Journal of Engineering and Applied Sciences 11 (4): 772-777, 2016
ISSN: 1816-949X

Improving Power Quality of Distribution Grids Using Multilevel Converter-Based Unified Power Quality Conditioner

Masoud Farhadi, Pedram Ghavidel, Ramin Rahimi and Seyed Hossein Hosseini
Department of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran

Abstract: Power Quality (PQ) is one of the major concerns in the power grids. Where various devices such as Dynamic Voltage Restorer (DVR) and Uninterruptible Power Supply (UPS) have been designed and used to control PQ although, these devices have satisfactory performance and they have some problems such as installation restriction and high cost. This study, proposes a multilevel converter-based Unified Power Quality Conditioner (UPQC) to solve the power quality disturbances. Impact of proposed UPQC on the power quality parameters is discussed in the IEEE 14-bus system. In order to verify the results, PSCAD/EMTDC Software is used to simulate the system.

Key words: Power quality, distribution grid, multilevel converter, UPQC, SPWM

INTRODUCTION

Now a days, renewable energy sources and Distributed Generations (DG) sources are used in order to reduce the environmental pollutions. Using these new generating units cause to the power quality and voltage disturbances in distribution grid which is one of the major concerns in the distribution grid.

Previously, various devices such as Dynamic Voltage Restorer (DVR) and Uninterruptible Power Supply (UPS) have been designed and implemented to control quality voltage. Although, these devices have satisfactory performance and they have some problems such as installation restrictions and high cost (Pal *et al*., 2008). In this study the effect of Unified Power Quality Conditioner (UPQC) on the system under the fault conditions, disturbance, major block outs is being verified. UPQC has different functions such as improving transient stability (Mihalic *et al*., 1996), the oscillation damping (Adware *et al*., 2010) and power flow control (Gyugyi *et al*., 1995). In earlier works (Mihalic *et al*., 1996), UPQC is designed based on two-level power converters. It brings drawbacks such as high THD, low efficiency and etc. This study suggests using three-level UPQC in order to overcome the mentioned shortcomings. Finally, proposed scheme is tested on IEEE 14-bus system.

Power quality: One definition of the PQ is "measurement, analysis and modification of bus voltage, to keep it at rated sinusoidal voltage and frequency" and another definition is "a power quality disturbance is a change in the frequency or voltage and current that causes defects or incorrect performance of the consumer equipment". The most important factor in order to the classification of the disturbances, is occurrence duration of the disturbance. IEEE-159 standard uses two factors, including occurrence duration of disturbance and its amplitude. According to this standard, the PQ disturbances are divided into three categories: transient, short-term variations and long-term variations which it is related to short-term variations mainly such as sag, swell and short-term interruptions (Hosseini *et al*., 2012). Therefore, these disturbances should be reduced to improve the PQ.

MATERIALS AND METHODS

Performance principles and configuration of UPQC: UPQC is one of the Flexible AC Transmission Systems (FACTS) devices used widely to simultaneous control of power flow and transport parameters (i.e., voltage, impedance and phase angle). UPQC consists of two source converters i.e., series and shunt converter with a DC link capacitor (Fig. 1) which is connected in back-to-back form (Hingorani and Gyugyi, 1999). The series converter is often used to control active and reactive power flow by appropriate injection. P_{ref} and Q_{ref} are applied as reference signals to the series converter. Shunt converter is often used to dc-link voltage stabilization by reactive power appropriate injection; therefore, V_{ref} applies as a reference signal to shunt converter. The difference from V_{ref} is measured with α that obtained from; In this equation, V_{ref} is the amplitude of the shunt bus voltage and I_{shq} is reactive current which injected by shunt converter. It is

Corresponding Author: Masoud Farhadi, Department of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran

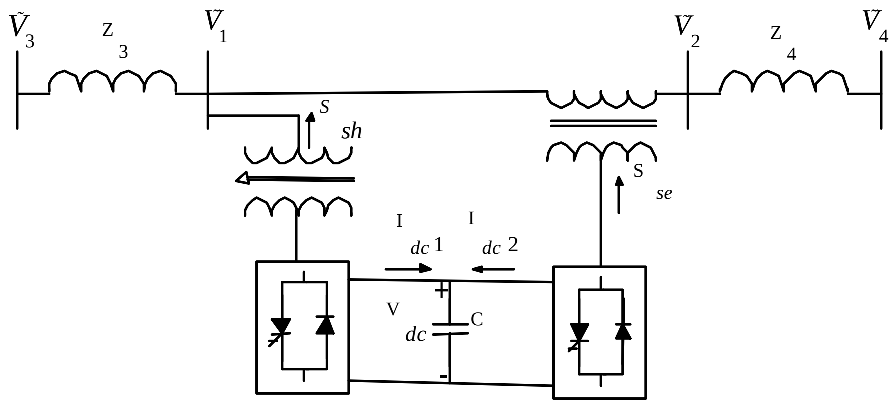

Fig. 1: Configuration of UPQC

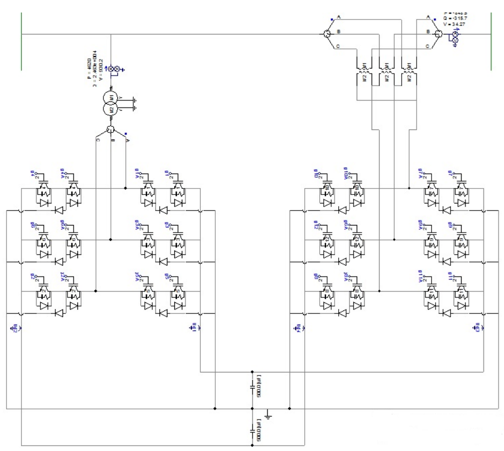

Fig. 2: UPQC circuit in PSCAD/EMTDC

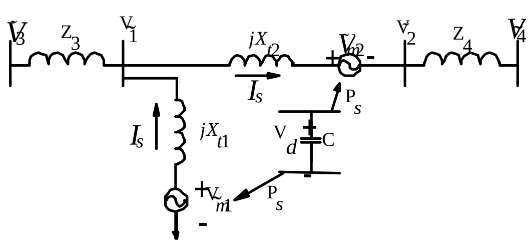

Fig. 3: Positive sequence model of UPQC

clear that for $\alpha = 0$, the voltage drop is zero, otherwise, the controller should produce appropriate fire-pulses in order to compensate this voltage drop. Figure 2 shows UPQC which designed in PSCAD/EMTDC. Figure 3 shows positive sequence model of UPQC which converters are modeled as a voltage source in series with the reactance (the reactance is due to the transformers). The voltage of this converters are defined as follows:

$$\tilde{V}_{m1} = K_1 V_{dc} e^{j(\alpha_{sh} + \theta_1)} \quad (1)$$

$$\tilde{V}_{m2} = K_2 V_{dc} e^{j(\alpha_{se} + \theta_1)} \quad (2)$$

where, α_{sh} and α_{se} are obtained according to the shunt bus voltage. Voltage regulation and controlling power flow are realized by control of parameters K_1 and K_2. Shunt converter, as an adjustable voltage source, injects current and active power to the system which is as follows in Eq. 3 and 4.

$$I_{sh} = \frac{V_{m1} - V_1}{jX_{t1}} \quad (3)$$

$$P_{sh} = \frac{V_1 V_{m1} \sin(\alpha_{sh})}{X_{t1}} \quad (4)$$

Series converter controls power flow with voltage injection (V_{m2}) to the system. Injective current and injective active power of series converter are as follows:

$$I_{se} = \frac{V_1 - (V_{m2} + V_2)}{jX_{t2}} \quad (5)$$

$$P_{se} = \frac{-V_1 V_{m2} \sin(\alpha_{se}) - V_2 V_{m2} \sin(\alpha_{se} + \theta_1 - \theta_2)}{X_{t2}} \quad (6)$$

$$S_2 = V_2 I^*_{se} = \frac{V_2 \left(V^*_1 - V^*_{m2}\right) - V_2^2}{-jX_{t2}} = P + jQ \quad (7)$$

DC voltage collapse should be prevented in order to UPQC operates correctly. DC-link capacitor current is defined as follows:

$$C\frac{dV_{dc}}{dt} = I_{dc} \quad (8)$$

$$V_{dc} I_{dc} = -(P_{sh} + P_{se}) \quad (9)$$

$$\frac{dV_{dc}}{dt} = -\frac{1}{CV_{dc}}\left(P_{sh} + P_{se}\right) \quad (10)$$

So, for a fixed capacitor voltage, series converter active power should be compensated by shunt converter (Jiang *et al*., 2008). Thus, a controller has been used to coordinating reactive power in transient conditions to prevent voltage capacitor and another controller has been used to coordinating active power against bus voltage variations. In order to improve the dynamic performance, controllers have been modeled independently. The D-Q standard form has been used for modeling and designing the controllers (Padiyar and Kulkarni, 1998).

RESULTS AND DISCUSSION

UPQC simulation results on the IEEE 14-bus system: As mentioned above, the UPQC has different functions such as improving transient stability, the oscillation damping and power flow control which they have been reported in the papers. In this study, UPQC is used to improve power quality. In order to demonstrate the effectiveness of UPQC on grid quality, such as voltage sag and swell improve, two modes are considered for the system. In the first case, a single-phase fault occurs over a time period of 30ms and in the second case a capacitor bank is applied to the system over a time period of 40 ms. Total Harmonic Distortion (THD) criterion has been used in order to illustrate harmonic reduction with UPQC.

In this study, UPQC has been simulated on the IEEE 14-bus system which it single-line diagram is shown in Fig. 4. This system consists of 20 lines which is modeled as π model. The system consists of five synchronous machines with type 1 excitation system which three of them, as a synchronous condenser are just to support reactive power. There are 11 loads in the system which is purely 259^{MW} and 81.3^{MVAR}. The excitation systems, generators, buses and transmission lines data's which used in IEEE 14-bus system, has been given by Milano (2007).

The impact of UPQC on voltage sag and swell: In this study, a single phase fault occurs in t = 0.5 sec over a time period of 30 ms and a capacitor bank is applied to the system in t = 0.8 sec over a time period of 40 ms. Figure 5 and 6 show instantaneous voltage and RMS voltage waveforms of bus 4 when UPQC is not connected to the system and this waveform when UPQC is connected to the system are shown in Fig. 7 and 8. It can be observed that when UPQC is installed in the system, voltage regulation is done and voltage swell or voltage sag is reduced Table 1.

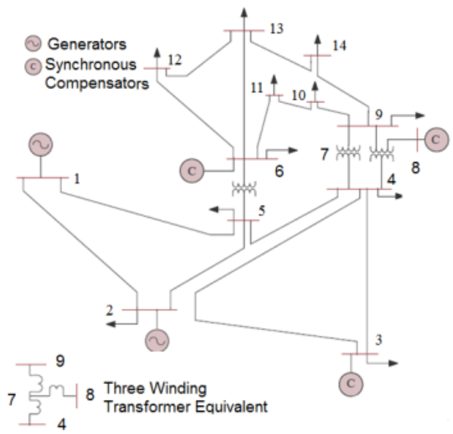

Fig. 4: Bus-14 system single-line

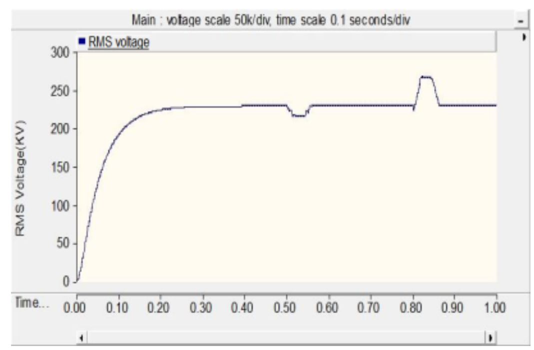

Fig. 5: Bus 4 RMS voltage without UPQC

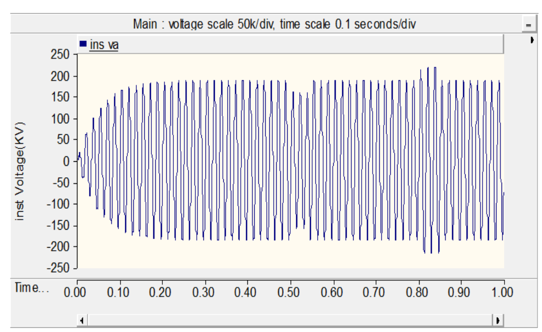

Fig. 6: Bus 4 instantaneous voltage without UPQC

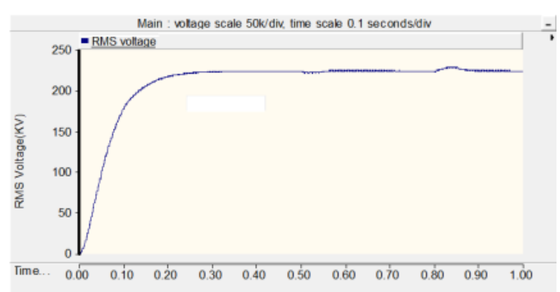

Fig. 7: Bus 4 RMS voltage with UPQC

Table1: The values used in the simulation of the 14-bus system

Variables	Values
Base line-line voltage	230^{kV}
Base power	100^{MVA}
Frequency	60^{Hz}
Voltage amplitude variation range	0.95^{pu}-1.05^{pu}
Phase-angle variation range	-45'-+45'
Exciter type	Type 1

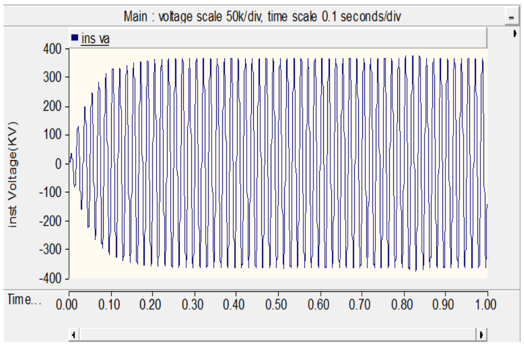

Fig. 8: Bus 4 instantaneous voltage with UPQC

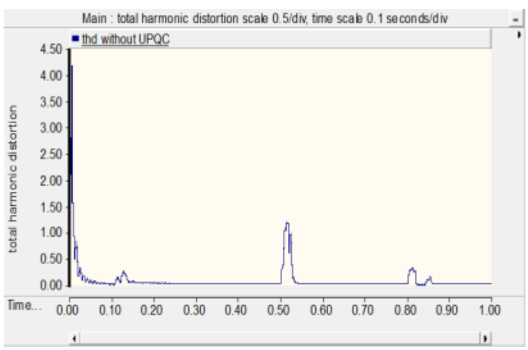

Fig. 9: THD without UPQC

Upqc impact on system harmonics during voltage sag and voltage swell: Harmonics has always been existed in the power system. Today due to increasing use of non-linear loads such as rectifiers and power electronics devices, harmonic value and it destructive effects on the system has increased. In power quality references, to study and control of harmonics, various indices have been presented which one of these useful indicators is THD. If this index is greater than a certain value, then the harmonics will be damaged to grid equipment and will be considered as a pollution source in grids (Hosseini *et al*., 2012).

Figure 9 and 10 show system THD index in the presence and absence of UPQC in power system. The simulation results show that harmonic components of the system are reduced when a voltage sag/swell occurs in the system. Therefore, applying a voltage with high THD to grid equipment is prevented.

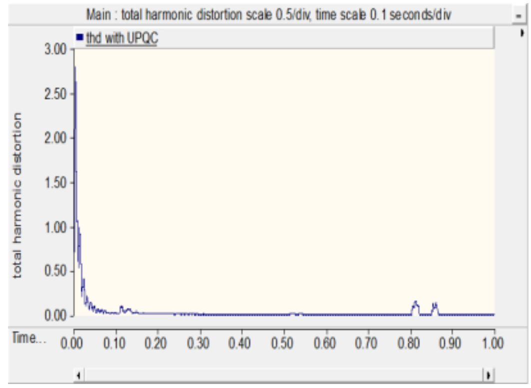

Fig. 10: THD with UPQC

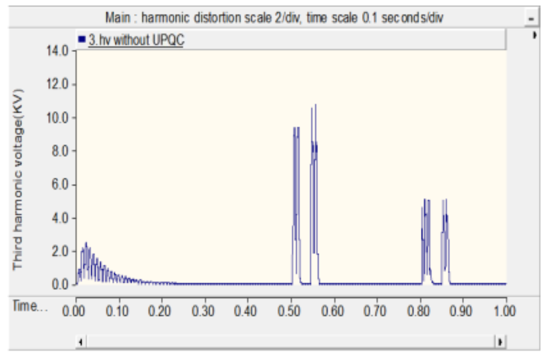

Fig. 11: Voltage third harmonic without UPQC

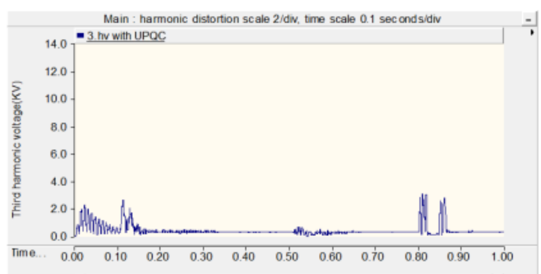

Fig. 12: Voltage third harmonic with UPQC

Figure 11 and 12 show voltage third-harmonic in the presence or absence of UPQC during voltage sag and voltage swell. It can be observed that third-harmonic amplitude has reduced significantly.

The impact of upqc on power oscillations damping during voltage sag and voltage swell: Power oscillations damping in power system has always been as one of the most important issues in the electricity industry (Kundur, 1994). Usually, PSS is used to damp the power oscillations; however because PSS is designed to damp local-mode oscillations, thus it cannot damp region between-mode

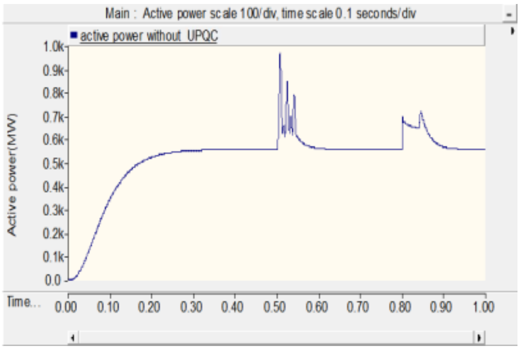

Fig. 13: Active power without UPQC

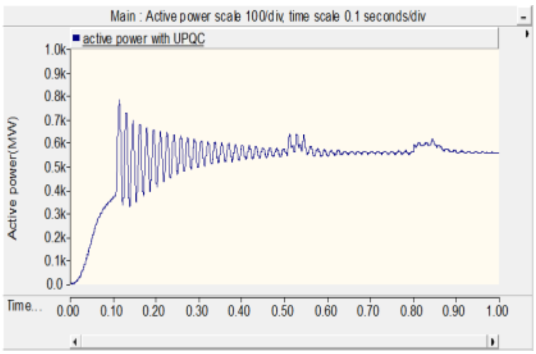

Fig. 14: Reactive power without UPQC

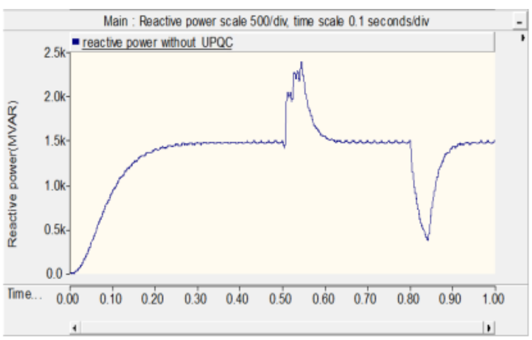

Fig. 15: Active power with UPQC

oscillations in large systems sufficiently (Mithulananthan *et al*., 2002). Therefore, it is better that one of FACTS devices such as UPQC, used to improve damping of region between-modes oscillations (Talebi and Akbarzadeh, 2011). Figure 13-16 show active power oscillations and reactive power oscillations during applying a single-phase fault (t = 0.4 sec) and capacitor banks (t = 0.8 sec) to the power system. It can be observed that UPQC can reduce active power and reactive power oscillations.

The impact of UPQC on rotor-angle oscillations damping: The main cause of low-frequency fluctuations in the power grid is the generator's rotor angle oscillations. It is necessary to damp this oscillation quickly to maintain grid's stability. Figure 17 and 18 show, UPQC prevents the buildup of the rotor-angle.

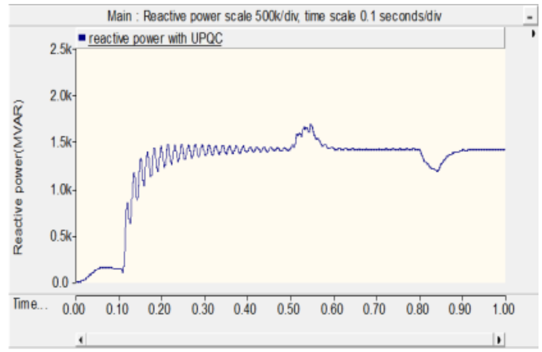

Fig. 16: Reactive power with UPQC

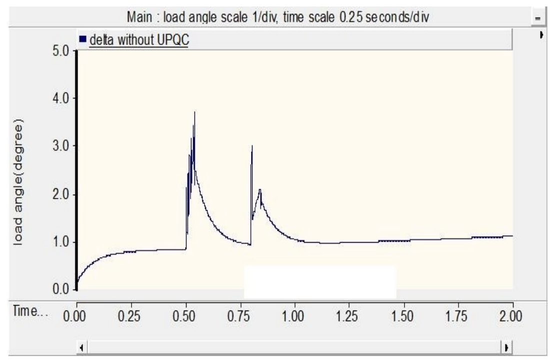

Fig. 17: Load angle without UPQC

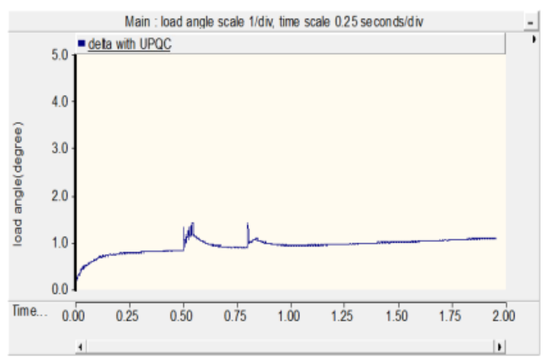

Fig. 18: Load angle with UPQC

Dc link voltage stabilization: As mentioned above, in order to prevent dc-link voltage collapse, a coordination between series and shunt converters should be done. Figure 19 shows that dc-link voltage stabilization is realized with an appropriate simulation of UPQC's controllers.

In this study, the importance of improving Power Quality (PQ) in distribution grids was discussed. Then a

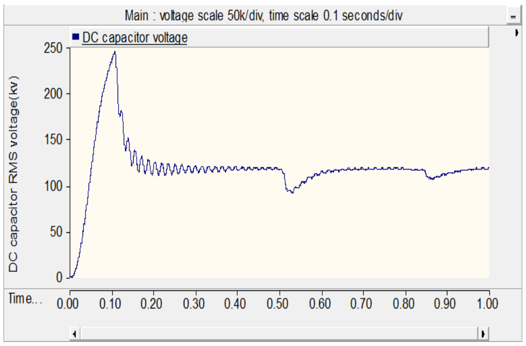

Fig. 19: DC-Link voltage

three-level converter-based UPQC, controlled by SPWM technique is proposed in order to resolve the disturbances in distribution grids. UPQC's performance on the IEEE 14-bus system is analyzed using various simulations which carried out in PSCAD/EMTDC Software. Simulation results show the good performance of UPQC and rapid response of it against the voltage sag and voltage swell. UPQC reduces THD and amplitude of harmonics. Moreover, power oscillations and rotor angle oscillations are damped, perfectly when a fault occurs.

CONCLUSION

In this study, the importance of improving Power Quality (PQ) in distribution grids was discussed. Then a three-level converter-based UPQC, controlled by SPWM technique, is proposed in order to resolve the disturbances in distribution grids. UPQC's performance on the IEEE 14-bus system is analyzed using various simulations which carried out in PSCAD/EMTDC software. Simulation results show the good performance of UPQC and rapid response of it against the voltage sag and voltage swell. UPQC reduces THD and amplitude of harmonics. Moreover, power oscillations and rotor angle oscillations are damped, perfectly when a fault occurs.

ACKNOWLEDGEMENTS

Researcher wish to thank the helpful comments and suggestions from my teachers and colleagues in power electronics lab of University of Tabriz.

REFERENCES

Adware, R.H., P.P. Jagtap and J.B. Helonde, 2010. Power system oscillations damping using UPFC damping controller. Proceedings of the 3rd International Conference on Emerging Trends in Engineering and Technology, November 19-21, 2010, Goa, India, pp: 340-344.

Gyugyi, L., C.D. Schauder, S.L. Williams, T.R. Rietman, D.R. Torgerson and A. Edris, 1995. The unified power flow controller: A new approach to power transmission control. IEEE Trans. Power Delivery, 10: 1085-1097.

Hingorani, N.G. and L. Gyugyi, 1999. Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. 1st Edn., Wiley IEEE Press, New York, USA., ISBN-13: 978-0-7803-3455-7, Pages: 452.

Hosseini, S., T. Nouri and M. Farhadi, 2012. Power Quality in Distributed Networks. 1st Edn., Daneshjou Book Press, Tehran, Iran.

Jiang, X., J.H. Chow, A.A. Edris, B. Fardanesh and E. Uzunovic, 2008. Dynamic control modes of unified power flow controllers for transmission reinforcement. Proceedings of the IEEE/PES Transmission and Distribution Conference and Exposition, April 21-24, 2008, Chicago, IL., USA., pp: 1-8.

Kundur, P., 1994. Power System Stability and Control. McGraw-Hill Professional, New York, USA., ISBN-13: 978-0070359581, Pages: 1176.

Mihallic, R., P. Zunko and D. Povh, 1996. Improvement of transient stability using unified power flow controller. IEEE Trans. Power Delivery, 11: 485-491.

Milano, F., 2007. Documentation for power system analysis toolbox (PSAT). http://www.power.uwaterloo.ca/~fmilano/downloads.htm.

Mithulananthan, N., C.A. Canizares and J. Reeve, 2002. Tuning, performance and interactions of PSS and FACTS controllers. Proceedings of the Power Engineering Society Summer Meeting, Volume 2, July 25-25, 2002, Chicago, IL., USA., pp: 981-987.

Padiyar, K.R. and A.M. Kulkarni, 1998. Control design and simulation of unified power flow Controller. IEEE Trans. Power Delivery, 13: 1348-1354.

Pal, Y., A. Swarup and B. Singh, 2008. A review of compensating type custom power devices for power quality improvement. Proceedings of the IEEE International Conference on Power System Technology, October, 12-15, 2008, New Delhi, pp: 1-8.

Talebi, N. and A. Akbarzadeh, 2011. Damping of Low Frequency Oscillations in power systems with neuro-fuzzy UPFC controller. Proceedings of the 10th International Conference on Environment and Electrical Engineering, May 8-11, 2011, Rome, Italy, pp: 1-4.