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MITIGATION OF POWER QUALITY PROBLEMS USING UNIFIED SERIES SHUNT COMPENSATOR IN MATLAB/SIMULINK

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Abstract

This paper deals with the simulation of a unified series-shunt compensator (USSC), which is aimed at mitigating various power quality issues in power distribution systems. The USSC model comprises of two 12-pulse inverters, one connected in series and another in shunt to the system. A generalized sinusoidal pulse width modulation (SPWM) switching technique has been developed in the proposed controller design for fast control action of the USSC. Simulations were carried out using the MATLAB/SIMULINK to examine the performance of the USSC model. Simulation results from the proposed model demonstrated the capabilities of a unified series shunt compensator (USSC) in performing voltage sag compensation, flicker reduction, voltage unbalance mitigation, UPS mode, power-flow control and harmonics elimination. The USSC has mitigated various power quality problems giving better performance.

Keywords:Unified series shunt compensatorGTO switches, Power quality SPWM technique Power quality mitigation

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1. Introduction

In recent years, both electric utilities and customers are becoming more concerned to the Quality of Electric Power. Power quality issues have received much attention to researchers in few decades. Electrical Power quality is the degree of any deviation from the nominal values of the voltage magnitude and frequency. Power Quality is mainly affected by the increased use of non-linear loads such as power electronic equipment, variable speed drives, electronic control gears etc. The main power quality issues are voltage sag, voltage swell, voltage fluctuations, voltage unbalance, harmonics etc. Poor Power Quality affects the safe, reliable and efficient operation of the electrical equipments. For power-quality improvement, the development of power electronic devices, such as Flexible AC Transmission Systems (FACTS) and custom power devices have introduced an emerging branch of technology providing the power system with versatile new control capabilities. In general, FACTS devices are used in transmission control whereas custom power devices are used for distribution control. Since the introduction of FACTS and custom power concept, devices such as unified power-flow controller (UPFC), synchronous static compensator (STATCOM), dynamic voltage restorer (DVR), solid-state transfer switch, and solid-state fault current limiter are developed for improving power quality and reliability of a system. Investigations have been carried out to study the effectiveness of these power quality compensating devices in the mitigation of power quality issues, such as voltage, voltage swell, voltage unbalance, voltage flicker and harmonics. A power quality compensating devices have been developed for mitigating specific power-quality problems. For example, UPFC works well for power-flow control. The custom power devices are mitigating a particular type of power-quality problem. DVR acts as a series compensator which is used for voltage sag compensation. STATCOM acts a shunt compensator which is used for reactive power and voltage sag compensation. So, it is necessary to develop a new kind of unified series-shunt compensator (USSC) which can mitigate various power quality problems. By using a unified approach of series-shunt compensators, it is possible to compensate the various power-quality problems in a distribution system, such as, voltage sag compensation, voltage swell compensation, voltage unbalance mitigation and voltage flicker reduction. The unified series-shunt compensator (USSC) is almost similar to the UPFC, but the only differences is that UPFC consists of the shunt-series inverters and are used in transmission systems whereas the USSC is the combination of series and shunt voltage source inverters and are used in distribution systems. In this paper, the capabilities of USSC in mitigating power quality problems issues, voltage sag, voltage swell, voltage unbalance, voltage flicker, and UPS mode are explored. The proposed USSC model comprises two 12-pulse inverters. The modeling and simulation of the USSC has been carried out using the MATLAB/SIMULINK. For fast action of the USSC sinusoidal pulse width modulation switching technique have been implemented. However, not much work has been carried out in the development of a USSC. Analyzes have been made by comparing the performance of the USSC with the STATCOM and the DVR and the investigations are carried out in MATLAB/SIMULINK.

2. Principle of Operation of USSC

The Unified Series Shunt Compensator (USSC) is the combination of two 12-pulse voltage source inverters as shown in Fig. 1.

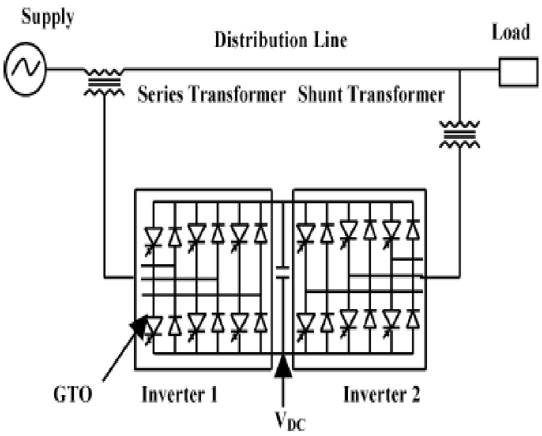

Fig.1. Basic Configuration of a Unified series shunt compensator (USSC).

Both the voltage source inverters are composed of forced commutated power semiconductor switches, typically Gate Turn Off (GTO) thyristor valves. One 12- pulse voltage source inverter is connected in series with the line through a set of series injection transformers, and another 12-pulse inverter is connected in shunt with the line through a set of shunt transformers. The dc terminals of both the voltage source inverters are connected together and their common dc voltage is supported by a capacitor bank.

The principle of operation of a USSC is described by referring to the model of Fig. 2. The inverter connected in series with the distribution line injects a series voltage, V_{dq} to the line, which in turn changes the voltage V_L and line reactance X_L, hence changing the passage of current and the power flow through the distribution line. The exchange of real power P_{inv} and reactive power Q_{inv} can be written in terms of phase angle Φ (angle between the series injected voltage V_{dq} and the line current I_L), line current I_L and series voltage V_{dq} as:

$$P_{inv}= V_{dq} I_L \cos \Phi \qquad (1)$$

$$Q_{inv} = V_{dq} I_L \sin \Phi \qquad (2)$$

The current injected by the shunt inverter have two components, I_d (real or direct current component) and I_q (quadrature current component). Current component, I_d is in phase or in opposite phase with the line voltage V_L, while component, I_q, is in quadrature with the line voltage, thereby emulating an inductive or a capacitive reactance at the point of connection with the distribution line. The reactive current component, I_q, can be independently controlled which in turn will regulate the line voltage, V_L.

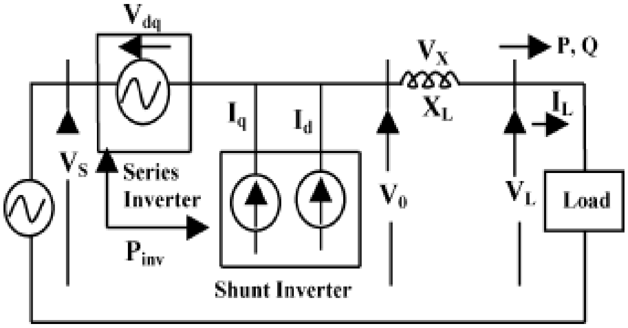

Fig. 2. Principle of operation of USSC.

The USSC behaves as an ideal ac-to-ac inverter, in which the exchange of real power at the terminal of one inverter to the terminal of the other inverter is through the common dc link capacitor. The shunt inverter is controlled in such a way as to provide precisely the right amount of real power at its dc terminal to meet the real power needs of the series inverter and to regulate the dc voltage of the dc bus. Thus, real power is absorbed from or delivered to the distribution line through the shunt connected inverter, which injects a current at the point of connection. Thus, USSC includes the functions of both series and shunt connected inverters which generates or absorbs reactive power to regulate voltage magnitude and current flow at the ac terminal, respectively.

3. Simulation Model of the USSC

The simulation model of the USSC which has been developed to mitigate various power quality problems using the MATLAB/SIMULINK software is shown in Fig. 3. The USSC consists of two 12-pulse voltage source inverters, one 12-pulse voltage source inverter is connected in series and another is connected in shunt with the line. The series and shunt combination of 12-pulse voltage source inverters consists of a two-level, three-phase, 24 self-commutated GTO switches with anti-parallel diodes. This valve combination has capability to act as a rectifier or as an inverter with instantaneous current flows in positive or negative direction, respectively, is the basic voltage source converter concept. The inverter connected in shunt to the line by means of two sets of three single-phase transformers which are of Y-Y (star/star) and Y-Δ (star/delta) configurations to avoid phase shift of other than the order of harmonics in the secondary of the transformers, which may result in large circulating current due to common core of flux. The phase to neutral Harmonic voltages of Y-Y connected secondary, other than the order of 12n±1, i.e., 5th, 7th, 17th, 19th are opposite to those of the phase to phase harmonic voltages of Y connected secondary and with 1/3 times the amplitude. Therefore, the output voltage of shunt inverter would be a 12-pulse wave form, and its harmonic order, 12n±1. However, the inverter is connected in series to the source by means of the two sets of three single-phase transformers with each of Y-Δ (star/delta) configurations. This is because, usually Y (star) connection in the secondary windings of transformers allow the injection of positive, negative and zero sequence voltages, whereas the delta (Δ) connection in the secondary windings allow only the injection of positive and negative sequence voltages. The delta (Δ) connected secondary of the transformers prevents the flow of zero sequence currents into the system from the inverter.

The primary windings of all the single-phase transformers are connected in series for avoiding the harmonic circulating current in the system. For all single-phase transformers the value of the leakage reactance is kept low so as to prevent a large voltage drop. For 22/4.16-kV step-down transformers, the leakage reactance of 0.01 per unit have been considered. One 12-pulse voltage source inverter is configured from two consecutive 6-pulse inverters. The phase shift between two 12-pulse inverters is determined by using the phase shift displacement angle formula, that is, $2\pi/6$ m, where m is the number of the 6-pulse inverters used.

The value of the phase shift is 30^0. The capacitor plays an important role in the USSC operation and it acts as a dc source to provide reactive power to the distribution system and to regulate the dc voltage. In this simulation, the value of an capacitor,considered as 3340 μF.

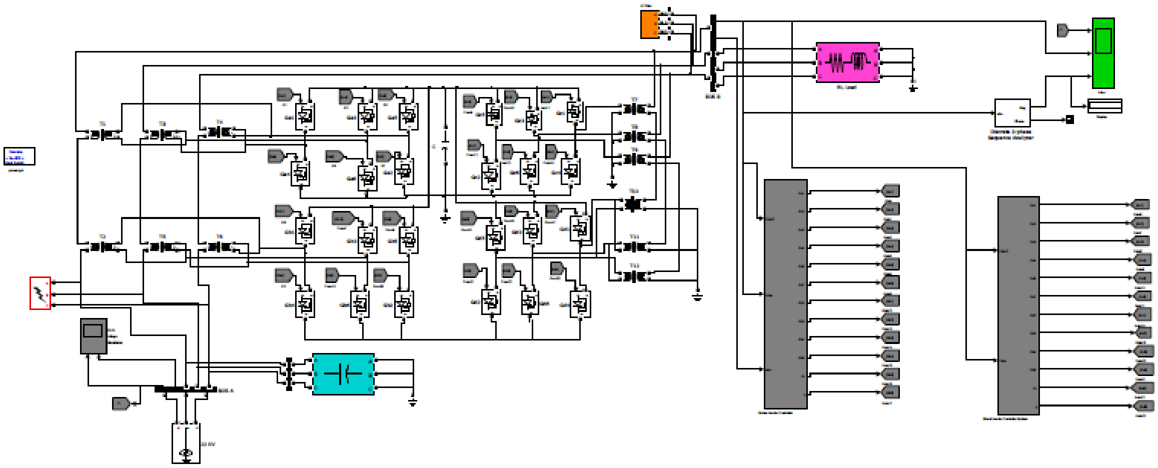

Fig.3. Simulation Model of the Unified Series Shunt Compensator (USSC).

4. Control Systems of the USSC

The control system of the USSC comprises two controllers, namely a shunt inverter controller and a series inverter controller. The function of a series controller is to regulate the series injected voltage, whereas the shunt controller controls the shunt current. When the series and the shunt connected inverters operate as stand-alone devices, they exchange almost exclusively reactive power at their dc terminals. The series connected inverter injects a voltage in quadrature with the line current thereby emulating an inductive or a capacitive reactance in series with the line. The inverter connected in shunt to the system, however, injects a reactive current, thereby also emulating a reactance at the point of connection. When both series and shunt-connected inverters operate together as a USSC, the series injected voltage can be at any angle with respect to the line current. The exchange of real power flow can be between the terminals of series and shunt connected inverters through the common dc link capacitor,C,.

A. Shunt Controller of USSC

The controller connected with a 12-pulse shunt voltage inverter operates as the voltage source inverter in a manner that the phase angle between the inverter voltage and the line voltage is dramatically adjusted so that the shunt inverter generates or absorbs reactive power at the point of connection of the system. The block diagram of the shunt controller of a USSC is shown in Fig.4. This controller is based on sinusoidal pulse width modulated (SPWM) switching technique which is implemented in MATLAB/SIMULINK. In the voltage control loop, the measured three-phase voltages are fed to the phase locked loop (PLL1), its function to detect the phase angles and angular positions of the voltages. The phase locked loop (PLL1) provides the voltage synchronizing signal with an angle, θ. The measured voltages, $V_{p.u}$ is fed to maximum block to obtain the maximum value of the measured voltage. The maximum measured voltage, $V_{p.u}$, now processed by the low pass filter and fed to a comparator. A comparator compares the output voltage of low pass filter with an reference voltage, V_{ref} and it gives error voltage, V_{err}, which is processed by the lag-lead network. The output of the Lag-lead network, Y(t), is fed to the PI controller. The output of the PI controller generates an angle of order δ, which gives either a leading or lagging phase angle, which is necessary to adjust the voltage of the capacitor. The generated angle order, δ, represents the shift between the system voltage and the voltage generated by the shunt inverter. The angle order, δ, combined with voltage synchronizing signal and generates voltage modulating signal, θ, which becomes the voltage modulating signal in which the magnitude and phase angles of the voltages are controlled. The Phase Locked Loop (PLL2), also provides another voltage synchronizing signal which is multiplied by a carrier frequency of 1.65 kHz which is passed through a non-linear block. A Non-linear block converts the ramp signal into triangular carrier signal and fixed the amplitude of triangular signal in between -1 to 1. In the SPWM technique, the triangular carrier signal is compared with the voltage-modulating signal for obtaining the firing signals of the GTOs. The zero crossings of the voltage ramps fire/block the GTOs, depending on the displacement angle δ. If $\delta = 0$, the shunt inverter output voltage is said to be in phase with the ac system voltage. However, if there is an error between the reference voltage, V_{ref}, and the system voltage, $V_{p.u}$, in per unit, that is, $V_{p.u} < V_{ref}$, then the displacement angle $\delta > 0$ and the shunt inverter voltage lags behind the ac system voltage thus causing the flow of real power into the shunt voltage inverter. Consequently, the dc capacitor voltage will increase, thus causing an increase in the ac output voltage of the shunt inverter. The increase in ac output voltage causes a reduction in the error voltage until $V_{p.u} = V_{ref}$. If $V_{p.u} > V_{ref}$, then the displacement angle $\delta < 0$ and the shunt inverter voltage leads the ac voltage thus causing the flow of real power into the system. Consequently, the dc capacitor voltage will decrease, thus causing a decrease in the ac output voltage of the shunt inverter and a reduction in the error voltage until Vp.u = Vref.

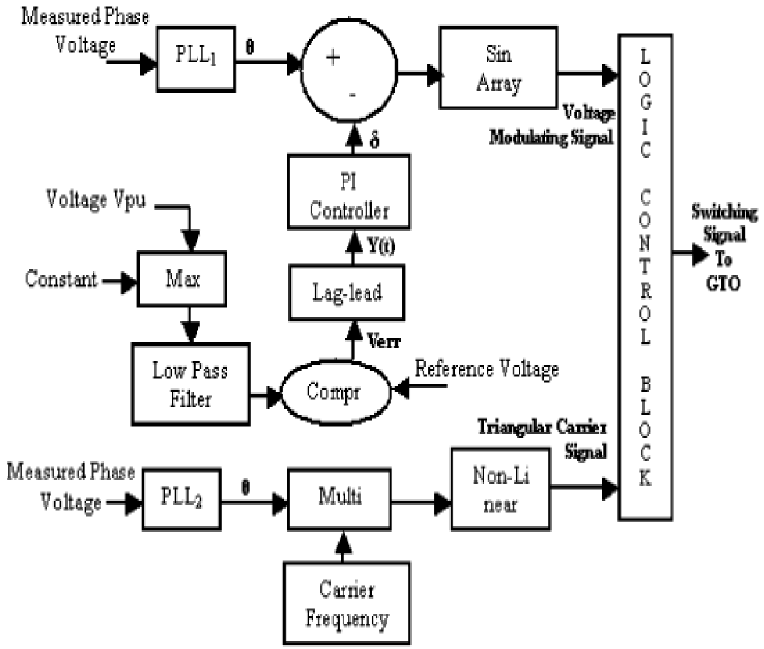

Fig.4. Shunt controller of the USSC.

B. Series Controller of USSC

The controller of a series inverter, is also used the sinusoidal pulse width modulated (SPWM) switching technique to control the magnitude and phase angles of the ac voltage by synchronizing the GTO’s switching to the ac system voltages. The control action for the series inverter is almost same to that of the shunt inverter, but the only difference is that, the measured phase currents are input to the PLL. The series inverter injected voltages are kept in quadrature with the line currents to provide series compensation, whereas in the shunt inverter injected currents are kept in quadrature with the line voltage.

5. Simulation Results

The performance of the USSC model is evaluated by means of simulations using the MATLAB/SIMULINK. The USSC is connected in a 22-kV distribution system with a static load of 5.2 MVA. In a simulation model there are twelve single-phase transformers, each rated at 1 MVA, 22/4.16 kV with a leakage reactance of 0.01 p.u., and connecting the USSC to the 22-kV distribution system. Simulations were carried out to illustrate its effectiveness in compensation for voltage sag, voltage swell, voltage unbalance, voltage flicker, and UPS mode of operation. The harmonic elimination of USSC is also presented.

(a) **USSC for Voltage Sag Compensation**

To illustrate the use of the USSC in compensating the voltage sags, a voltage sag condition is simulated by creating a balanced three phase to ground fault using a three-phase fault generator. Simulation results showing the use of USSC for compensating voltage sags are shown in Fig. 5 in terms of the load voltage in per unit. For the system without the USSC, the load voltage drops from the 0.9 p.u. to 0.5 p.u.,as shown in Fig. 5 (a). This is a voltage sag condition which is due to a three-phase fault, created at time t = 1 s for a duration of 0.75 s. For the system with the USSC connected, the load voltage increases from 0.50 to 1.0 p.u., as shown in Fig. 5 (b).The minimum and maximum voltage values obtained at the starting and ending of voltage sag, are 0.91 and 1.1 p.u., respectively. Thus it can be seen from the results from the simulated USSC model that the USSC shows a better voltage sag compensation capability in terms of the voltage magnitudes.

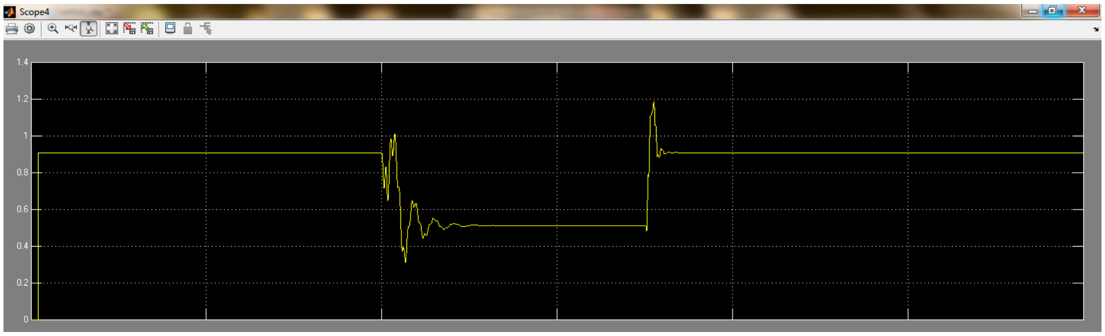

Fig. 5(a). Load Voltage during Voltage Sag without USSC.

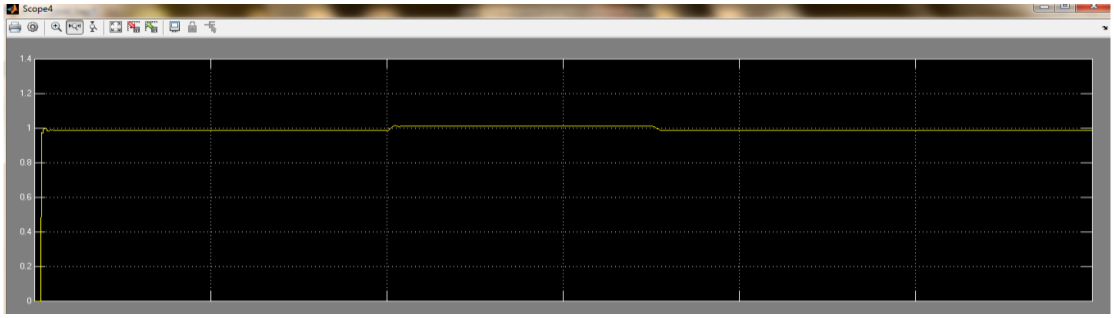

Fig.5(b). Load Voltage during Voltage Sag with USSC

(b) USSC for Voltage Swell Compensation

To illustrate the use of the USSC in compensating the voltage swell, a voltage swell condition is generated by connecting a capacitive load to the line by switching on the breaker at time t = 1 s and is switched off at time t = 1.75 s. For the system without the USSC, the load voltage increases from 0.9 to 1.3 p.u. due to the energization of the capacitor, as shown in Fig. 6(a). For the system with the USSC connected, the load voltage is decreased from 1.7 p.u. to the rated value 1.1 p.u., as shown in Fig. 6 (b). The minimum and maximum voltages values at the starting and ending of voltage swell are 0.94 p.u. and 1.07 p.u., respectively. Thus it can be seen from the results from the simulated USSC model that the USSC shows a better voltage sag compensation capability in terms of the voltage magnitudes.

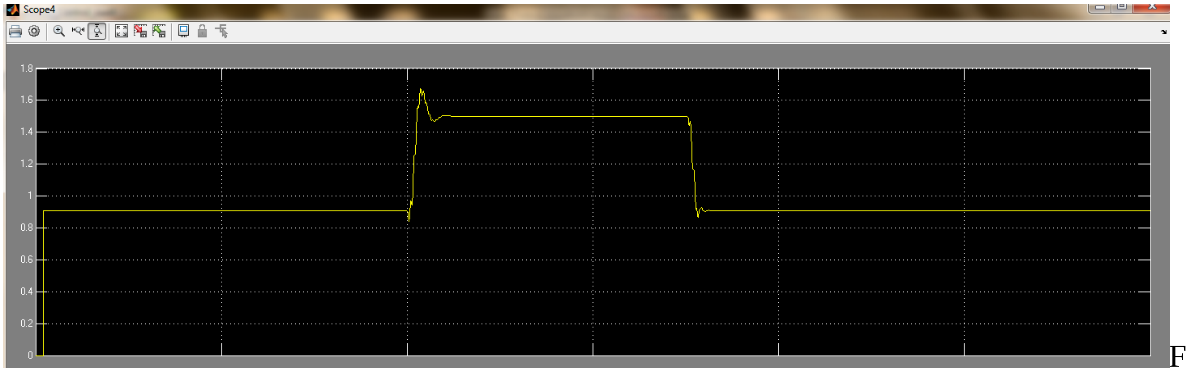

Fig. 6(a). Load Voltage during Voltage Swell without USSC.

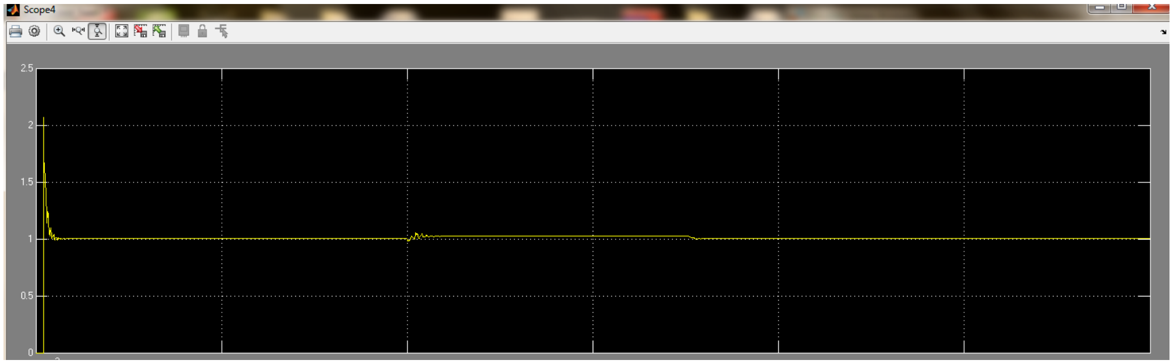

Fig. 6 (b). Load Voltage during Voltage Swell with USSC.

(c)USSC for Voltage Unbalance Compensation

The effect of voltage unbalance is detrimental as it causes heating in motors, thus requiring them to be derated. Unbalance affects the sensitive single phase loads because the unbalance of voltage creates under voltage in one or more of the lines. Therefore, it is necessary to investigate that a unified series shunt compensator (USSC) can able to mitigate voltage unbalance. A two LG faults are created on the phases A and C at time t = 1 s for a fault duration of 100 ms. It is seen in the simulation results as shown in Fig. 7 (a) the three-phase voltages of the system are becomes unbalanced, and the USSC is not connected to the system. It can be seen that during the fault condition, the maximum voltages of phase A, B and C are, V_{Amax}=12.25 kV, V_{Bmax}=16 kV and V_{Cmax}=9.5 kV. The percentage of voltage unbalance is 27.15 %. This value of voltage unbalance indicates that is severe during the fault because the limit of the voltage unbalance is prescribed as 2%.

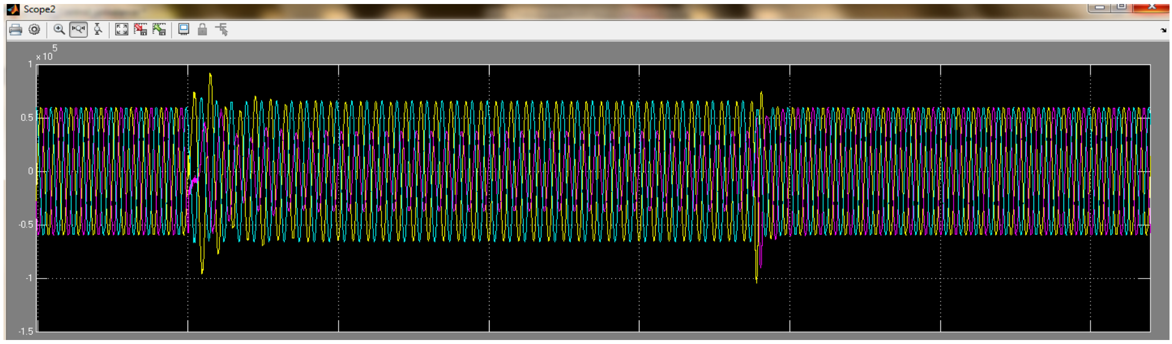

Fig. 7(a). Three Phase Load Voltages during Voltage Unbalance caused by two LG faults without USSC connected

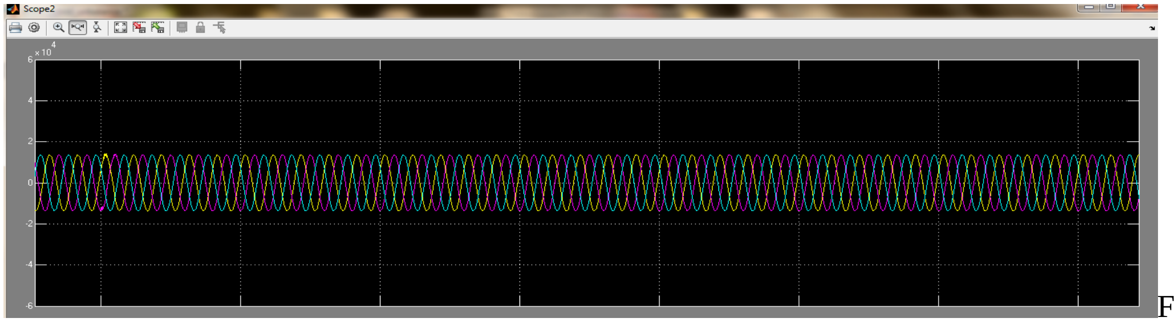

Fig. 7(b). Three Phase Load Voltages during Voltage Unbalance caused by two LG faults with USSC connected

By connecting the USSC into the system, the three-phase load voltages are obtained as shown in Fig. 7 (b). In Fig 8 (a), it is seen that the maximum voltages of phase A, B and C, are V_{Amax}= 18.13 kV, V_{Bmax}=18.5 kV and V_{Cmax}= 17.8 kV. Here, the percentage of voltage unbalance is 1.892 %. Due to the presence of USSC, the load voltage profile has improved in which the phase

A and C voltages are increased and the phase B voltage is reduced and thus making the three phase voltages more balanced. The percentage of voltage unbalance decreases from 27.15 % to 1.892%.

(d)USSC for Voltage Flicker Reduction

Voltage flicker is a phenomenon of annoying light intensity fluctuation resulted by variable electric loads and arc furnaces have been a major power-quality concern.

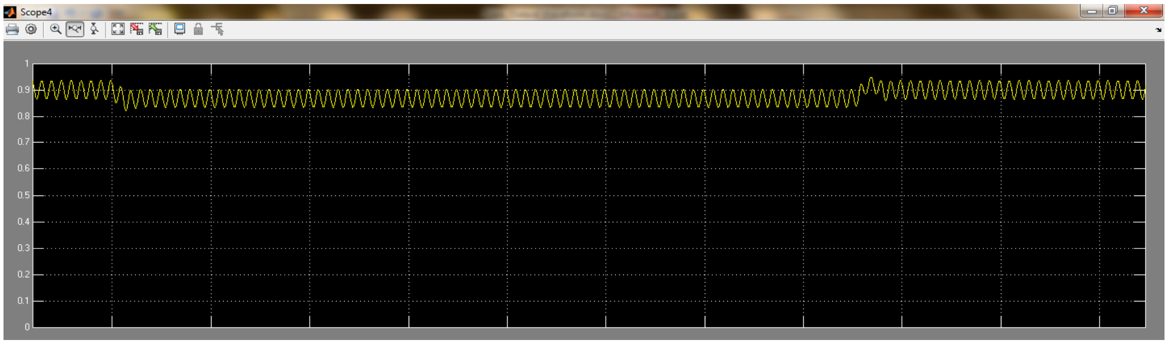

Fig.8(a) Load Voltage during Voltage Flicker without USSC.

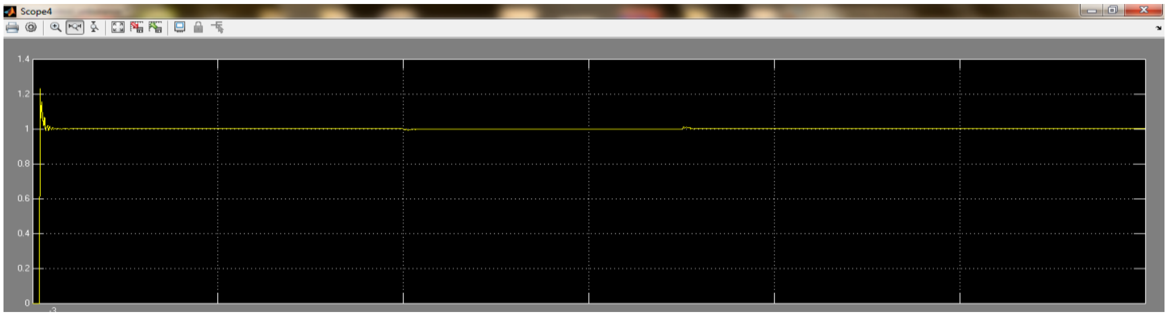

Fig. 8 (b) Load Voltage during Voltage Flicker with USSC.

To illustrate the use of the USSC in reducing voltage flicker, simulations were carried out by considering a variable electric load of 5.2 MVA and connected to a 22 kV source, where 22 kV acts as a source of voltage flicker. The flicker effects phase A voltage of the system as shown in Fig.8 (a) and the unified series shunt compensator USSC is not connected with the system. To eliminate the flicker effect from phase A voltage connecting the USSC into the system so it be seen that the phase A voltage becomes flicker free, as shown in Fig. 8 (b). The simulation results shown here are for the phase A voltage. The responses are also similar for the voltages of phase B and phase C. The simulation results show that without the USSC connected to the system, the effect of the variable electric load results in a voltage flicker index of 0.321 this value exceeds the IEEE SCC22 standard limit of 0.07. However, with the USSC connected to the system, it is observed that the calculated voltage flicker index is reduced to 0.013.

(e)USSC for UPS mode of operation

To operate the USSC in Uninterruptible Power Supply (UPS) mode, an outage is first created by applying a three phase fault at time t = 1 s for a duration of 0.75 s. A DC source is connected to the common DC bus which acts as an energy source for UPS operation and which supply real power to the load. The simulation result is shown in Fig. 9 (a). When the USSC is connected in the system, the USSC recovers the load voltage from 0.0 to 1.0 p.u. within a short time as shown in Fig. 9(b). In the UPS mode, both the series and shunt inverters of the unified series shunt compensator USSC operates in parallel and supports a load of the sum of the inverters rating.

Fig. 9 (a) Load Voltage during Outage without USSC.

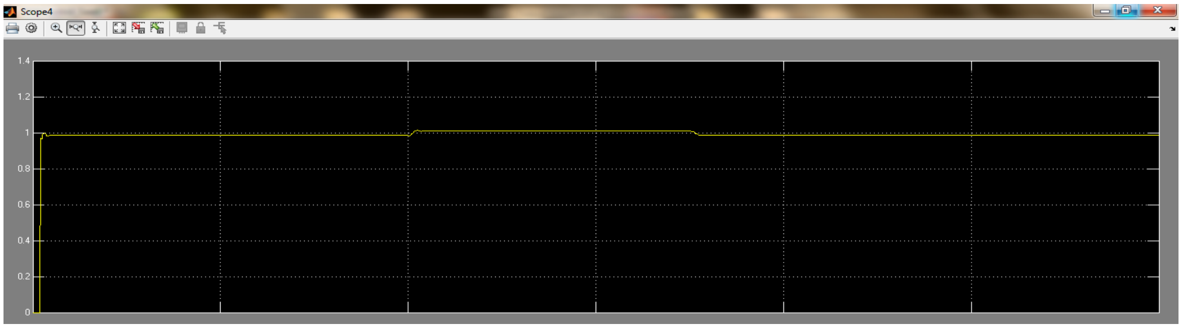

Fig. 9(b). Load Voltage during Outage with USSC

(f)USSC for Harmonic Elimination

Due to high frequency switching losses, the inverters have generated a voltage Total Harmonic Distortion (THD) of about in the range of 45% to 60% as shown in Fig. 10(a). This value of Total Harmonic Distortion (THD) is higher than the acceptable level which is 5%. To reduce the

Total Harmonic Distortion (THD), an inductance-capacitance (LC) passive filter is connected at the load side of distribution system. The values of an inductance, L, and Capacitance, C, are considered as L = 0.1 mH and C = 25 μF in the passive LC filter. Simulations were carried out and the recorded result of THD of the system without filter is shown in Fig. 10 (a) and with the insertion of a Filter into the system is shown in Fig. 10 (b).

From the simulation results, it is observed that with inserting the LC filter in the system, the harmonics are suppressed and the value of THD of the system is reduced to about 4 to 5 %. This value of THD of the system is below the value of the IEEE standard THD limit of 5%. The three phase load voltages without and with passive LC filter connected into the system is shown in Fig. 10(a) and Fig. 10(b), respectively. From both the Figs. 10 (a) and 10 (b), are clear that the distortions in the voltage waveforms due to the harmonics generated by the USSC have been reduced by connecting a passive LC filter into the system.

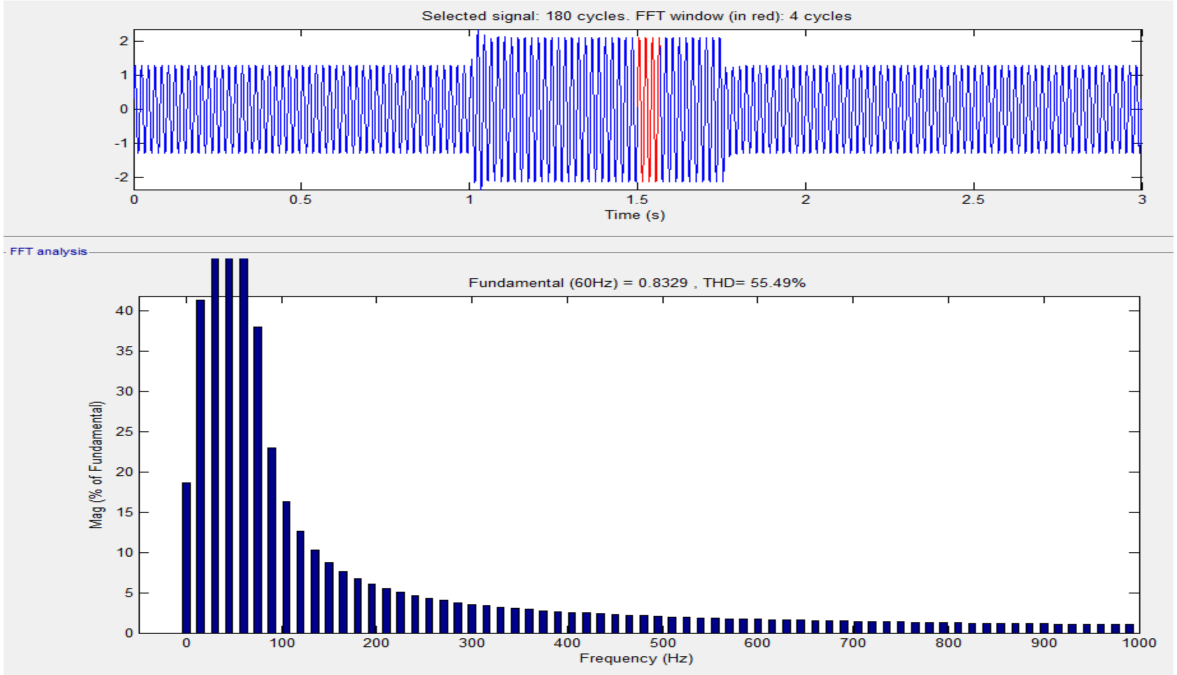

Fig. 10 (a). Total Harmonic Distortion without Filter.

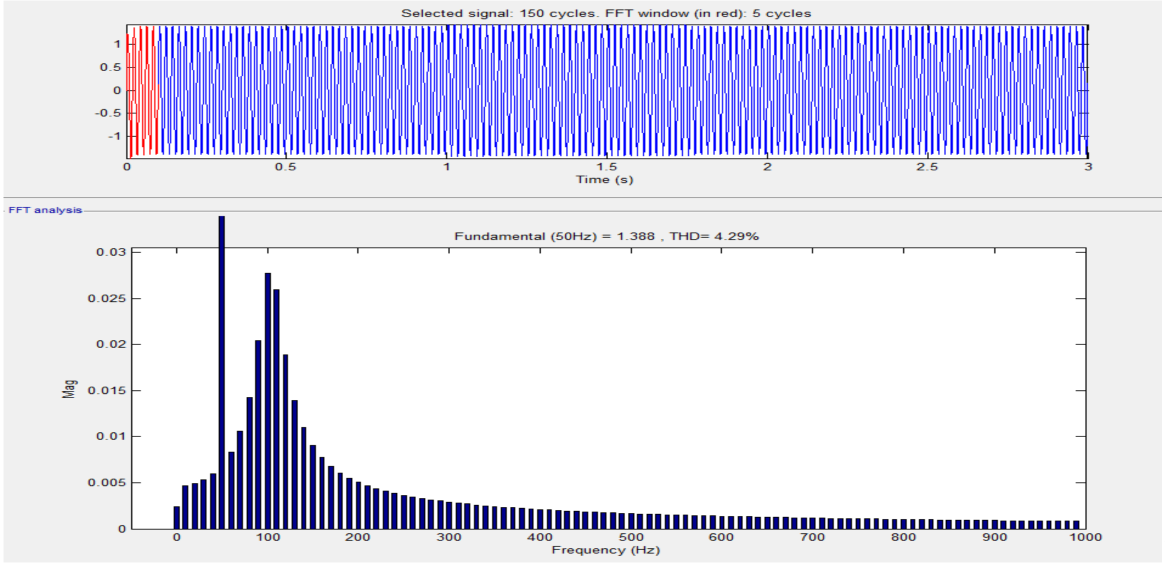

Fig. 10 (b). Total Harmonic Distortion with Filter.

6. Conclusion

The Unified Series Shunt Compensator incorporating 12-pulse series and shunt connected inverters with SPWM based control scheme has been modeled using the MATLAB/SIMULINK. Simulations have been carried out on USSC to evaluate its performance in mitigating various power quality problems. In this paper we investigated the role of the Unified Series Shunt Compensator [USSC] in the distribution networks for the mitigation of the various power quality problems (voltage sag, voltage swell, voltage flicker, voltage unbalance and harmonic distortion). Custom power devices are mainly used for the mitigation of the PQ problems in the distribution networks. The main custom power devices used for the mitigation of the PQ problems are DSTATCOM, DVR, UPQC. The two level USSC incorporating 12-pulse series and shunt connected inverters has been modeled in MATLAB software. The 12-pulse series and shunt inverters comprised the power semiconductor devices, i.e, GTOs. The Switch Pulse Width Modulation (SPWM) -based control scheme has been implemented to control the GTOs of the inverters. Simulations have been carried out to evaluate the performance of the USSC under various operating conditions and power quality disturbances. Simulation results revealed that the USSC can mitigate effectively voltage sag, flicker reduction, and voltage unbalance. It was also shown that harmonics generated by the USSC can be significantly reduced by connecting a passive filter to the system.

References

[1] L. Gyugyi, "Unified power-flow control concept for flexible AC transmission systems", IEE Proceedings-C, Vol. 139, No. 4, pp. 323–331, July 1992.

[2] L. Gyuqyi, T. R Rietman, A. Edris, C. D. Schaudar, D. R Torgerson, S. L. Williams, "The unified power flow controller: A New approach to power transmission control", IEEE Transactions on Power Delivery, Vol. 10, No. 2, April 1995.

[3] I. Papic, P. Zunko, D. Povh, and M.Weinhold, "Basic control of unified power flow controller," IEEE Transactions on Power Systems, Vol. 12, No. 4, pp. 1734–1739, November 1997.

[4] Stephen W. Middlekauff, and E. Randolph Collins, "System and Customer Impact: Considerations for Series Custom Power Devices", IEEE Transactions on Power Delivery, Vol. 13, No. 1, January 1998.

[5] Enslin, J.R, "Unified approach to power quality mitigation", Proceeding of IEEE International Symposium on Industrial Electronics (ISIE '98), pp: 8-20, 1998 DOI:10:1109/ISIE.1998.707741.

[6] C. D. Schaudar, D.M Hamai, L. Gyuqyi, T. R Rietman, A. Edris, M.R Lund , D. R Torgerson, "Operation of the unified power flow controller (UPFC) under practical constraints", IEEE Transactions on Power Delivery, Vol. 13, No. 2, April 1998.

[7] B. Singh, K. Al-Haddad, and A. Chandra, "A review of active filters for power quality improvement," IEEE Transactions and Industrial Electronics, Vol. 46, No. 5, pp. 960–971, 1999.

[8] N. G. Hingorani and L. Gyugyi, Understanding FACTS Concept and Technology of Flexible AC Transmission System. New York: IEEE Press, 2000.

[9] P. Pohjanheimo and E. Lakervi, "Steady state modeling of custom power components in power distribution networks," in Proceedings of IEEE Power Engineering Society Winter Meeting, Vol. 4, pp. 2949–2954. January 2000.

[10] M.H. Haque, "Compensation of distribution system voltage sag by DVR and D-STATCOM", Proceedings of IEEE Conference, Porto, Portugal, 2001.

[11] A. L. Olimpo and E. Acha, "Modeling and analysis of custom power systems by PSCAD/EMTDC," IEEE Transactions on Power Delivery, Vol. 17, No. 1, pp. 266–272, January 2002.

[12] M. A. Hannan and A. Mohamed, “Modeling and Analysis of a 24-Pulse Dynamic Voltage Restorer in a Distribution System”, IEEE proceedings, Student Conference on Research and Development, 2002.

[13] M. A. Hannan and Azah Mohamed, “PSCAD/EMTDC Simulation of Unified Series-Shunt Compensator for Power Quality Improvement” IEEE Transactions on Power Delivery, Vol. 20, No. 2, April, 2005.

[14] Alexander Domijan, Jr., Alejandro Montenegro, Albert J. F. Keri, and Kenneth E. Mattern, “Custom Power Devices: An Interaction Study”, IEEE Transactions on Power Systems, Vol. 20, No. 2, May 2005.

[15] Yong-June Shin, Edward J. Powers, Mack Grady, and Ari Arapostathis “Power Quality Indices for Transient Disturbances” IEEE Transactions on Power Delivery, Vol. 21, No. 1, January, 2006.

[16] S.V Ravi Kumar and S. Siva Nagaraju, “Simulation of D-STATCOM and DVR in Power Systems”, ARPN Journal of Engineering and Applied Sciences, Vol. 2, No. 3, June 2007.

[17] Ashwin Kumar Sahoo and T. Thyagarajan, “Modeling of Facts and Custom Power Devices in Distribution Network to Improve Power Quality”, Third International Conference on Power Systems, Kharagpur, INDIA, December 2009.

[18] S. Asha Kiranmai, M.Manjula and A.V.R.S.Sarma, “Mitigation of Various Power Quality Problems Using Unified Series Shunt Compensator in PSCAD/EMTDC”, 16th National Power Systems Conference, 15th -17th, December, 2010.

[19] M. Najafi, M. Hoseynpoor, M. Davoodi, T. Karimi “Mitigation of Power Quality Problems with Series Active Filter” Australian Journal of Basic and Applied Sciences, Vol. 5, No.7, pp. 622-628, 2011.

[20] S.Sundeep, Dr. G. Madhusudhana Rao, “Modelling and Analysis of Custom Power Devices for Improve Power Quality”, International Journal of Electrical and Computer Engineering (IJECE), Vol.1, No.1, pp. 43-48, September, 2011.

[21] Neha Bajpai and S.Gupta “Simulation of Unified Series Shunt Compensator for Power Quality Improvement” International Journal of Computer Applications (0975 – 8887) on Electronics, Information and Communication Engineering – ICEICE, No.2, Dec 2011.

[22] “A Robust Control Strategy for UPFC to Mitigate Voltage Flicker Using Fuzzy Bang-Bang Control” Trends in Advanced Science and Engineering, TASE, Vol. 3, No.2, pp. 43-53, 2012.

[23] S.Sahaysa elsi and M.Rajaram "Modeling of unified series shunt compensator", European Journal of Scientific Research, Vol, 91, No. 4,pp. 604-614, December, 2012.

[24] Shin, Y.J., E.J. Powers, M. Grady and A. Arapostathis, 2006, Power quality indices for transient disturbances, IEEE Trans. Power Delivery, 21: 253-261. DOI: 10.1109/TPWRD. 2005.855444.

[25] Oliver, J.A., R. Lawrence and B.B. Banerjee, How to specify power-quality-tolerant process equipment. IEEE Industrial Applied Magazine, 8: 21-30. DOI: 10.1109/MIA.2002.1028387, 2002.

[26] Parle, J.A., M. Madrigal and E. Acha, Trends in power quality monitoring. IEEE Power Engineering. Rev., 21: 3-21. DOI: 10.1109/39.954584, 2001.

[27] Le Roux, A.D., H.T. Mouton and H. Akagi, 2003. Digital control of an integrated series active filter and diode rectifier with voltage regulation. IEEE Transactions on Industrial Application, 39: 1814-1820. DOI: 10.1109/TIA.2003.819440.

[28] Hideaki Fujita and Hirofumi Akagi, "The Unified Power Quality Conditioner: The Integration of Series- and Shunt-Active Filters", IEEE Transactions on Power Electronics, Vol. 13, No. 2, March 1998.

[29] C. Su and G. Joos, "Series and shunt active power conditioners for compensating distribution system faults," in Canadian Conf. Electrical and Computer Engineering, Vol. 2, Mar. 2000, pp. 1182–1186.

[30] D. E. Soto-Sanchez and T. C. Green, "Voltage balance and control in a multi-level unified power flow controller," IEEE Transactions on Power Delivery, Vol. 16, No. 4, pp. 732–738, October 2001.

[31] R. L. V. Arnez and L. C. Zanetta, "Unified power flow controller (UPFC): its versatility in handling power flow and interaction with the network," in Proc. IEEE/PES Asia Pacific Transmission and Distribution Conference and Exhibition, Vol. 2, pp. 1338–1343, October 2002.

[32] Bie, Z.H., Y.H. Song, X.F. Wang, G.A. Taylor and M.R. Irving, Integration of algorithmic and heuristic techniques for transition-optimized voltage and reactive power control. IEE Proceeding Generation Transmission Distribution, 153: 205-210. DOI: 10.1049/ip-gtd:20050019, 2006.