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Realization of Multi Converter Using Unified Power Quality Conditioning System

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Abstract: *This paper presents a new unified power-quality con-ditioning system (MC-UPQC), capable of simultaneous compen-sation for voltage and current in multibus/multifeeder systems. In this configuration, one shunt voltage-source converter (shunt VSC) and two or more series VSCs exist. The system can be applied to ad-jacent feeders to compensate for supply-voltage and load current imperfections on the main feeder and full compensation of supply-voltage imperfections on the other feeders. In the proposed config-uration, all converters are connected back to back on the dc side and share a common dc-link capacitor. Therefore, power can be transferred from one feeder to adjacent feeders to compensate for sag/swell and interruption. The performance of the MC-UPQC as well as the adopted control algorithm is illustrated by simulation. The results obtained in Simulink on a two-bus/two-feeder system show the effectiveness of the proposed configuration.*

Index Terms: *Power quality (PQ), Simulink, unified power-quality conditioner (UPQC), voltage-source converter (VSC).*

I. Introduction

With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, power-quality (PQ) problems, such as harmonics, flicker, and imbalance have become serious concerns. In addition, lightning strikes on transmission lines, switching of capacitor banks, and various network faults can also cause PQ problems, such as transients, voltage sag/swell, and interruption. On the other hand, an increase of sensitive loads involving digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper load operation [1].

In order to meet PQ standard limits, it may be necessary to include some sort of compensation. Modern solutions can be found in the form of active rectification or active filtering [2]. A shunt active power filter is suitable for the suppression of negative load influence on the supply network, but if there are supply voltage imperfections, a series active power filter may be needed to provide full compensation [3].

In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. The application of FACTS concepts in distribution systems has resulted in a new generation of compensating devices. A unified power-quality conditioner (UPQC) [4] is the extension of the unified power-flow controller (UPFC) [5] concept at the distribution level. It consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a supply feeder [6]–[8].

Recently, multi converter FACTS devices, such as an interline power-flow controller (IPFC) [9] and the generalized unified power-flow controller (GUPFC) [10] are introduced. The aim of these devices is to control the power flow of multi lines or a sub network rather than control the power flow of a single line by, for instance, a UPFC.

When the power flows of two lines starting in one substation need to be controlled, an interline power flow controller (IPFC) can be used. An IPFC consists of two series VSCs whose dc capacitors are coupled. This allows active power to circulate between the VSCs. With this configuration, two lines can be controlled simultaneously to optimize the network utilization.

The GUPFC combines three or more shunt and series converters. It extends the concept of voltage and power-flow control beyond what is achievable with the known two-converter UPFC. The simplest GUPFC consists of three converters one connected in shunt and the other two in series with two trans-mission lines in a substation. The basic GUPFC can control total five power system quantities, such as a bus voltage and independent active and reactive power flows of two lines. The concept of GUPFC can be extended for more lines if necessary. The device may be installed in some central substations to manage power flows of multi lines or a group of lines and provide voltage sup-port as well. By using GUPFC devices, the transfer capability of transmission lines can be increased significantly. Furthermore, by using the multiline-management capability of the GUPFC, active power flow on lines cannot only be increased, but also be decreased with respect to operating and market transaction requirements. In general, the GUPFC can be used to increase the transfer capability and relieve congestions in a flexible way.

This concept can be extended to design multi converter con-figurations for PQ improvement in adjacent feeders. For ex-ample, the interline unified power-quality conditioner (IUPQC), which is the extension of the IPFC concept at the distribution level, has been proposed in [11]. The IUPQC consists of one series and one shunt converter. It is connected between two feeders to regulate the bus voltage of one of the feeders, while regulating the voltage across a sensitive load in the other feeder. In this configuration, the voltage regulation in one of the feeders is per-formed by the shunt-VSC. However, since the source impedance is very low, a high amount of current would be needed to boost the bus voltage in case of a voltage sag/swell which is not feasible. It also has low dynamic performance because the dc-link capacitor voltage is not regulated.

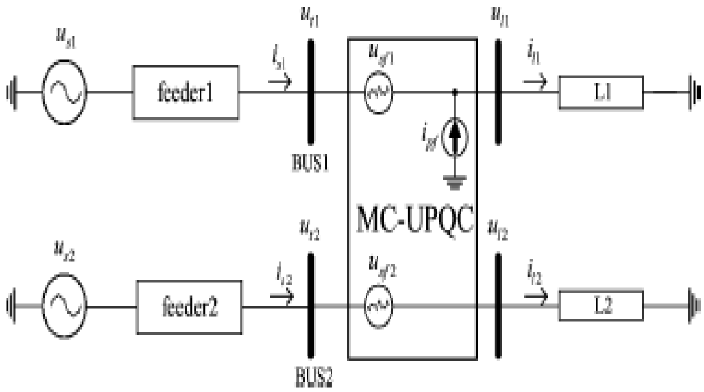

Fig. 1. Single-line diagram of a distribution system with an MC-UPQC.

In this paper, a new configuration of a UPQC called the multiconverter unified power-quality conditioner (MC-UPQC) is presented. The system is extended by adding a series-VSC in an adjacent feeder. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations.

II. Proposed Mc-Upqc System

A. Circuit Configuration

The single-line diagram of a distribution system with an MC-UPQC is shown in Fig. 1.As shown in this figure, two feeders connected to two different substations supply the loads L1 and L2. The MC-UPQC is connected to two buses BUS1 and BUS2 with voltages of u_{t1} and u_{t2}, respectively. The shunt part of the MC-UPQC is also connected to load L1 with a current of i_{l1}Supply voltages are denoted by u_{s1} and u_{s2} while load voltages are u_{l1} and u_{l2}. Finally, feeder currents are denoted by i_{s1} and i_{s2} and load currents are i_{l1} and i_{l2}.

Bus voltages u_{t1} and u_{t2} are distorted and may be subjected to sag/swell. The load L1 is a nonlinear/sensitive load which needs a pure sinusoidal voltage for proper operation while its current is non sinusoidal and contains harmonics. The load L2 is a sensitive/critical load which needs a purely sinusoidal voltage and must be fully protected against distortion, sag/swell, and interruption. These types of loads primarily include production industries and critical service providers, such as medical centers, airports, or broadcasting centers where voltage interruption can result in severe economical losses or human damages.

B. MC–UPQC Structure

The internal structure of the MC–UPQC is shown in Fig. 2. It consists of three VSCs (VSC1, VSC2, and VSC3) which are connected back to back through a common dc-link capacitor. In the proposed configuration, VSC1 is connected in series with BUS1 and VSC2 is connected in parallel with load L1 at the end of Feeder1. VSC3 is connected in series with BUS2 at the Feeder2 end.

Each of the three VSCs in Fig. 2 is realized by a three-phase converter with a commutation reactor and high-pass output filter as shown in Fig. 3. The commutation reactor(L_f) and high pass

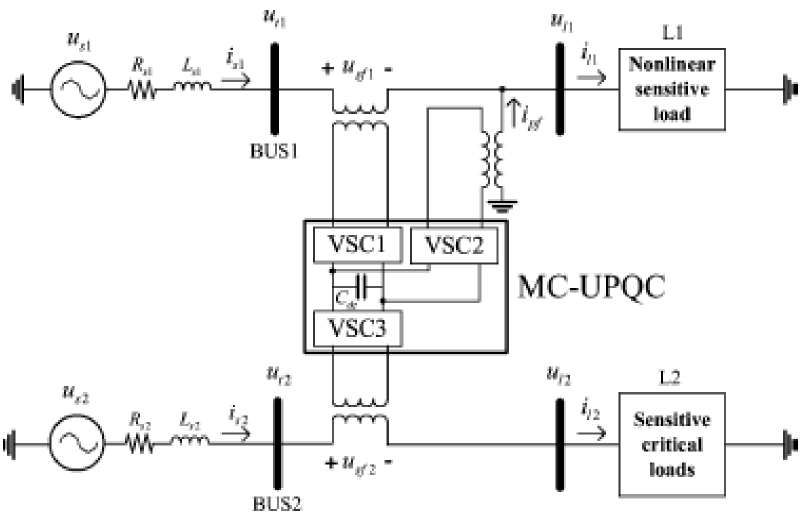

Fig. 2. Typical MC-UPQC used in a distribution system.

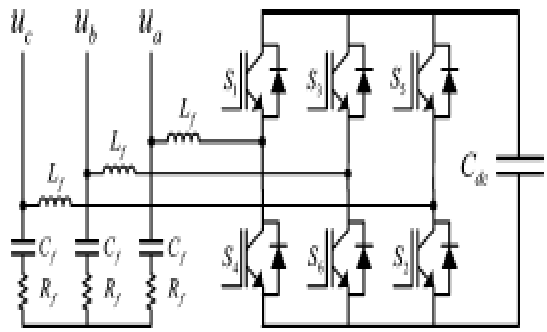
Fig. 3. Schematic structure of a VSC.

Pass output filter (R_f, C_f) are connected to prevent the flow of switching harmonics into the power supply. As shown in Fig. 2, all converters are supplied from a common dc-link capacitor and connected to the distribution system through a transformer. Secondary (distribution) sides of the series-connected transformers are directly connected in series with BUS1 and BUS2, and the secondary (distribution) side of the shunt-connected transformer is connected in parallel with load L1. The aims of the MC-UPQC shown in Fig. 2 are:

1) to regulate the load voltage (u_{l1}) against sag/swell and disturbances in the system to protect the nonlinear/sensitive load L1;
2) to regulate the load voltage (u_{l2}) against sag/swell, interruption, and disturbances in the system to protect the sensitive/critical load L2;
3) to compensate for the reactive and harmonic components of nonlinear load current (i_{l1}) .

In order to achieve these goals, series VSCs (i.e., VSC1 and VSC3) operate as voltage controllers while the shunt VSC (i.e.,VSC2) operates as a current controller.

III. Power-Rating Analysis Of The Mc-Upqc

The power rating of the MC-UPQC is an important factor in terms of cost. Before calculation of the power rating of each VSC in the MC UPQC structure, two models of a UPQC are analyzed and the best model which requires the minimum power rating is considered. All voltage and current phasors used in this section are phase quantities at the fundamental frequency.

There are two models for a UPQC quadrature compensation (UPQC-Q) and in phase compensation (UPQC-P). In the quadrature compensation scheme, the injected voltage by the se-ries-VSC maintains a quadrature advance relationship with the supply current so that no real power is consumed by the series VSC at steady state. This is a significant advantage when UPQC mitigates sag conditions. The series VSC also shares the volt-ampere reactive (VAR) of the load along with the shunt-VSC, reducing the power rating of the shunt-VSC.

Fig. 4 shows the phasor diagram of this scheme under a typical load power factor condition with and without a voltage sag. When the bus voltage is at the desired value (U_l = U_t = U_0) the series-injected voltage

(U_{sf}) is zero [Fig. 6(a)]. The shunt VSC injects the reactive component of load current I_c , resulting in unity input-power factor. Furthermore, the shunt VSC compensates for not only the reactive component, but also the harmonic components of the load current. For sag compensation in this model, the quadrature series voltage injection is needed as shown in Fig. 4(b). The shunt VSC injects in such a way that

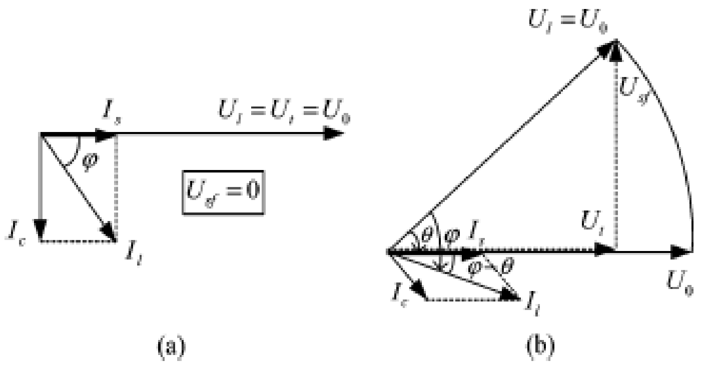

Fig. 4. Phasor diagram of quadrature compensation. (a) Without voltage sag.

(b) With voltage sag.

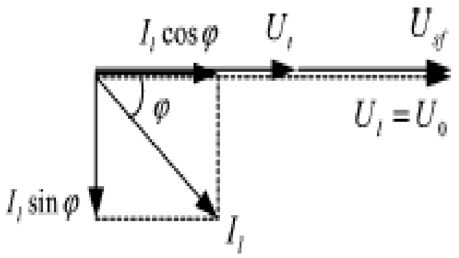

Fig. 5. Phasor diagram of inphase compensation (supply voltage sag).

The active power requirement of the load is only drawn from the utility which results in a unity input-power factor.

In an in phase compensation scheme, the injected voltage is in phase with the supply voltage when the supply is balanced. By virtue of in phase injection, series VSC will mitigate the voltage sag condition by minimum injected voltage. The phasor diagram of Fig. 5 explains the operation of this scheme in case of a voltage sag.

A comparison between in phase (UPQC-P) and quadrature (UPQC-Q) models is made for different sag conditions and load power factors in [13]. It is shown that the power rating of the shunt-VSC in the UPQC-Q model is lower than that of the UPQC-P, and the power rating of the series-VSC in the UPQC-P model is lower than that of the UPQC-Q for a power factor of less than or equal to 0.9. Also, it is shown that the total power rating of UPQC-Q is lower than that of UPQC-P where the VAR demand of the load is high.

As discussed in Section II, the power needed for interruption compensation in Feeder2 must be supplied through the shunt VSC in Feeder1 and the series VSC in Feeder2. This implies that power ratings of these VSCs are greater than that of the series one in Feeder1. If quadrature compensation in Feeder1 and in phase compensation in Feeder2 are selected, then the power rating of the shunt VSC and the series VSC (in Feeder2) will be reduced. This is an important criterion for practical applications.

Based on the aforementioned discussion, the power-rating calculation for the MC-UPQC is carried out on the basis of the linear load at the fundamental frequency. The parameters in Fig. 4 are corrected by adding suffix "1," indicating Feeder1, and the parameters in Fig. 5 are corrected by adding suffix "2," indicating Feeder2. As shown in Figs. 4 and 5, load voltages in both feeders are kept constant at U_0 regardless of bus voltages variation, and the load currents in both feeders are assumed to be constant at their rated values (i.e., I_{01} and I_{02} , respectively).

$$U_l = U_t = U_0 \qquad (1)$$

$$\begin{cases} I_{l1} = I_{01} \\ I_{l2} = I_{02} \end{cases} \qquad (2)$$

The load power factors in Feeder1 and Feeder2 are assumed

To be $cos\varphi_1$ and $cos\varphi_2$ and the per-unit sags, which must be compensated in Feeder1 and Feeder2, are supposed to be and
x_1, respectively.
If the MC-UPQC is lossless, the active power demand supplied
by Feeder1 consists of two parts:
1) the active power demand of load in Feeder1;
2) the active power demand for sag and interruption compensation in Feeder2.
Thus, Feeder1 current (I_{s1}) can be found as

$$U_{t1}I_{s1} = U_{l1}I_{l1}\cos\varphi_1 + U_{sf2}I_{l2}\cos\varphi_2 \quad (3)$$

$$(1-x_1)U_0I_{s1} = U_0I_{01}\cos\varphi_1 + x_2U_0I_{02}\cos\varphi_2 \quad (4)$$

$$(1-x_1)I_{s1} = I_{01}\cos\varphi_1 + x_2I_{02}\cos\varphi_2 \quad (5)$$

$$I_{s1} = \frac{I_{01}\cos\varphi_1}{(1-x_1)} + \frac{x_2I_{02}\cos\varphi_2}{(1-x_1)}. \quad (6)$$

From Fig. 4, the voltage injected by the series VSC in Feeder1
can be written as in (7) and, thus, the power rating of this converter (S_{vsc1})can be calculated as

$$U_{sf1} = U_{t1}\tan\theta = U_0(1-x_1)\tan\theta \quad (7)$$

$$S_{VSC1} = 3U_{sf1}I_{s1} = 3U_0(1-x_1)\tan\theta \times \left(\frac{I_{01}\cos\varphi_1}{1-x_1} + \frac{x_2I_{02}\cos\varphi_2}{1-x_1}\right). \quad (8)$$

The shunt VSC current is divided into two parts.
1) The first part (i.e., I_{c1}) compensates for the reactive component (and harmonic components) of Feeder1 current and can be calculated from Fig. 4 as

$$I_{c1} = \sqrt{I_{l1}^2 + I_{s1}^2 - 2I_{l1}I_{s1}\cos(\varphi_1-\theta)} = \sqrt{I_{01}^2 + I_{s1}^2 - 2I_{01}I_{s1}\cos(\varphi_1-\theta)} \quad (9)$$

Where I_{s1} is calculated in (6). This part of the shunt VSC current only exchanges reactive power (Q) with the system
2) The second part provides the real power (P), which is needed for a sag or interruption compensation in Feeder2. Therefore, the power rating of the shunt VSC can be calculated as

$$S_{VSC2} = 3U_{l1}I_{pf} = 3\sqrt{Q^2+P^2} = 3\sqrt{(U_{l1}I_{c1})^2 + (U_{sf2}I_{l2}\cos\varphi_2)^2} = 3U_0\sqrt{I_{c1}^2 + (x_2I_{02}\cos\varphi_2)^2} \quad (10)$$

where I_{c1} is calculated in (9).
Finally, the power rating of the series-VSC in Feeder2 can be
calculated by (11). For the worst-case scenario (i.e., interruption
compensation), one must consider $x_2 = 1$. Therefore

$$S_{VSC3} = 3U_{sf2}I_{l2} = 3x_2U_0I_{02}. \quad (11)$$

IV. Simulation Results

The proposed MC-UPQC and its control schemes have been tested through extensive case study simulations using Matlab Simulink. In this section, simulation results are presented, and the performance of the proposed MC-UPQC system is shown.

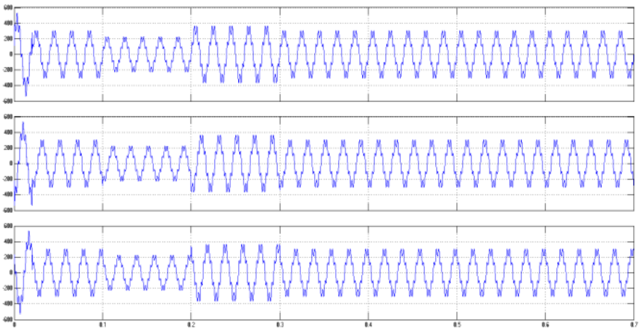

Fig.6 Three Phase Source Voltages

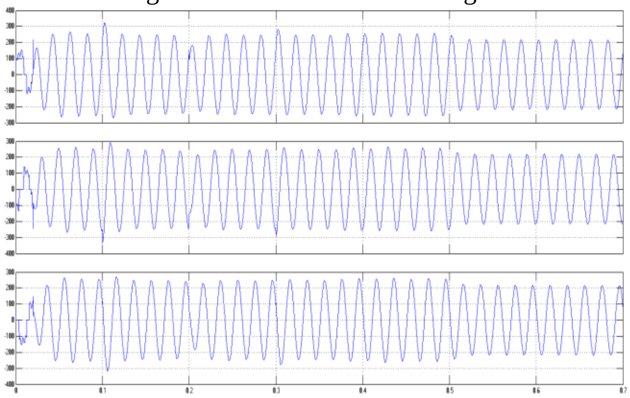

Fig.7 Three Phase Load Voltages

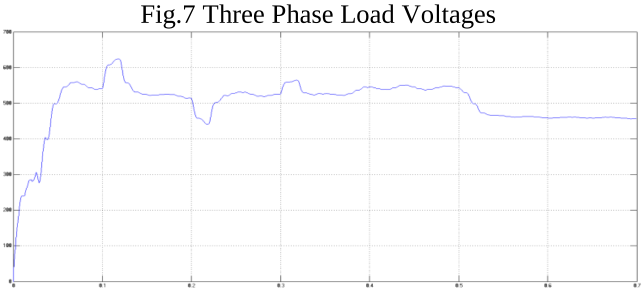

Fig.8 DC Link Voltage

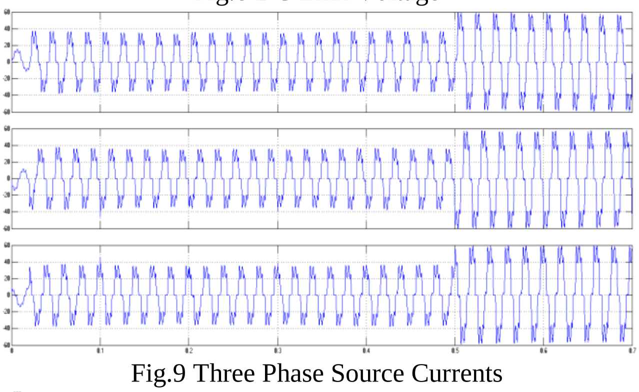

Fig.9 Three Phase Source Currents

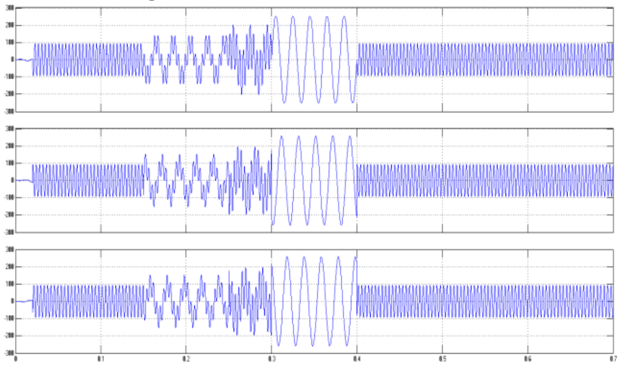

Fig.10 UPQC Voltages

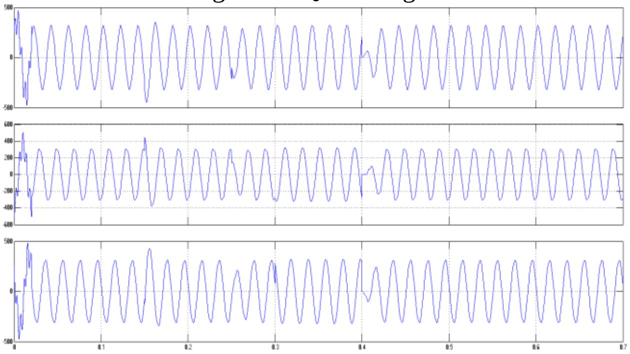

Fig.11 Sensitive load Voltages

V. Conclusion

In this paper, a new configuration for simultaneous compensation of voltage and current in adjacent feeders has been proposed. The new configuration is named multi converter unified power-quality conditioner (MC-UPQC). Compared to

A conventional UPQC, the proposed topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell, and interruption in two-feeder systems. The idea can be theoretically extended to multibus/multifeeder systems by adding more series VSCs. The performance of the MC-UPQC is evaluated under various disturbance conditions and it is shown that the proposed MC-UPQC offers the following advantages:

1) power transfer between two adjacent feeders for sag/swell and interruption compensation;

2) compensation for interruptions without the need for a battery storage system and, consequently, without storage capacity limitation;

3) sharing power compensation capabilities between two adjacent feeders which are not connected

References

[1] D. D. Sabin and A. Sundaram, "Quality enhances reliability," *IEEE Spectr.*, vol. 33, no. 2, pp. 34–41, Feb. 1996.

[2] M. Rastogi, R. Naik, and N. Mohan, "A comparative evaluation of harmonic reduction techniques in three-phase utility interface of power electronic loads," *IEEE Trans. Ind. Appl.*, vol. 30, no. 5, pp. 1149–1155, Sep./Oct. 1994.

[3] F. Z. Peng, "Application issues of active power filters," *IEEE Ind. Appl. Mag.*, vol. 4, no. 5, pp. 21–30, Sep../Oct. 1998.

[4] H. Akagi, "New trends in active filters for power conditioning," *IEEE Trans. Ind. Appl.*, vol. 32, no. 6, pp. 1312–1322, Nov./Dec. 1996.

[5] L. Gyugyi, C. D. Schauder, S. L. Williams, T. R. Rietman, D. R. Torjerson, and A. Edris, "The unified power flow controller: A new approach to power transmission control," *IEEE Trans. Power Del.*, vol. 10, no. 2, pp. 1085–1097, Apr. 1995.

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

[7] A. Ghosh and G. Ledwich, "A unified power quality conditioner (UPQC) for simultaneous voltage and current compensation," *Elect. Power Syst. Res.*, pp. 55–63, 2001.

[8] 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.

[9] L. Gyugyi, K. K. Sen, and C. D. Schauder, "Interline power flow controller concept: A new approach to power flow management in transmission systems," *IEEE Trans. Power Del.*, vol. 14, no. 3, pp. 1115–1123, Jul. 1999.

[10] B. Fardanesh, B. Shperling, E. Uzunovic, and S. Zelingher, "Multi-converter FACTS Devices: The generalized unified power flow controller (GUPFC)," in *Proc. IEEE Power Eng. Soc. Summer Meeting*, 2000, vol. 4, pp. 2511–2517.

[11] A. K. Jindal, A. Ghosh, and A. Joshi, "Interline unified power quality conditioner," *IEEE Trans. Power Del.*, vol. 22, no. 1, pp. 364–372, Jan. 2007.

[12] M. Hu and H. Chen, "Modeling and controlling of unified power quality compensator," in *Proc. 5th Int. Conf. Advances in Power System Control, Operation and Management*, Hong Kong, China, 2000, pp. 431–435.

[13] M. Basu, S. P. Das, and G. K. Dubey, "Comparative evaluation of two models of UPQC for suitable interface to enhance power quality," *Elect. Power Syst. Res.*, pp. 821–830, 2007.