Unified Power Quality Conditioner using PV Fed SVPWM based Multilevel Converters for Power Quality Improvement

P. Chandra Sekhar

***Abstract**: This paper presents a solar photovoltaic based unified power quality conditioner (PV-UPQC). The proposed system consists of a shunt compensator (ShC), series compensator (SeC) and PV array connected in parallel to a common dc-link. A three-level diode clamped multilevel inverter configuration is used as shunt and series converters. The SVPWM technique provides reduction in the common mode voltage and the balancing of the dc link voltage. The shunt compensation converter extracts power from PV array and provides compensation for load harmonic currents. The series compensation converter compensates for the power quality (PQ) problems such as grid voltage sags/swells and source harmonic voltages. The proposed system utilizes space vector pulse width modulation (SV-PWM) in multilevel converter topology for the mitigating the power quality problems using PV-UPQC. The proposed system improves PQ and also utilize RES, it also simultaneously improves both current and voltage disturbances. The performance of the system is analyzed in MATLAB/Simulink for nonlinear load conditions.*

Keywords: Power quality, space vector pulse width modulation, shunt compensator, series compensator, solar photovoltaic, unified power quality conditioner, multilevel inverter.

I. INTRODUCTION

The sudden increase in the use of non-linear loads in distribution systems has caused increase in the power quality issues which has caused recent increase in research in this area. The advancement of power electronic switches has paved the way for power quality conditioners towards the enhancement of power quality in the system. [1], [2]. Various types of power conditioners have been developed, out of which UPQC has been most preferred due to its better performance for mitigating voltage/current perturbations in the electrical distribution system [2], [3].

The renewable energy sources like wind and solar have low environmental impact and abundant in resource. Thus, they are now widely used in the proliferation of distribution systems.

Revised Manuscript Received on April 30, 2020.
***** Correspondence Author
P. Chandra Sekhar*, Department of Electrical and Electronics Engineering at Mahatma Gandhi Institute of Technology, Hyderabad, India. E-mail: pchandrasekhar@mgit.ac.in

PV in particular is more utilized since it can be used for all types of applications and also for different power ratings [4]. The integration of renewable energy systems (RES) with PQ improvement technology such as dynamic voltage restorer (DVR), UPQC, and DSTATCOM gives the benefits of clean energy and PQ improvement. The recent research on RES based PQ systems is on shunt converter-based systems. A PV-DSTATCOM provides grid current PQ enhancement [5]. The PV-DVR systems is proposed in [6]. The DSTATCOM performs voltage regulation but it draws reactive power from the PCC. The DSTATCOMs do no provide harmonic protection at the load. The UPQC with both series and shunt converters provides load voltage regulation and grid current enhancement [7]. The use of UPQC with PV based system increases the performance of traditional UPQC and thus PQ solutions can be achieved [8], [9]. The recent developments in multilevel converters (MLC) and pulse width modulation techniques help in the reduction of total harmonic distortion to meet the international standards for power supply [10]. This paper proposes the use of solar photo voltaic based multilevel converters with space vector pulse width modulation (SV-PWM) in the UPQC topology for improving power quality for nonlinear load. The proposed system aims to improve PQ and also utilize RES, it also aims to simultaneously improve both current and voltage disturbances.

II. SYSTEM ARCHITECTURE

The general block diagram of the proposed PV-UPQC is shown in Fig. l; it consists of a PV array connected to UPQC with a boost converter. This converter operates in maximum power point tracking (MPPT) mode for peak power extraction of the PV array. The UPQC consists of a SeC and ShC compensator connected to a common DC-bus. A detailed circuit diagram of the PV-UPQC system is shown in Fig. 2. The circuit comprises of three phase power which is supplying a nonlinear load.

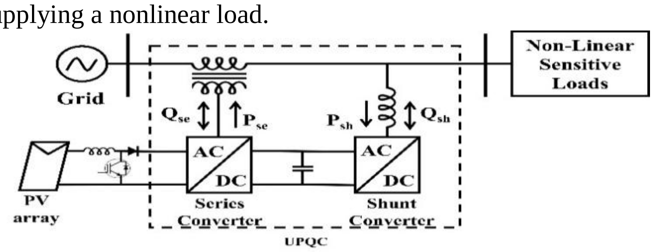


Fig. 1. General block diagram of PV fed UPQC configuration.

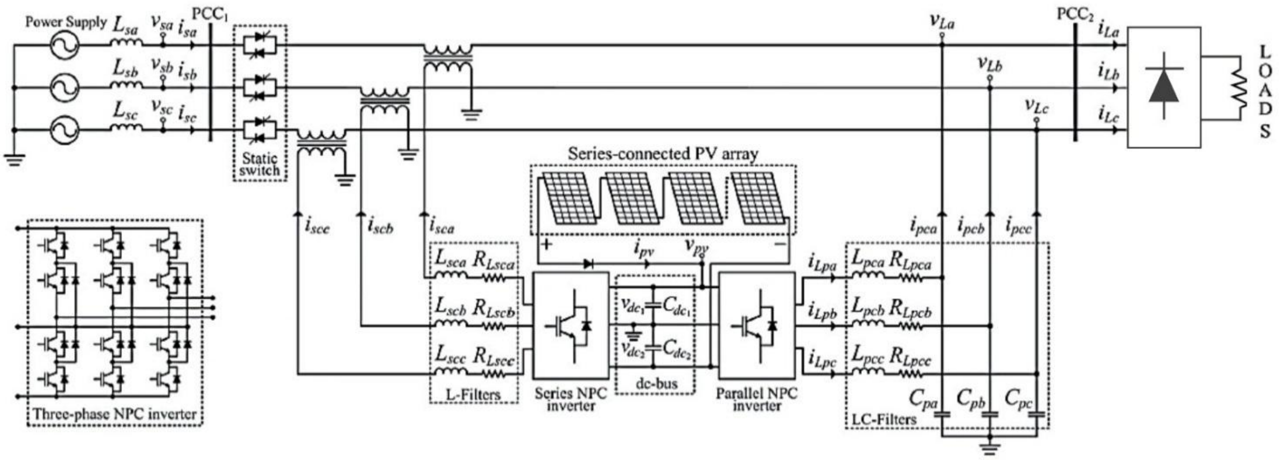


Fig. 2. Detailed circuit diagram of the PV-UPQC system

A UPQC system composed of two back-to-back diode-clamped three level multi-level converters connected through dc link is connected to the grid though coupling transformers. A solar PV array with boost converter is connected to the UPQC at the dc link. The dc-bus voltage reference is determined by the MPPT algorithm.

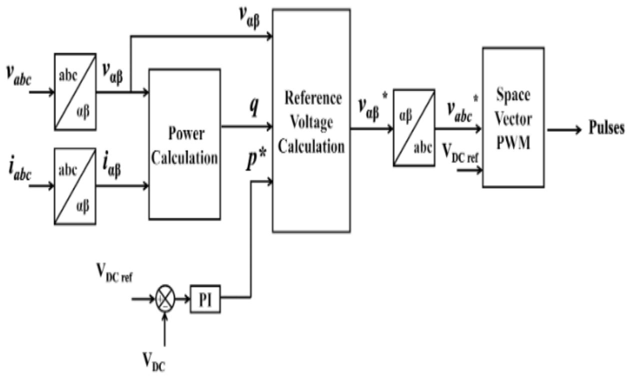


Fig. 3. Shunt compensation control diagram.

The proposed model primarily focuses on consolidating the various demographic, knowledge from surveys, study related characteristics as dataset. Many existing systems focused purely on the performance of the student regarding the data from the time of admission. Whereas this system gathers the data through pretest Extended project qualification [EPQ]. EPQ is a course taken by many of the students of England and Wales to gain a lot of information regarding the academic content and explore their interests. This data in the form of questionnaire which drive towards student's interests and greater value placed on results achieved. In addition to that the data is also collected from the academic performance and also library through resource scale. Resource scale refers to the type and the number of resources accumulated. Resources visited, discussions attended, announcements viewed are all acquired for this scaling. The final result dataset is formed consisting of 16 attributes of 480 students after EPQ analysis and resources utilization analysis. In this paper we aim to use random forest classifier as a classification algorithm for the result dataset. Random Forest constructs the decision trees for all possible attributes and predicts the class label with maximum votes from the decision trees. Finally, the classifier predicts the accuracy of the final predicted model and visualize the confusion matrix. Fig. 1 shows the work flow of the proposed model.

Therefore, during the PV normal operating conditions the dc-bus voltage amplitude is higher than low operating conditions. All the converters are controlled independently in this configuration. The ShC compensates reactive power, harmonic components at the load and capacitor voltage regulation. The SeC mitigates sag and swell in voltage, current harmonics and voltage harmonics. The SeC control is based on SRF theory. The power quality (PQ) theory is used to control the ShC as shown in Fig 3.

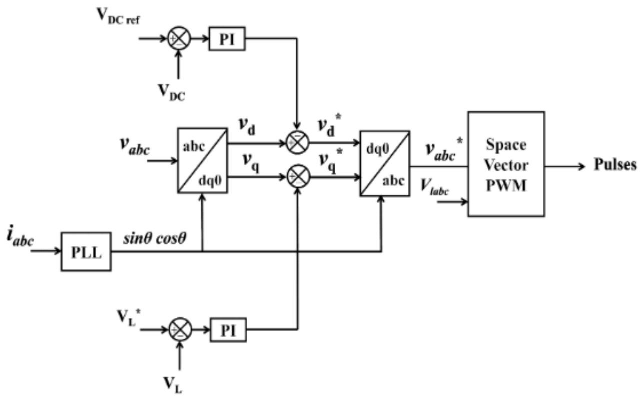


Fig. 4. Series compensation control diagram.

The SeC control diagram is presented in Fig.4. The SeC injectes voltages (V_{inja}, V_{injb} and V_{injc}) compensate the distortions in the supply voltages (V_{sa}, V_{sb} and V_{sc}). This ensures perfectly sinusoidal voltages at PCC (V_{la}, V_{lb} and V_{lc}). In SRF theory, using dq transformation, a voltage reference is calculated. The DC bus voltage is regulated by PI controller. PI control regulation is also provided for load voltage. Gate trigger to the SeC is provided by SVPWM controller.

The SVPWM technique is more preferred compared to the other PWM techniques as it helps in the reduction of common mode voltage and balancing of the dc link capacitor voltage for the MLC system. The implementation of SVPWM involves complex computations. The control diagram for SVPWM is shown in Fig. 5. Based on the reference voltage, the sector in which the voltage vector lies is identified.

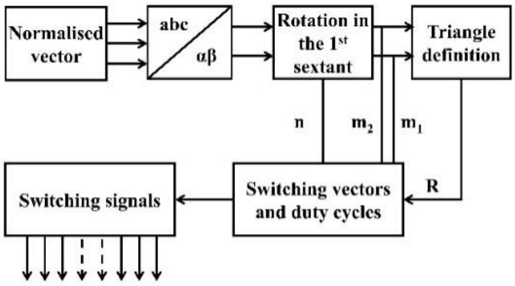


Fig. 5. Control diagram for SVPWM.

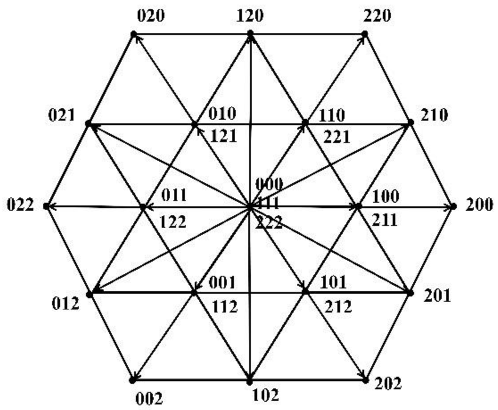


Fig. 6. Space vector representation.

The sector division is shown in Fig.6. The duty cycles and voltage states are determined. To calculate the vector location of reference voltage, a hexagonal coordinate system is utilized and the components are shown in Table.1.

Table- I: Equivalent Components in First Sector

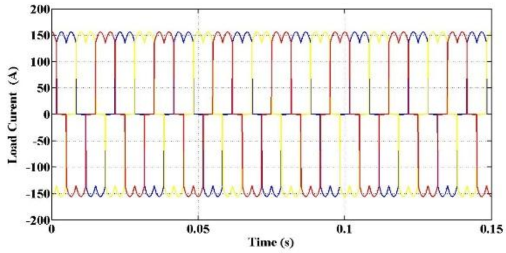
gh components	Sector	Equivalent Components
$V_g > 0$ & $V_h >= 0$	1	$m_1 = V_g$, $m_2 = V_h$
$V_g < 0$ & $V_h >= 0$ & $(V_g + V_h) >= 0$	2	$m_1 = V_g$, $m_2 = V_g + V_h$
$V_g < 0$ & $V_h >= 0$ & $(V_g + V_h) < 0$	3	$m_1 = V_h$, $m_2 = -V_g - V_h$
$V_g < 0$ & $V_h < 0$	4	$m_1 = -V_h$, $m_2 = -V_g$
$V_g > 0$ & $V_h < 0$ & $(V_g + V_h) < 0$	5	$m_1 = -V_g - V_h$, $m_2 = V_g$
$V_g >= 0$ & $V_h < 0$ & $(V_g + V_h) >= 0$	6	$m_1 = V_g + V_h$, $m_2 = V_h$

III. SYSTEM PERFORMANCE ANALYSIS

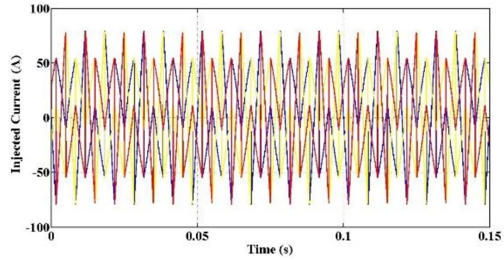
The propose system is tested for three conditions. The performance during the production of current harmonics due to nonlinear load, the permeance during the production of voltage harmonics at the source and the performance during the sag and swell conditions at the source.

A. Performance during Current Harmonics

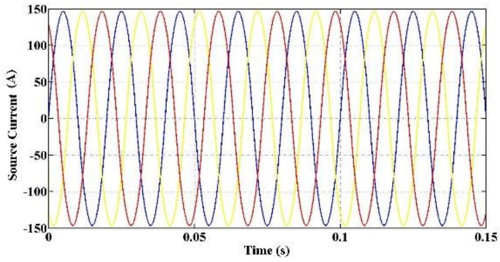
A resistive load of 100Ω is connected at the end of the diode bridge rectifier. When a grid supplies this load, a non-linearities are developed in terms of harmonics in the load current as shown in Fig. 7 (a) and the THD is 30.84%. A current is injected from the PV-UPQC as presented in Fig. 7(b) to provide compensation, as a result the source currents are almost sinusoidal as shown in Fig. 7(c). and the THD is 3.08%.



(a) Load current.



(b) Injected current.



(c) Source current.

Fig. 7. Voltages and currents.

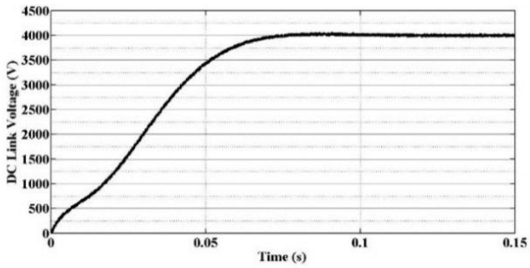
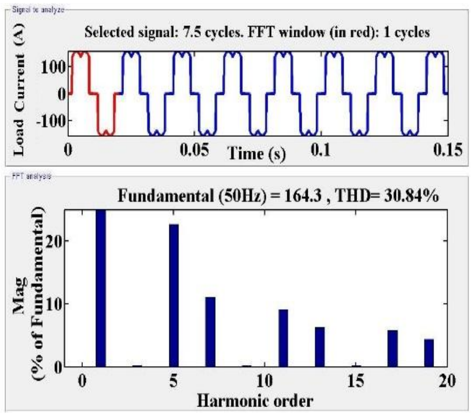
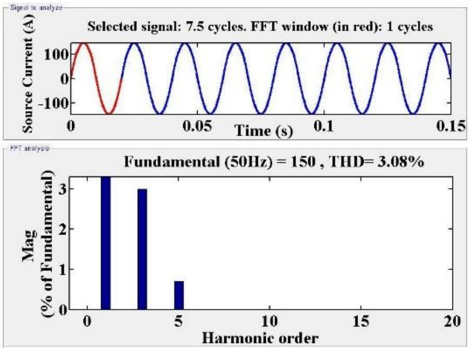


Fig. 8. DC link voltage

The performance of the capacitor voltage is presented in Fig. 8. The FFT analysis is presented in Fig. 9.



(a) Load current.

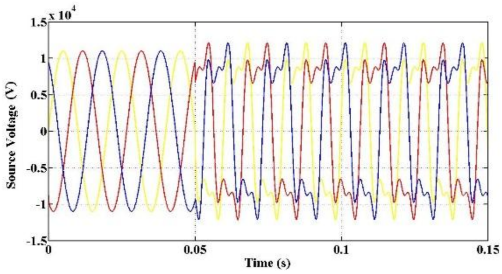


(b) Source current.

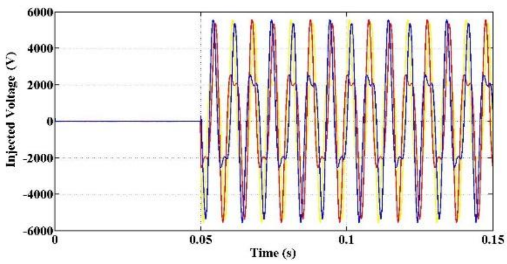
Fig. 9. FFT analysis.

B. Performance during Voltage Harmonics

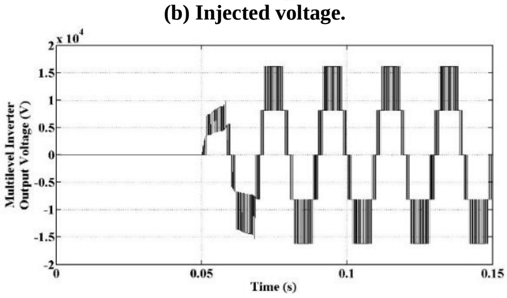
15% of Third and 20% of fifth harmonics are added from 0.05s, to provide distortions in the supply voltage. as shown in Fig. 10. (a). The voltage is injected and the multilevel converter voltage for a phase ‘a’ is presented in Fig. 10 (b) and (c) and as a result the load voltage is almost sinusoidal as shown in Fig. 10 (d).



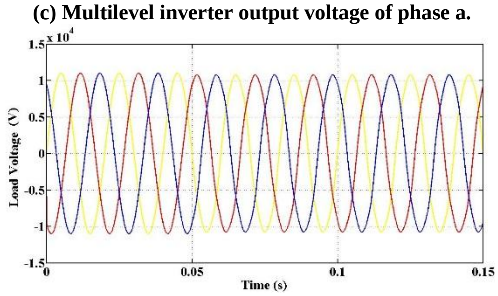
(a) Source voltage.



(b) Injected voltage.

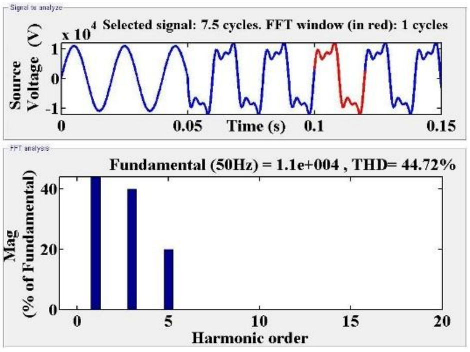


(c) Multilevel inverter output voltage of phase a.

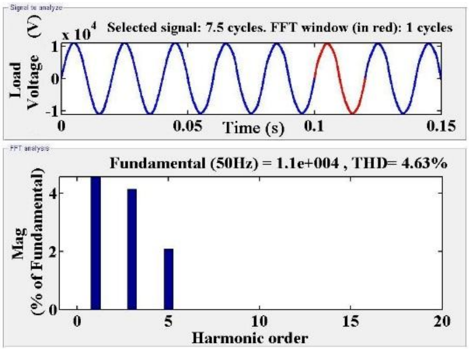


(d) Load voltage.

Fig. 10. Voltages and currents.



(a) Source voltage.



(b) Load voltage.

Fig. 11. FFT analysis.

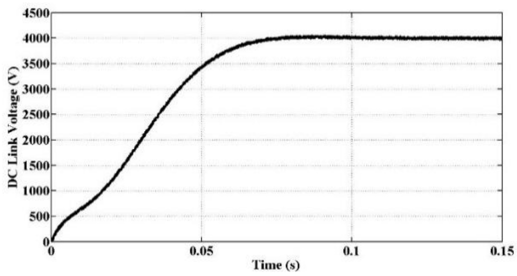


Fig. 12. DC link voltage.

The imperfections in the source voltage with THD of 44.72% is compensated at the load side with THD of 4.63%. The FFT analysis are shown in Fig. 11. The response of the DC capacitor can be seen in Fig.12.

C. Performance during Sag and Swell

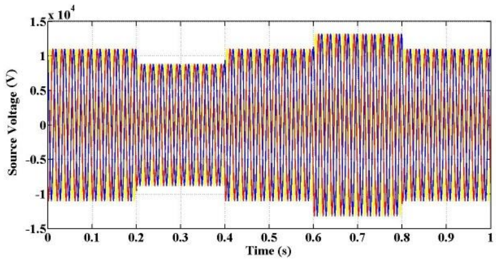
Both 20% sag and 20% swell are created at the source voltage. The power is supplied to RL load of 50Ω and 100mH. The source voltage, injected voltage, multilevel converter voltage for a phase ‘a’ and load voltage are shown in Fig. 13. The results show the load voltage is not disturbed by the variations due to sag and swell at the source. The load voltage remains constant. The voltages at the load are corrected through the injection of appropriate voltages.

The performance of the DC capacitor is presented in Fig. 14. The voltage varies based the sag and swell conditions.

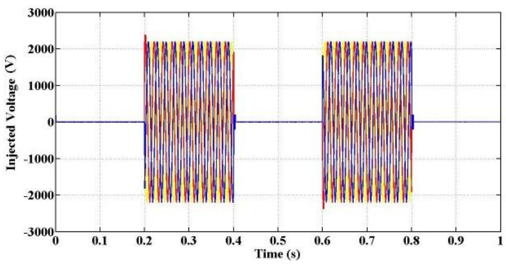
IV. CONCLUSION

The solar photovoltaic based unified power quality conditioner with space vector pulse width modulation for multilevel converters is presented in this paper. A three-level diode clamped multilevel inverter configuration is used as shunt and series converters.

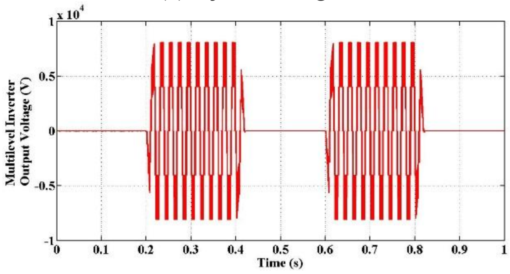
The SVPWM technique provided reduction in the common mode voltage and the balancing of the dc link voltage. The results show that the proposed system has the capability of voltage regulation at the load end with protection from voltage imperfections in the source. In addition, compensation of harmonic content and sag/swell compensations also are provided. The proposed system improves PQ and also utilize RES, it also simultaneously improves both current and voltage disturbances. Thus, the PV-IUPQC is a better solution for the power quality problems in electrical distribution systems. The entire system is modeled in MATLAB/SIMULINK and the performance is evaluated from the simulation results.



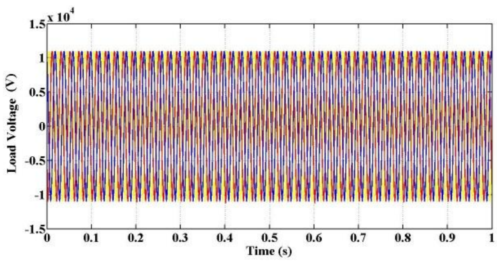
(a) Source voltage.



(b) Injected voltage.



(c) Multilevel inverter output voltage of phase a.



(d) Load voltage.

Fig. 13. Voltages and currents.

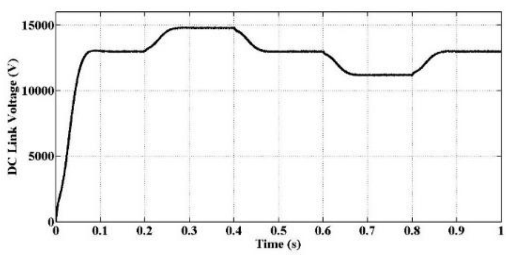


Fig. 14. DC link voltage.

REFERENCES

1. H. Fujita and H. Akagi, "The unified power quality conditioner: The integration of shunt and series filters," IEEE Trans on Power Electron, vol. 13, no. 2, pp. 315-322. Mar.1998.
2. S. K. Dash and P. K. Ray, "Platform specific FPGA based hybrid active power filter for power quality enhancement," Int. J. of Emerging Electric Power Sys. vol. 18, no. 1, Feb. 2017.
3. K. A. Chandra, A.O. Barry, and T.D. Nguyen, "Power quality enhancement utilizing single-phase unified power quality conditioner: digital signal processor-based experimental validation," IET Power Electron. vol. 4, no.3, pp. 323–331, 2011.
4. N. D. Tuyen and G. Fujita "PV-active power filter combination supplies power to nonlinear load and compensates utility current," IEEE Power and Energy Technology Systems Journal, vol. 2, no. 1, pp. 32-42, March 2015.
5. S. Devassy and B. Shing "Modified p-q theory-based control of solar PV integrated UPQC-S," in Proc. IEEE Industry Application Society Annual Meeting, Oct. 2016, pp.1-8.
6. S. K. Dash, P. K. Ray, S. Mishra, and G. H. Beng, "UPQC-PV solving power quality issues based on system generator FPGA controller," in Proc. IEEE ICPEICES, July 2016, pp.1-6.
7. M. Kesler and E. Ozdemir, "Syncronous reference frame-based control method for UPQC under unbalanced and distorted load conditions," IEEE Trans. On Inds. Electronics. vol. 58, no. 9, pp. 3967-3975, Sep. 2011.
8. Y. Pal, A Swarup, and B. Shing, "Performance of UPQC for power quality improvement" in Proc. IEEE PEDES. Dec. 2010, pp.1-7.
9. Q. N. Trinh and H. H. Lee, "Improvement of unified power quality conditioner performance with enhanced resonant control strategy," IET Generation, Trans. and Distr. vol.8, no.12, pp. 2114-2123, 2014.
10. B. Subudhi, P. K. Ray, and A. M. Panda, "Parameter estimation technique applied to power networks," in Proc. IEEE TENCON, Nov. 2008, pp. 1-5.
11. K. Karanki, G. Geddada, M. K. Mishra, and B. K. Kumar, "A modified three-phase four-wire UPQC topology with reduced dc-link voltage rating," IEEE Trans. Ind. Electron., vol. 60, no. 9, pp. 3555–3566, Sep. 2013.
12. M. C. Cavalcanti, G. M. S. Azevedo, B. A. Amaral, F. A. S. Neves, D. C. Moreira, and K. C. Oliveira, "A grid connected photovoltaic generation system with compensation of current harmonics and voltage sags," Brazilian Power Electron. J., vol. 11, no. 2, pp. 93–101, Jul. 2006.
13. S. Devassy and B. Singh, "Dynamic performance of solar PV integrated UPQC-P for critical loads," in Proc. Annu. IEEE India Conf., 2015, pp. 1–6.
14. B. Han, B. Bae, H. Kim, and S Baek, "Combined operation of unified power quality conditionerwith distributed generation," IEEE Trans. Power Del., vol. 21, no. 1, pp. 330–338, Jan. 2006.
15. V. D. Bacon and S. A. O. Silva, "Performance improvement of a threephase phase-locked-loop algorithm under utility voltage disturbances using non-autonomous adaptive filters," IET Power Electron., vol. 8, no. 11, pp. 2237–2250, Nov. 2015.

AUTHOR PROFILE

P. Chandra Sekhar completed his Ph.D. in the area of Power Systems in the year 2012 from JNTUH, Hyderabad. He is an Associate Professor in the Department of Electrical and Electronics Engineering, Mahatma Gandhi Institute of Technology, Hyderabad, India. He has more than 19 years of teaching and research experience. At present he is guiding 6 PhD scholars. He published 24 research papers in International journals and has presented 31 papers in International and national conferences. He is Member ISTE. His areas of interests are artificial intelligence, power quality, distributed generation, power system analysis & control and application of power electronics in power systems.