M. C. Wong, and Y. D. Han, "Analysis and control of UPQC and its DC-link power by use of p-q-r instantaneous power theory," in *Proc. Power Electron. Syst. Appl.*, Nov. 9–11, 2004, pp. 43–53.

[49] L. H. Tey, P. L. So, and Y. C. Chu, "Unified power quality conditioner for improving power quality using ANN with hysteresis control," in *Proc. Int. Conf. Power Syst. Technol.*, Nov. 21–24, 2004, pp. 1441–1446.

[50] G. Chen, Y. Chen, and K. M. Smedley, "Three-phase four-leg active power quality conditioner without references calculation," in *Proc. Appl. Power Electron. Conf.*, 2004, pp. 587–593.

[51] R. Strzelecki, G. Benysek, J. Rusinski, and H. Debicki, "Modeling and experimental investigation of the small UPQC systems," in *Proc. Compat. Power Electron.*, Jun. 1, 2005, pp. 223–237.

[52] J. R. Reyes, J. R. Espinoza, and C. Sepulveda, "Operating region of single-phase UPQCs," in *Proc. Power Electron. Spec. Conf.*, Jun. 16, 2005, pp. 1726–1731.

[53] M. Khoor andM.Machmoum, "Simplified analogical control of a unified power quality conditioner," in *Proc. Power Electron. Spec. Conf.*, Jun. 16, 2005, pp. 2565–2570.

[54] J. Correa, F. Farret, and M. Simoes, "Application of a modified singlephase P-Q Theory in the control of shunt and series active filters in a 400 Hz microgrid," in *Proc. Power Electron. Spec. Conf.*, Jun. 16, 2005, pp. 2585–2591.

[55] M. Aredes, J. A. Moor, J. C. Ferreira, L. F. Monteiro, R. M. Fernandes, and M. J. Siqueira, "A simplified control strategy for a unified power quality conditioner prototype," in *Proc. Power Electron. Spec. Conf.*, Jun. 16, 2005, pp. 2592–2597.

[56] J. Prieto, P. Salmeron, and R. S. Herrera, "A unified power quality conditioner for wide load range: Practical design and experimental results," in *Proc. IEEE Russia Power Technol.*, Jun. 27–30, 2005, pp. 1–7.

[57] S. Chakraborty and M. Simoes, "Fuzzy ARTMAP based forecast of renewable generation for a high frequency AC microgrid," in *Proc. 31st Annu. Conf. IEEE Ind. Electron. Soc.*, Nov. 6, 2005, pp. 1–6.

[58] K. Kwan, P. So, and Y. Chu, "Unified power quality conditioner for improving power quality using MVR with Kalman filters," in *Proc. 7t h Int. Power Eng. Conf.*, Nov. 29–Dec. 2, 2005, pp. 980–985.

[59] R. Strzelecki, J. Rusinski, and M. Jarnut, "Properties, simulation and experimental investigation of the series–parallel active power filters," in *Proc. Eur. Conf. Power Electron. Appl.*, 2005, pp. 1–9.

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