

Improved Unified Power Quality Conditioner Design and Numerical Simulation for Power Quality Improvement

Nandini Joshi^{1,*}, Bharat Bhushan Jain²

Abstract

Harmonic currents can distort the waveform voltage, resulting in a weak signal. There is also an increase in the number of loads requiring enough sinus tension to function properly. As electronic devices become more power-sensitive, people are becoming increasingly interested in power conditioning solutions. Therefore, if the amount of electricity being generated falls below a certain threshold, some type of compensation must be provided. Unified Power Quality Controller (UPQC) is an AC Transmission System family capable of managing voltage, impedance and phase angle during transmission. UPQC (FACTS). It is necessary to enhance the power system's power quality by employing a Dynamic Voltage Restorer, a Fuzzy Controlled Shunt Active Power Filter, and a UPQC. DVRs (Dynamic Voltage Restorers) are power converters fitted in responsive load arrays that give protection against disruptions on the supply side. It is a fantastic tool for improving the quality of electrical power because of its quick response time and high level of dependability. In order to illustrate the efficiency of the proposed system, the simulation results were compared to the basic system and enhanced.

Keywords: UPQC, FUZZY LOGIC, THD, SAG, SWELL, HARMONICS

INTRODUCTION

A variety of power quality challenges can now be addressed in new and inventive ways thanks to these power converter devices. The distribution grid is supplied into harmonic currents via non-linear equipment such electrical converters, which raise the total reactive power required by equivalent load. As a result of the increased demand for sensitive power, the feeder's voltage declines and its loss increases. Energy quality can be negatively affected by harmonic currents, which cause additional losses and voltage distortion. There has also been a growth in the number of delicate loads requiring optimum sinusoidal tension in order to function correctly. In the field of power technology, the increasing usage of electronic devices responsive power is a fueling factor. Some type of correction is also required to keep the power's efficiency within acceptable levels. Power electronic energy-conditioning systems can improve customer power quality [1–3]. Efficiency is raised, size is lowered, and control is improved with the power electronic transition. Non-linear loads are generated by switching actions in such systems (Figure 1).

***Author for Correspondence**
Nandini Joshi

¹Scholar, Department of Electrical Engineering, Jaipur Engineering College Kukas, Jaipur, Rajasthan, India

²Professor, Department of Electrical Engineering, Jaipur Engineering College Kukas, Jaipur, Rajasthan, India

Received Date: March 10, 2022

Accepted Date: March 18, 2022

Published Date: March 20, 2022

Citation: Nandini Joshi, Bharat Bhushan Jain. Improved Unified Power Quality Conditioner Design and Numerical Simulation for Power Quality Improvement. Journal of Microwave Engineering & Technologies. 2021; 8(3): 52–60p.

Industrial automation has reached previously unheard-of levels of complexity. An extensive public grid is needed to support the many complex technologies presently housed in facilities, including automobile manufacturing factories and chemical manufacturing plants. The grid, on the other hand, can deviate and disrupt in an unpredictable manner. If this network contains a sensitive charge, a power quality device, such as a DVR system or a SAPF, must be used to assure a

rock-solid, clean, and uninterrupted supply of power to the charge. Due to developments in semiconductor technology at higher voltage levels, the gadget appears promise to researchers for use in the transportation and distribution industry [4–8]. These systems, on the other hand, draw a trailing current from the source when they are linked to the benefits. These structures are distorted and deformed as a result of this. As a result, the power networks operate as substantial reactive voltage amplifiers into which harmonics are injected. Workers can be injured, waste material is produced, and the system must be restarted for long periods of time when voltage drops occur in the industrial setting. Low manufacturing quality can result in lost sales and/or contract fines as a result of system malfunctions, faults, extensive maintenance, and exorbitant service costs. Expenses can quickly rise into the millions of dollars, especially in high-volume industries like semiconductors, automobiles, and chemicals.

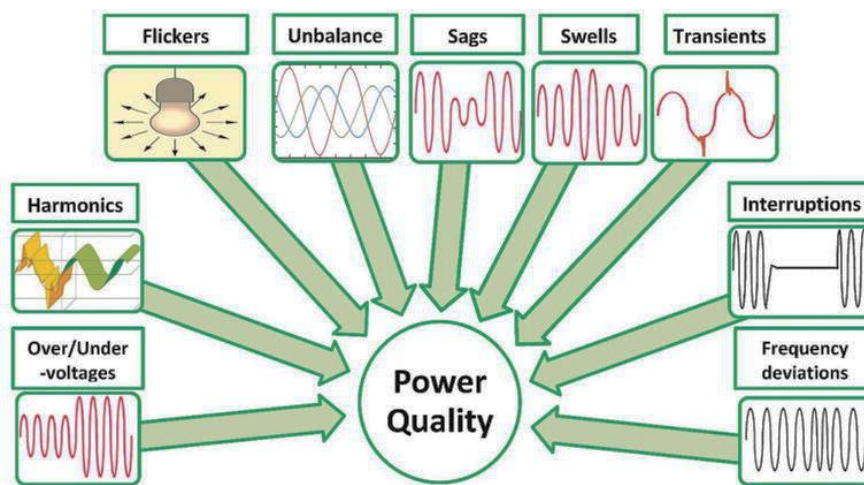


Figure 1. Power Quality Disturbances.

UNIFIED POWER QUALITY CONDITIONER

UPQC is also known as a universal power quality conditioning system, an active power line conditioner, or an active filter. The UPQC combines a shunt (Active Power Filter) with a series compensator to enable active power sharing via a shared DC link capacitor (Dynamic Voltage Restorer) [9–14]. Both the distribution network operator and the end consumer can address power quality concerns in a variety of ways. Because of the multiple benefits given by power electronic devices, power processing at the supply, load, and for reactive and harmonic compensation is becoming more frequent. The primary advantage of UPQC is that it does not require energy storage. It can be configured to attenuate any sag that reaches a specific magnitude, regardless of duration. This could lead to the development of a device that competes with the uninterruptible power supply (UPS), which is commonly used to protect low-power, low-voltage electronic equipment. DSTATCOM, which is personalised to each individual, is substantially less adaptable than UPQC. Multilevel topology, single-phase UPQC with two half-bridge converters, single-phase UPQC with three legs, and H bridge topology are all examples of UPQC topologies (Ghosh et al. 2004). UPQC is typically used to alter the voltage across a sensitive load on one feeder while also adjusting the bus voltage on the other. The MC-UPQC (multi converter universal power quality conditioner) is a revolutionary design that compensates voltage and current in adjacent feeds at the same time [15–20].

Shunt active power filters are typically connected across loads to address all current-related issues like reactive power compensation, power factor improvement, current harmonic compensation, and load unbalance compensation, whereas series active power filters are typically connected in series with a line via a series transformer to address all current-related issues like reactive power compensation, power factor improvement, current harmonic compensation, and load unbalance compensation. It functions as a regulated voltage source that may correct for voltage problems such

voltage harmonics, voltage sag, voltage swell, and flicker [4]. The shunt component facilitates in the rectification of energy quality concerns caused by users. This includes low-power loads, harmonic loads, load imbalances, and DC offset, to name a few. On the dc side, the UPQC's shunt section consists of a voltage source inverter (VSI) coupled to a shared DC storage condenser, and on the shunt side, an inductor and shunt link transformer. The VSI shunting frequency harmonics are filtered out using the shunt interface induction and the shunt filter condenser. The shunt link transformer balances the network and VSI voltages (Figure 2).

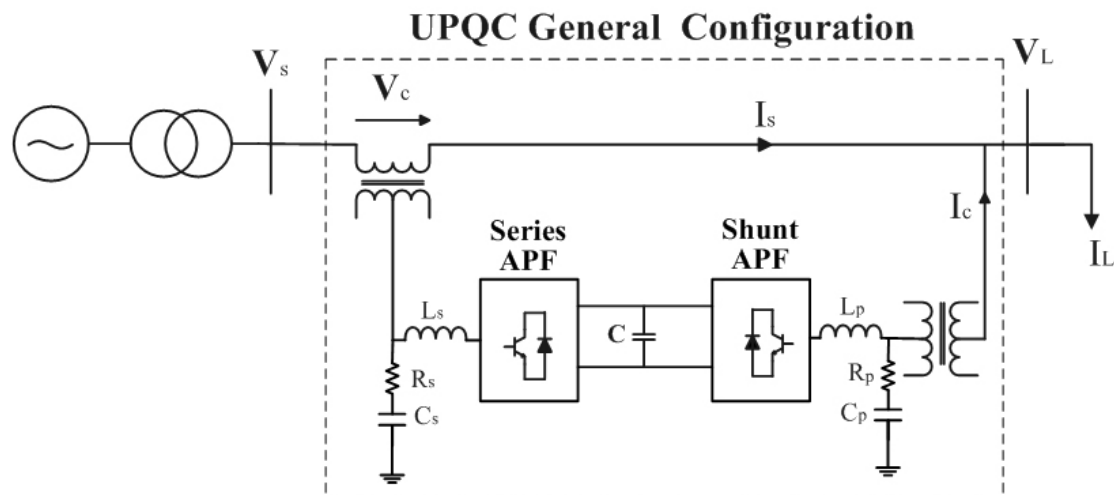


Figure 2. UPQC Block Diagram.

The compensation circuit's common connecting point is the shunt active filter, which cancels the reactive and harmonic components of charge currents and eliminates load current unbalance. The dc storage condenser and the Shunt VSI are used to inject current into the circuit. The control system creates the necessary switching signals for the VSI Shunt switches based on predicted currents and voltages. The true currents and voltages calculated are influenced by the control strategy employed. In addition, the VSI-connected series process uses the shunt system as the real power flow conduit. In addition, the DC storage condenser keeps the average voltage constant. In present control mode, the VSI shunt is controlled. The necessary VSI switches are turned on and off from time to time to monitor the injected currents from the shunt active filter in a given hysteresis band (assuming that the hysteresis controller is issued) [21–26].

The dc condenser is turned on either positively or negatively by the VSI. The supply voltage is provided when the dc condenser tension is positive, causing the VSI current to rise. The VSI current reduces when a negative DC capacitor is employed because the voltage is the inverse of the supply voltage. As a result, within the hysteresis zone, the reference current alternates between increasing and decreasing. "Unit Control for Hysteresis" is the name given to this process. The dc side condenser has two basic functions: it keeps the dc voltage stable with low ripple and it operates as an energy storage device during the transient cycle by supplying a genuine power difference between load and source. To allow the shunt active filter to draw leading electricity, the average voltage across the dc condenser must be maintained constantly and must exceed the maximum voltage. A proportional integer control regulates the active current drawn by the device's shunt active filter. The UPQC's series section ensures that supply-side disturbances such voltage swells, flutters, voltage imbalances, and harmonics are kept to a minimum. It adds voltages to the load voltages to keep them balanced, distortion-free, and at the proper level [27–30]. The UPQC series contains a VSI connected to the same power condenser as well as a series of low pass filter (LPF) and coupling transformers separated from the feeder on the dc side. The VSI series is not included in the switching frequency harmonics scheme because of the LPF series. The voltage and isolation of the network, as well as the VSI, are supplied by the transformers in series.

Series active filter compensation achieves its goals by combining serial and supply voltages to align and sustain load voltages at the desired level. The voltage is injected using a dc storage condenser and the VSI series.. The control approach creates the necessary switching signals for the VSI switches based on the calculated supply and/or load voltages. The VSI series is powered utilizing the widely utilized modular pulse-width switching technology in voltage-control mode. A triangular waveform signal with a higher frequency is compared to the needed signal, and enough switching signals are generated to provide the voltage injecting the desired magnitude, waveform, phase shift, and frequency. The dc condenser is connected to the inverter outputs with positive and negative polarity. Although there are no desired signals in the series VSI's output voltages, switching harmonics do exist and are filtered out by the system's low-pass filter. The amplitude, phase shift, frequency, and harmonic content of the injected voltages are all controlled [30–34].

PROPOSED METHODOLOGY

The design of power semiconductor systems, the modulation technique used, the design of coupling components, the method used to determine the active filter current and tension references, and the dynamics and resilience of current and tension control loops are all factors that influence UPQC performance. We present band voltage and current control algorithms for fluctuating hysteresis, in which the system parameters modulate the band to a virtually constant modulation frequency. While maintaining a high dynamic response, the FLC compensation method effectively eliminates harmonic voltage and current sizes. UPQC is an active power filter that connects the shunt and serial series with a common direct current connection. Harmonic voltage, voltage imbalance, voltage flickering, voltage drops, voltage swells, current harmonics, current imbalance, and reactive current are all issues that can be remedied. The capacity of UPQC to attenuate voltage slopes and swells has recently gotten increasing attention. The goal is to maintain a constant sinusoidal load bus voltage in all operational scenarios. Figure 2 depicts one form of UPQC structure used in distribution networks Active power filtering has proven to be one of the most effective approaches for addressing serious power quality issues. All current problems, including current harmonics, reactive current, and current imbalance, are solved with the APF shunt. In contrast, the APF series solves all voltage issues, such as harmonics, voltage sags, swelling, and voltage unbalance (Figure 3).

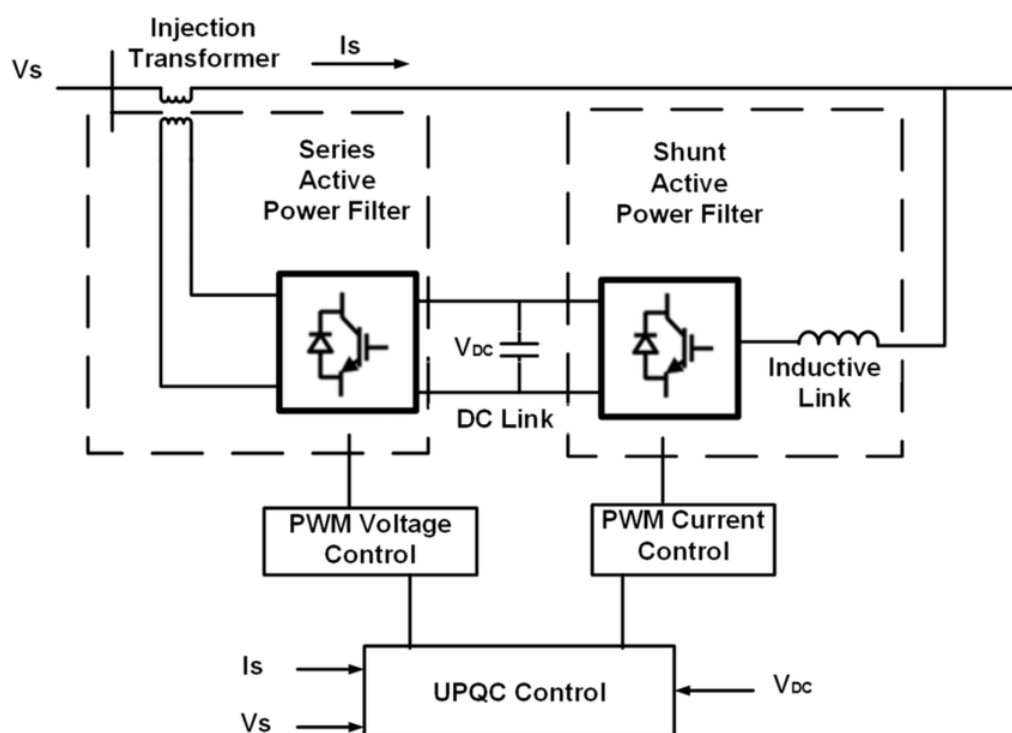


Figure 3. Unified power conditioner Control Circuit.

The inverter is governed by direct control, which provides sinusoidal current and voltage. To maintain the electric power grid's power supply current, the power supply is unitary, and the output load voltage is sinusoidal. The series inverter protects the electrical grid from load voltage changes, whereas the shunt inverter protects the grid from reactive energy and harmonic load currents, as well as the neutral current. PWM controlled inverters are also more efficient at controlling asymmetry, notably imbalanced failures over current, when the grid is turned off or recovered. In this control scheme, three single-phase PWM VSIs are used. The DVR power circuit's single phase H-bridge PWM inverters can inject positive, negative, and non-sequence voltages.. The voltage is controlled by using an inverter to modulate the output voltage waveform. The PWM inverter's main advantage is that the power switches function at a fast rate of speed. PWM technology combines quickness and simplicity. High switching frequencies can also be used to improve the efficiency of the converter without causing considerable switching loss [21]. Fuzzy set theory is widely utilized in the control field, and it has been used to dc-to-dc converter systems in some cases. A series of rules based on human understanding of system behaviour make up a simple fuzzy logic control. The dynamic behaviour of a dc-to-dc converter and the performance of proposed controllers are studied using a Matlab/Simulink simulation model. Furthermore, unlike linear control, the design of a fuzzy logic controller can give desirable small and huge signal dynamic performance at the same time. As a result, fuzzy logic controllers may be able to increase the dc-to-dc converter's robustness. A fuzzy logic controller's basic scheme is shown in Figure 5, and it consists of four main components: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; and a decision-making logic, which simulates a human decision process by inferring the fuzzy control action from knowledge of the linguistic definitions and the control rule set [34–38].

SIMULATIONS AND RESULTS

The fuzzy logic controller's dynamic response time was significantly faster in this case. This section describes the MATLAB simulation that was used to demonstrate the efficacy of the proposed control schemes for harmonic current filtration, reactive power compensation, load current equilibrium, and active filter neutral power elimination. All compensators are incorporated using equivalent discrete blocks. To determine the shunt filter's voltage correction efficiency, the shunt is turned on and the serial filter is enabled. The source impedance is almost minimal with R_s and L_s values of 0.1 ohms and 0.1mH, respectively. Both the inverter series and shunt are modelled using a universal bridge consisting of IGBTs/diodes. The power circuit is modelled as a nonlinear three-phase four-wire system composed of a three-phase rectified RL-loaded diode-bridge rectifier (Figures 4–5).

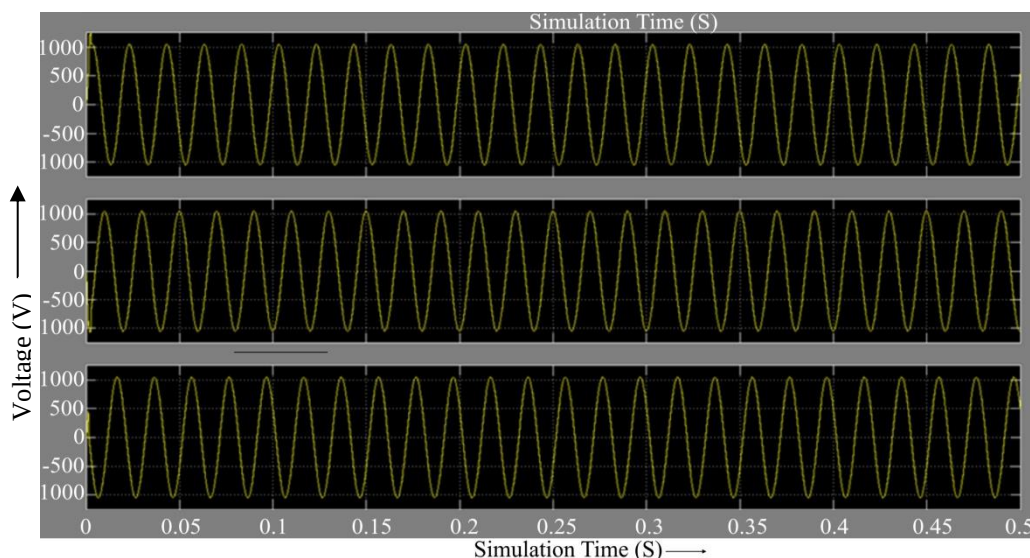


Figure 4. Waveform of Uncompensated System Having Power Quality Disturbances (Sag and Swell).

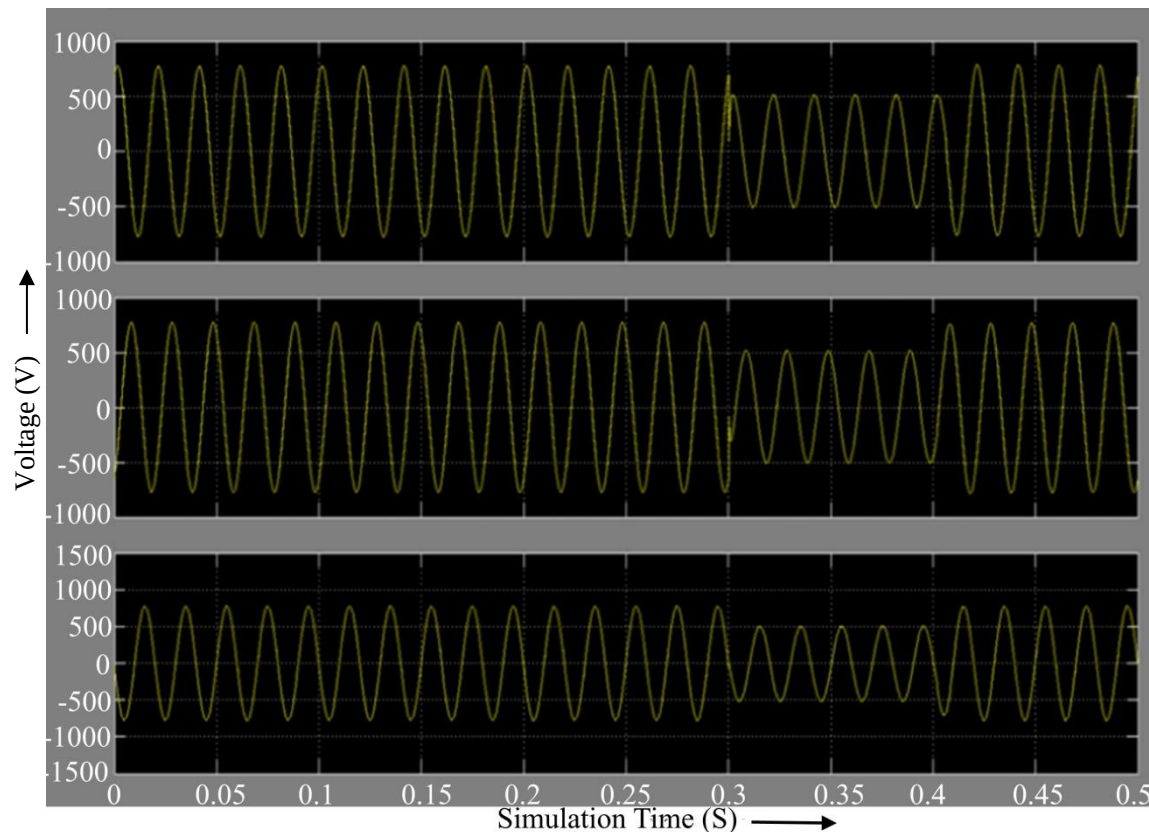
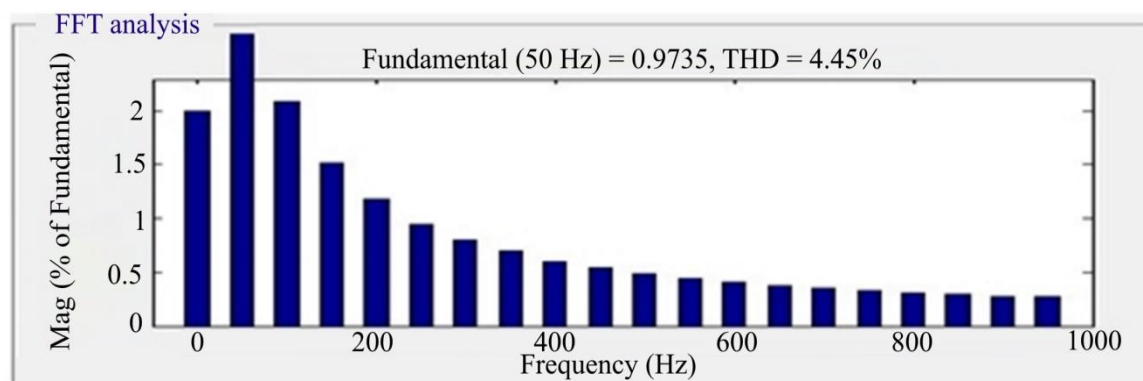
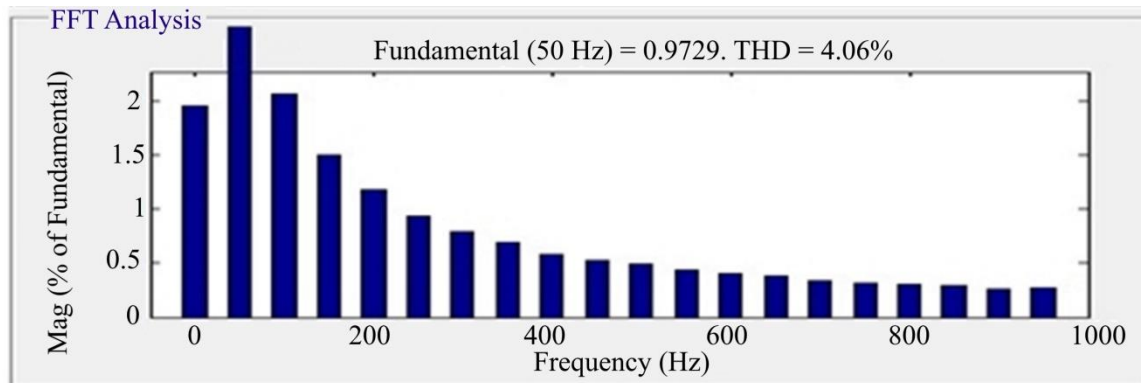


Figure 5. Waveform of Compensated System with Fuzzy-UPQC.

Three-phase load voltages are shown in Figure 3 prior to compensation. The APF series starts immediately by injecting the harmonic voltage out of the phase, freeing the distortion of the load voltage. 12 indicates the voltage pumped through the array. 10 displays three-phase load voltages following compensation. The THD of the three-phase distorted load voltages is respectively 47.5%, 44.78% and 43.19%. In Phase A, Band C the THD of load voltages dropped to 4.1%, 4.06% and 3.99% respectively. Such simulation results demonstrate that the application of fluid logic in regulating loops enables even the most adverse conditions to meet the desired requirements. The effects of the simulation when a voltage interruption of 0.06 s is performed at the source from 0.06 to 0.12s, with 3-stage charging voltages at a voltage interruption. The shunt inverter provides only load power during the voltage interruption (Figure 6). The DC bus voltage retains a constant value by FLC help throughout the interruption of the voltage. 3-phase Load voltages after adjustment for voltage interruption. The stability and trustworthiness of the proposed system are therefore demonstrated.



(a)



(b)

Figure 6. THD analysis of compensated system.

Figure of merits as discussed above illustrates the application of proposed methodology in application of reducing harmonics through the fuzzy logic controlled UPQC. The method has been successfully implemented for the reduction of harmonics in unbalanced load condition and has been compared with traditional methods, uncompensated and contemporary research for analysis and enhancement. Harmonic analysis of proposed methodology is also shown by Table 1.

Table 1. Harmonic analysis of proposed methodology.

Methods	%THD
Uncompensated	47.10%
DSTATCOM	14.21%
DVR	11.90%
UPQC-FUZZY	4.10%

CONCLUSIONS

The most common power quality issues among commercial and industrial utility consumers are voltage sag and current harmonics. These power quality issues can be caused by sensitive electronic equipment, erratic installation processes, and significant cost losses. Custom control devices have piqued interest for more than a decade as a way to improve the efficiency and quality of power delivered to electricity users. UPQC is a control system that consists of two inverters connected by a DC standard and may perform APF and DVR operations at the same time. The primary goal of this study was to develop UPQC control algorithms for better performance. The UPQC, on the other hand, does not provide varied levels of power to its consumers because it exclusively addresses concerns with end-user power quality. An instantaneous symmetrical component theory is simple to construct and provides a reasonable dynamic response. The control strategy generates a reference compensating sequence active filter voltages and a reference compensating shunting active filter currents, causing the source and load side currents and voltages to become sinusoidal and equilibrated under various power quality conditions. The neutral current is essentially offset since it can flow to the neutral transformer point at absolute zero potential. An adequate mathematical model of UPQC has been created based on the instantaneous active and reactive power theory. The UPQC controller was created using a zero transforming and effectively positive sequence detecting instantaneous power system. This control technique is used to evaluate harmonic identification, reactive power compensation, and effects.

REFERENCES

1. Toshifumi Ise, Yusuke Hayashi and Kiichiro Tsuji, "Definitions of Power Quality Levels and the Simplest Approach for Unbundled Power Quality Services", IEEE Proceedings of Ninth International Conference on Harmonics and Quality of Power, vol.-2, pp. 385–390, 2000.

2. Roger C. Dugan, Mark F. McGranaghan, Surya Santoso and H.Wayne Beaty, "Electrical Power Systems Quality", The McGraw-Hill, Second Edition, 2004.
3. K.R. Padiyar, "Facts Controllers in Power Transmission and Distribution", New Age International Publishers, 2007.
4. Alexander Kusko, Sc.D. and Marc T.Thompson, "Power Quality in Electrical Systems", McGraw-Hill, 2007.
5. Swati Pal, Pallavi Singh Bondriya and Yogesh Pahariya, "MATLAB-Simulink model based Shunt Active Power Filter using Fuzzy Logic Controller to Minimize the Harmonics", International Journal of Scientific and Reserch Publications, vol.-3, no.-12, pp. 2250–3153, December 2013.
6. N.G. Hingorani, "Introducing Custom Power", IEEE Spectrum, vol.-32, no.-6, pp. 41–48, June 1995.
7. Arindam Ghosh and Gerard Ledwich, "Power Quality Enhancement Using Custom Power Devices", Kluwer Academic Publishers, 2002.
8. Angelo Baggingi, "Handbook of Power Quality", John Wiley & Sons Ltd, 2008.
9. T.A. Short, "Distribution Reliability and Power Quality", Taylor & Francis Group, CRC Press, 2006.
10. Afshin Lashkar Ara and Seyed Ali Nabavi Niaki, "Comparison of The Facts Equipment Operation In Transmission and Distribution Systems", 17th International Conference on Electricity Distribution Barcelona, Session No.2, Paper No.44, pp. 12–15 May 2003.
11. Juan W. Dixon, Gustavo Venegas and Luis A. Mor'an, "A Series Active Power Filter Based on a Sinusoidal Current-Controlled Voltage-Source Inverter", IEEE Transactions on Industrial Electronics, vol.-44, no.-5, pp. 612–620, October 1997.
12. T.Devaraju, V.C.Veera Reddy and M. Vijay Kumar, "Modeling and Simulation of Custom Power Devices to Mitigate Power Quality Problems", International Journal of Engineering Science and Technology, vol.-26, pp. 1880-1885, 2012.
13. Mahesh Singh and Vaibhav Tiwari, "Modeling analysis and solution of Power Quality", 10th International Conference on Environment and Electrical Engineering, July 2011.
14. Yun Wei Li, D. Mahinda Vilathgamuwa, Poh Chiang Loh and Frede Blaabjerg, "A Dual-Functional Medium Voltage Level DVR to Limit Downstream Fault Currents" IEEE Transactions on power electronics, vol.-22, no.-4, July 2007.
15. Pedro Roncero-Sanchez, Enrique Acha, Jose Enrique Ortega-Calderon, Vicente Feliu, and Aurelio García-Cerrada, "A Versatile Control Scheme for a Dynamic Voltage Restorer for Power-Quality Improvement", IEEE Transactions on power delivery, vol.-24, no.-1, January 2009.
16. Rajan Sharma, Parag Nijhawan, "Effectiveness of DSTATCOM to Compensate the Load Current Harmonics in Distribution Networks under Various Operating Conditions", International Journal of Scientific Engineering and Technology, vol.-2, no.-7, pp. 713–718, July 2013.
17. Parag Nijhawan, Ravinder Singh Bhatia, Dinesh Kumar Jain, "Improved performance of multilevel inverter-based distribution static synchronous compensator with induction furnace load", IET Power Electronics, vol.-6, no.-9, pp. 1939-1947, 2013.
18. Rajan Sharma and Parag Nijhawan, "Role of DSTATCOM to Improve Power Quality of Distribution Network with FOC Induction Motor Drive as Load", International Journal of Emerging Trends in Electrical and Electronics (IJETEE-ISSN: 2320-9569), vol.-5, no.-1, July 2013.
19. Parag Nijhawan, Ravinder Singh Bhatia, Dinesh Kumar Jain, "Application of PI controller based DSTATCOM for improving the power quality in a power system network with induction furnace load", Songklanakarin J. Sci. Technology, vol.-2, no.-34, pp. 195–201, March-April 2012.
20. Parag Nijhawan, Ravinder Singh Bhatia, Dinesh Kumar Jain, "Role of DSTATCOM in a power system network with induction furnace load", IEEE 5th Power India Conference, Dec.19–22, 2012.
21. Ankush Malhar and Parag Nijhawan, "Improvement of Power Quality of Distribution Network with DTC Drive Using UPQC", International Journal of Emerging Trends in Electrical and Electronics (IJETEE ISSN: 2320-9569), vol.-5, no.-2, July-2013.

22. R.N. Bhargavi, "Power Quality Improvement Using Interline Unified Power Quality Conditioner", 10th International Conference on Environment and Electrical Engineering (EEEIC), pp. 1–5, 2011.
23. K. Palanisamy, J Sukumar Mishra, I. Jacob Raglend and D. P. Kothari, "Instantaneous Power Theory Based Unified Power Quality Conditioner (UPQC)", 25 Annual IEEE Conference on Applied Power Electronics Conference and Exposition (APEC), pp. 374–379, 2010.
24. G.O. Suvire, P.E. Mercado, "Combined control of a distribution static synchronous compensator/flywheel energy storage system for wind energy applications", IET Generation, Transmission & Distribution, vol.-6, no.-6, pp. 483–492, 2012.
25. G. Siva Kumar, P. Harsha Vardhana and B. Kalyan Kumar, "Minimization of VA Loading of Unified Power Quality Conditioner (UPQC)", Conference on POWERENG 2009 Lisbon, Portugal, pp: 552–557, 2009.
26. V. Khadkikar, A. Chandra, A.O. Barry and T.D. Nguyen, "Power quality enhancement utilising single-phase unified power quality conditioner: digital signal processor-based experimental validation", Conference on Power Electronics, vol.-4, pp. 323–331, 2011.
27. V. Khadkikar, A. Chandra, A.O. Barry and T.D. Nguyen, "Application of UPQC to Protect a Sensitive Load on a Polluted Distribution Network", IEEE PES General Meeting, 2006.
28. Metin Kesler and Engin Ozdemir, "A Novel Control Method for Unified Power Quality Conditioner (UPQC) Under Non-Ideal Mains Voltage and Unbalanced Load Conditions", 25th Annual IEEE Applied Power Electronics Conference and Exposition (APEC), pp. 374–379, 2010.
29. A. Kazemi, A. Mokhtarpour, and M. Tarafdar Haque, "A New Control Strategy for Unified Power Quality Conditioner (UPQC) In Distribution Systems", Conference on Power System Technology, pp. 1-5, 2006.
30. Luis F.C. Monteiro, Mauricio Aredes and Joao A. Moor Neto "A Control Strategy for Unified Power Quality Conditioner", IEEE International Symposium on Industrial Electronics, vol.-1, pp. 391–396, 2003.
31. Morris Brenna and Roberto Fara Enrico Tironinda, "A New Proposal for Power Quality and Custom Power Improvement OPEN UPQC", IEEE Transactions on Power Delivery, vol.-24, pp. 2107–2116, 2009.
32. Sai Shankar, Ashwani Kumar and W. GAO, "Operation of Unified Power Quality Conditioner under Different Situations", IEEE Power and Energy Society General Meeting, pp. 1–10, 2011.
33. M. Vasudevan, R. Arumugam and S. Paramasivam, "High Performance Adaptive Intelligent Direct Torque Control Schemes for Induction Motor Drives", Serbian journal of Electrical Engineering, vol.-2, no.-1, pp. 93–116, May 2005.
34. Jiangyuan Le, Yunxiang Xie, Zhang Zhi and Cheng Lin, "A Nonlinear control strategy for UPQC", International Conference on Electrical Machines and Systems, pp. 2067-2070, 2008.
35. R.V.D. Rama Rao, Subhransu and Sekhar Dash, "Power Quality Enhancement by Unified Power Quality Conditioner Using ANN with Hysteresis Control", International Journal of Computer Applications, vol.-6, pp. 9–15, September 2010.
36. Naresh K. Kummari, Asheesh K Singh and Pradeep Kumar, "Comparative Evaluation of DSTATCOM Control Algorithms for Load Compensation", IEEE 15th International Conference on Harmonics and Quality of Power (ICHQP), pp. 299–306, 2012.
37. S.S. Wamane, J.R. Baviskar, S.R. Wagh and S. Kumar. "Performance Based Comparison of UPQC Compensating Signal Generation Algorithms Under Distorted Supply and Non Linear Load Conditions", IEEE 8th Conference on Industrial Electronics and Applications (ICIEA), pp. 38–42, 2013.
38. A. Jeraldine Viji and M. Sudhakaran, "Generalized UPQC system with an improved Control Method under Distorted and Unbalanced Load Conditions", International Conference on Computing, Electronics and Electrical Technologies (ICCEET), pp. 193–197, 2012.