| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 7, June 2020 ||

Performance Analysis of 3 Phase Solar IntegratedPV-UPQC System using MATLAB

Rucha H. Belsare[1], Prasad D. Kulkarni[2]

PG Student [EPS], Dept. of EE, KCES's College of Engineering and IT, Jalgaon, Maharashtra, India[1]

Assistant Professor, Dept. of EE, KCES's College of Engineering and IT, Jalgaon, Maharashtra, India[2]

ABSTRACT: Unified Power Quality Conditioner system used on the distribution side of power system can be improvised by integrating with renewable energy resources like the photovoltaic system. The proposed system combines both the benefits of distributed generation and active power filtering. Solar integrated PV-UPQC system consists of back to back series and shunt compensators interlinked by a common DC link capacitor powered by the photovoltaic system. The reactive power compensation is achieved by shunt compensator of PV-UPQC system. The shunt compensator is also extracting maximum power from solar PV array by operating it at its maximum power point (MPP).The voltage fluctuations like voltage sag/swell are compensated by the series compensator. The performance of the proposed system is simulated in Matlab-Simulink under a nonlinear load consisting of a bridge of diode rectifier with voltage-fed load.

KEYWORDS: Power Quality, shunt compensator, series compensator, UPQC, Solar PV.

I.INTRODUCTION

The major issue in the power system is power quality maintenance due to the implementation of various power electronic circuits. Most of the developed and developing countries rely on renewable energy resources due to the depletion of fossil fuel. In the last ten years, the usage of renewable energy has been increased drastically and to integrate this distributed renewable energy resource usage of power electronic devices becomes necessary. The usage of power electronic devices leads to pollution of the power system by injection of harmonics by these power electronic devices. These harmonics are responsible for the voltage fluctuations in the power system. The voltage fluctuations can affect the sensitive loads and it leads to an increase in operation and maintenance cost in industries [1],[2]. The power quality can be improved by designing appropriate converters. The Power Electronic based Flexible AC Transmission Systems (FACTS) devices improve the quality of power flow in the power system. The main functionality of the FACTS (custom)devices is to provide active and reactive power compensation.

Custom power devices such as distribution static compensator (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) are used to mitigate power quality problems caused by loads as well as to protect the sensitive loads from grid side voltage quality problems. DSTATCOM [5] is a shunt connected power electronic system which compensates for the power quality issues caused by loads such as reactive current, harmonics and load imbalance in the system. DVR is a series connected power electronic system which compensates for the grid voltage sag/swells [6]. UPQC [7]consists of back to back connected shunt and series compensator which combines functionality of both DSTATCOM and DVR. Compared to conventional grid connected inverters, the solar PV integrated UPQC has numerous benefits such as improving power quality of the grid, protecting critical loads from grid side disturbances apart from increasing the fault ride through capability of converter during transients. In this paper, model is developed in the environment of MATLAB Simulink model & the performance analysis of a three-phase PV-UPQC is presented.

II.SYSTEM CONFIGURATION

Basic Structure of UPQC: UPQC is the combination of series and shunt converter. Basic structure of UPQC is as shown in fig. 1.
The various components used in UPQC are as follows:

1. Series inverter - The inverters connected in series to the supply known as the series active filter. This inverter behaves as a voltage source line which eliminates a voltage interruption.
2. Shunt inverter - The inverter connected in shunt to the supply line is known as shunt active filter. It eliminates the current related harmonics also minimize the reactive current in the load circuit.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 7, June 2020 ||

3. DC link - The capacitor or inductor can be used as common DC link. As shown in fig. 4 the capacitor is used as DC link, which supplies the DC voltage.
4. LC filter - The output of the series active filter produces high switching ripples. The LC filter minimizes the ripples in a system. The LC filter acts as the low-pass filter.
5. L_{sh} Filter - The L_{sh} filter act as a high-pass filter. The ripples during switching mode are minimized by L_{sh} filter.
6. Injection transformer - The series injection transformer connected to series convertor.

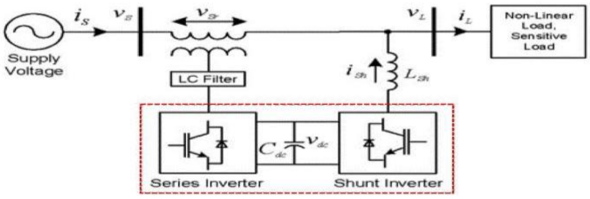


Fig. 1. Basic structure of UPQC

System Configuration

The structure of the PV-UPQC is shown in Fig. 2.The PV-UPQC is designed for a three-phase system. The PV-UPQC consists of shunt and series compensator connected with a common DC-bus. At load side, shunt compensator is connected. The solar PV array is directly integrated to the DC-link of UPQC through a reverse blocking diode. The series compensator used to compensate the voltage which can reduce the voltage sag and swell. The shunt and series compensators are connected to the grid through interfacing inductors. A series compensator injects the voltage into the grid by using series injection transformer. Harmonics are generated by converters are eliminated by using filters[8]. The magnitude of DC link voltage Vdc depends on the depth of modulation used and per-phase voltage of the system. The DC-link voltage magnitude should more than double the peak of per-phase voltage of the three phase system. The load used is a nonlinear load consisting of a bridge rectifier with a voltage-fed load. The DC-link capacitor is sized based upon power requirement as well as DC-bus voltage level. The interfacing inductor rating of the shunt compensator depends upon the ripple current, the switching frequency and DC-link voltage.

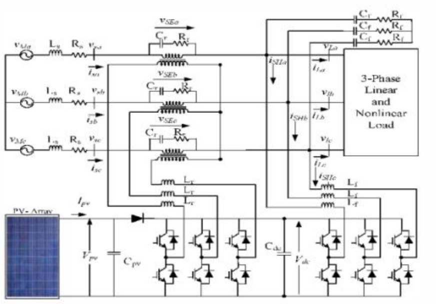


Fig. 2. System configuration of UPQC

III. CONTROL STRATEGY

Control Strategy for shunt compensator: The measured load current is transformed into the synchronous d-q-o reference frame. By this transform, the fundamental positive- sequence component, which is transformed into dc quantities in the *d* and *q* axes, can be easily extracted by low-pass filters (LPFs). Also, all harmonic components are transformed into ac quantities with a fundamental frequency shift. The shunt compensator extracts the maximum power from the solar PV array by operating at its maximum power point .The maximum power point tracking(MPPT) algorithm generates the reference voltage for the DC link of UPQC. Current from dc link is converted to the reference grid currents. The reference grid currents are compared with the sensed grid currents is given to hysteresis controller. Hysteresis controller generate the gating pulses for shunt converter. To extract DC component without deteriorating the dynamic performance, a moving average filter (MAF) is used to extract the DC component.

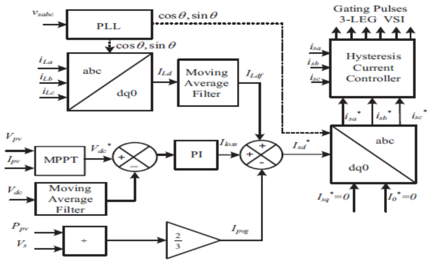


Fig. 3 .Control Structure of Shunt Compensator

Control of Series Compensator: The bus voltage is detected and then transformed into the synchronous dq0 reference frame. The control strategy for the series compensator are pre-sag compensation, in phase compensation and energy optimal compensation. In this work, the series compensator injects voltage in same phase as that of grid voltage, which results in minimum injection voltage by the series compensator. The control structure of the series compensator is shown in Fig.4 The fundamental component of PCC voltage is extracted using a PLL which is used for generating the reference axis in dq-0 domain. The reference load voltage is generated using the phase and frequency information of PCC voltage obtained using PLL. The PCC voltages and load voltages are converted into d-q-0 domain[7]. As the reference load voltage is to be in phase with the PCC voltage, the peak load reference voltage is the d-axis component value of load reference voltage. The q-axis component is kept at zero. The difference between the load reference voltage and PCC voltage gives the reference voltage for the series compensator. The difference between load voltage and PCC voltage gives the actual series compensator voltages. The difference between reference and actual series compensator voltages is passed to PI controllers to generate appropriate reference signals. These signals are converted to a-b-c domain and passed through pulse width modulation (PWM) voltage controller to generate appropriate gating signals for the series compensator.

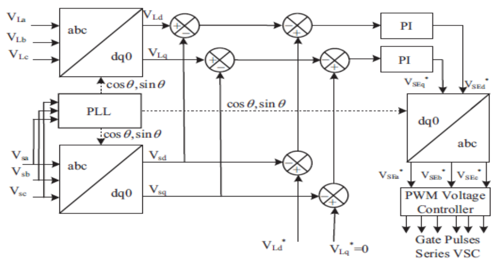


Fig.4 .Control Structure of Series Compensator

IV. SIMULATION AND RESULTS

The dynamic performances of PV-UPQC are analyzed by simulating the system in Matlab-Simulink software fig.5. The load used is a nonlinear load consisting of three phase diode bridge rectifier with R-L load. The system is subjected to various dynamic conditions such as sag and swell in PCC voltage and PV irradiation variation. The detailed system parameters are given in Appendix.

A. Performance of PV-UPQC at PCC Voltage Fluctuations

The dynamic performance of PV-UPQC under conditions of PCC voltage sags/swells is shown in Fig.6. The irradiation(G) is kept at 1000W/m2. The various sensed signals are PCC voltages (V_s), load voltages(V_L), series compensator voltages (V_{SE}), DC-link voltage (V_{dc}), solar PV array current (I_{pv}), solar PV array power (P_{pv}), grid currents (i_S), load currents (i_La, i_Lb, i_Lc), shunt compensator currents ($i_{SH}a$, $i_{SH}b$, $i_{SH}c$). Between 0.7s and 0.75s, there is voltage sag of 0.3pu and from 0.8s to 0.85s there is voltage swell of 0.3pu. The series compensator compensates for the grid voltage under these conditions by injecting a suitable voltage V_{SE} in opposite phase with the grid voltage disturbance to maintain the load voltage at rated voltage condition.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 7, June 2020 ||

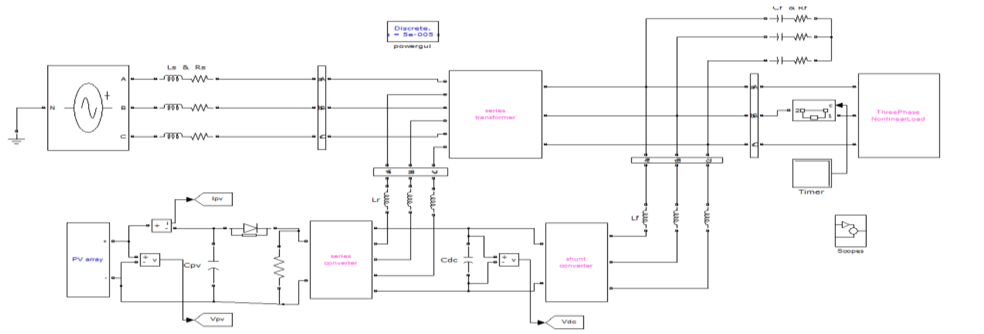
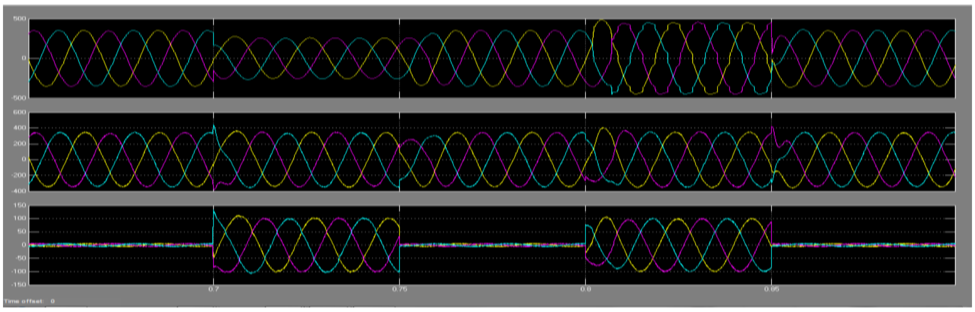
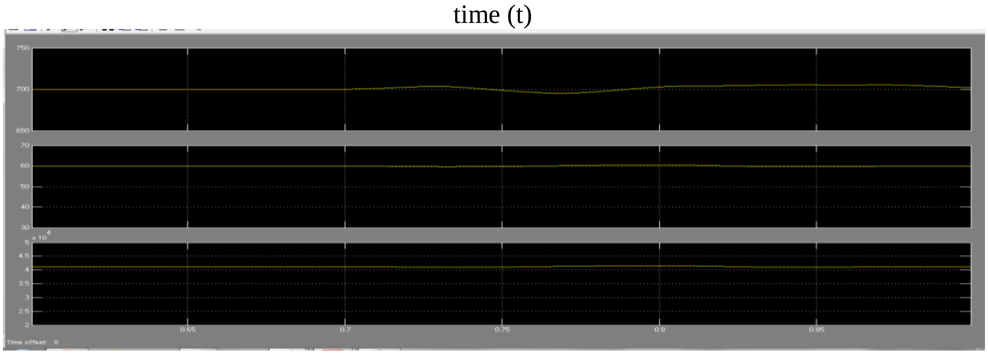


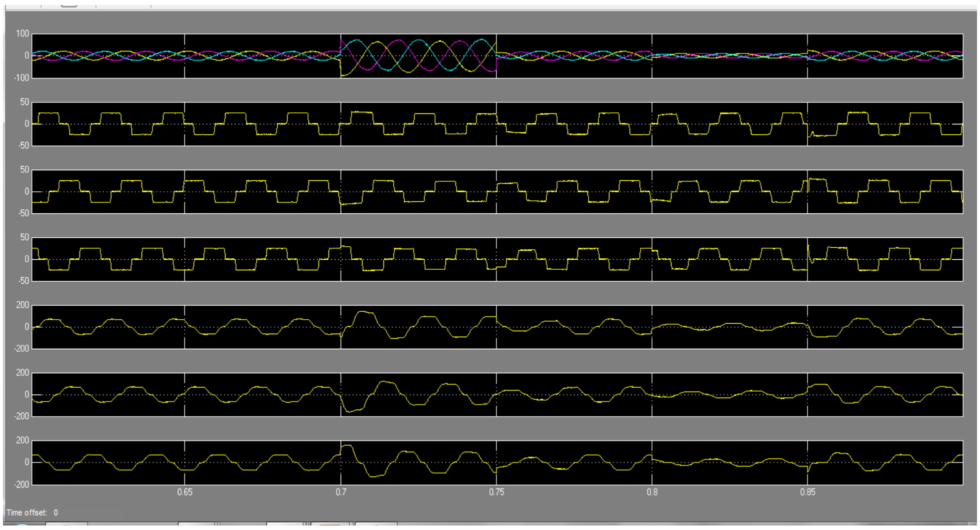
Fig. 5 MATLAB SIMULINK model of Solar integrated PV-UPQC



Waveforms of Grid voltages ($V_s$abc), load voltages ($V_L$abc)and series compensator voltages (V_{SE}) with respect to time (t)



DC- link voltage(V_{dc}), solar PV array current(I_{pv}) and PV array power (P_{pv})in KW with time in sec.



Grid currents(i_{sabc}), Load currents(i_{Labc}) ,Shunt compensator currents (i_{SHabc})with time (t)in sec

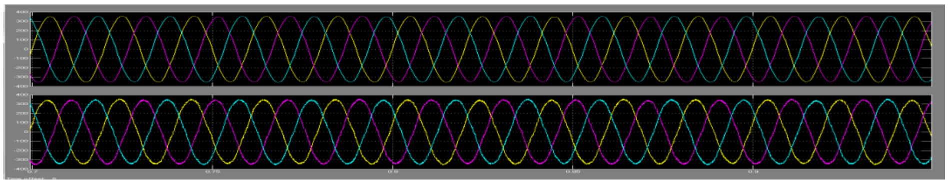
Fig.6 Performance of PV-UPQC under Voltage Sag and Swell Condition

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

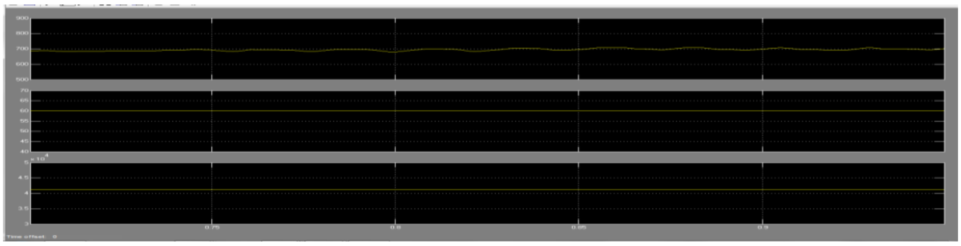
|| Volume 9, Issue 7, June 2020 ||

B. Performance of PV-UPQC at Load Unbalancing Condition

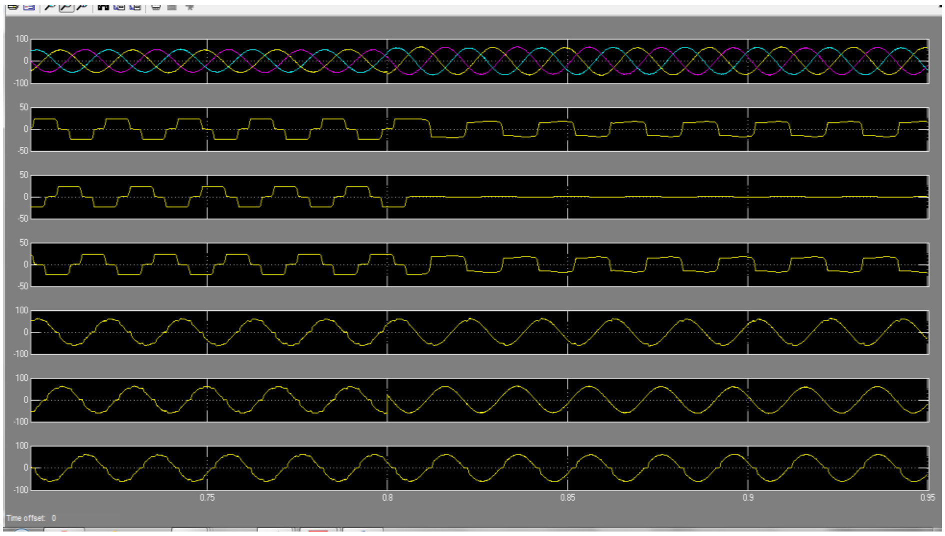
The dynamic performance of PV-UPQC under load unbalance condition is shown in Fig.7. At t=0.8s, phase 'b' of the load is disconnected. It can be observed that the grid current is sinusoidal and at unity power factor. The current fed into the grid rises leading due to the reduction in the total effective load. The DC-link voltage is also stable and it is maintained near its desired regulated value of 700 V.



Waveforms of Grid voltages ($V_s$abc)and load voltages ($V_L$abc)with respect to time (t)



DC- link voltage(V_{dc}), solar PV array current(I_{pv}) and PV array power (P_{pv})in KW with time in sec.

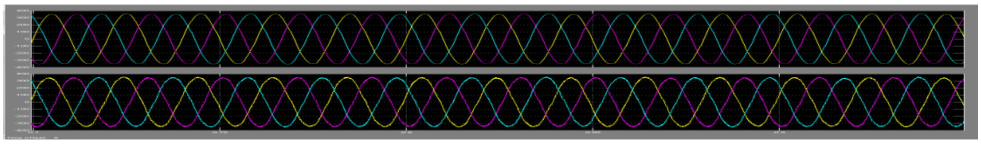


Grid currents(i_{sabc}), Load currents(i_{Labc}) ,Shunt compensator currents (i_{SHabc})with time (t)in sec.

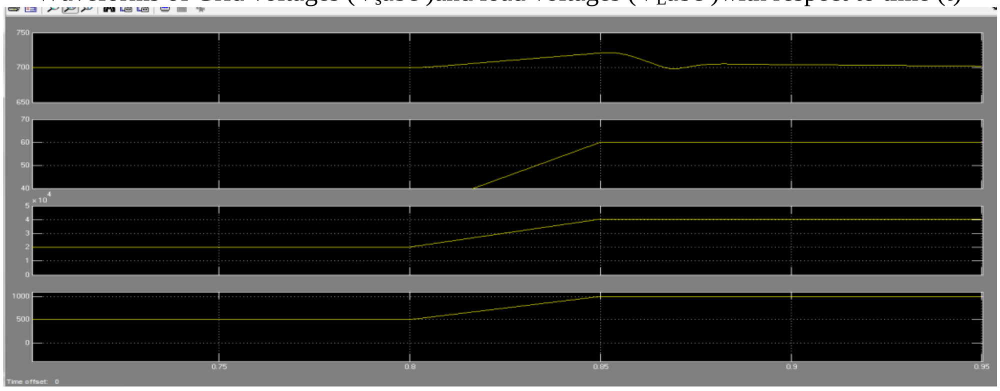
Fig.7 Performance of PV-UPQC during Load Unbalance Condition

C. Performance of PV-UPQC under Varying Irradiation

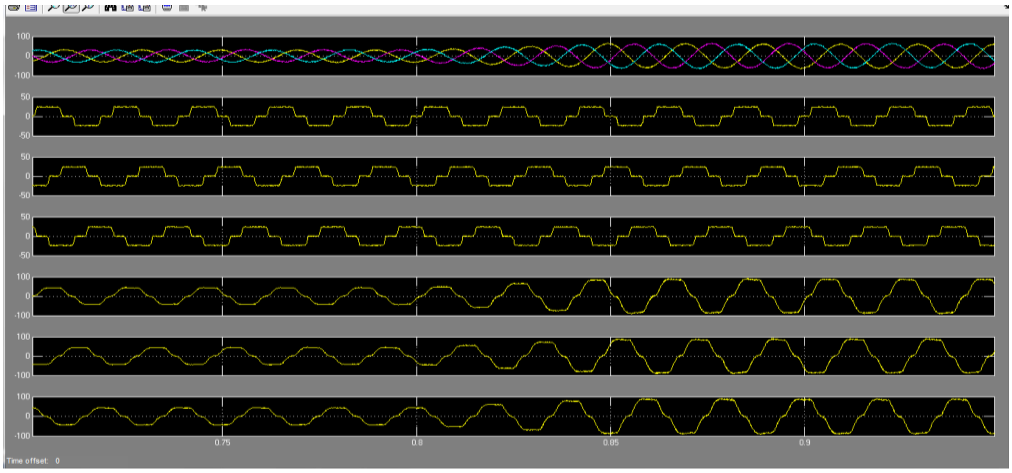
The dynamic performance of PV-UPQC under varying solar irradiation is shown in Fig.8. The solar irradiation is varied from 500W/m^2 at 0.8s to 1000W/m^2 at 0.85s. It is observed that as irradiation increases, the PV array output increases and hence grid current rises as the PV array is feeding power into the grid. The shunt compensator tracks MPPT along with compensating for the harmonics due to load current. The harmonic spectrum and THD load current and grid current are shown in Fig. 9 and Fig.10. It is observed that the load current THD is 24.81% and the grid current THD is 01.86% thus meeting the requirement of IEEE-519 standard[12].



Waveforms of Grid voltages ($V_s$abc)and load voltages ($V_L$abc)with respect to time (t)



DC- link voltage(V_{dc}), solar PV array current(I_{pv}) ,PV array power (P_{pv})in KW and Solar irradiation (G) in W/m^2 with time in sec.



Grid currents(i_{sabc}), Load currents(i_{Labc}) ,Shunt compensator currents (i_{SHabc})with time (t)in sec.

Fig. 8 Performance of PV-UPQC at Varying Irradiation Condition

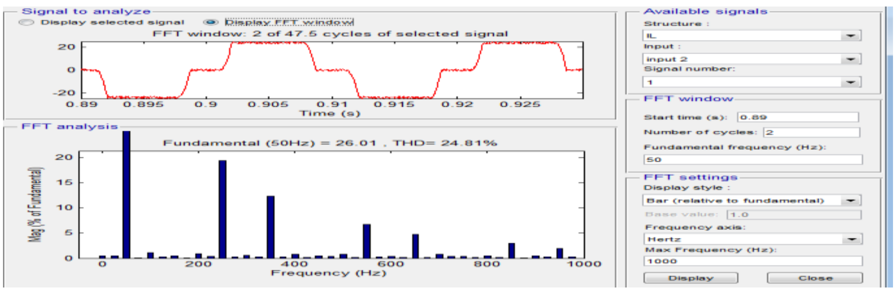


Fig.9 Load current Harmonic Spectrum and THD

Fig.9 shows the THD of load current of UPQC during swell. The load current THD is 24.81% due to presence of non-linear loads. Because of that harmonics contents in load current increases.

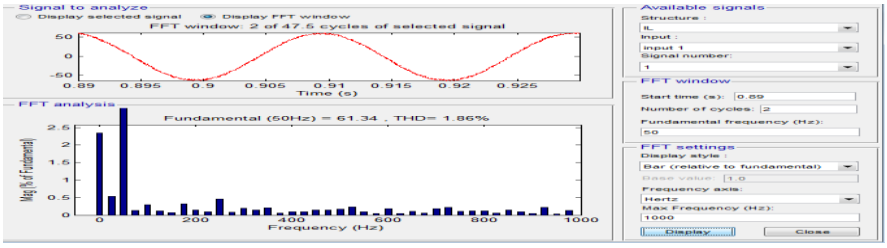


Fig.10 Grid current Harmonic Spectrum and THD

Fig.10 shows the THD of source current during swell. After use of UPQC the THD of source current reduces 1.86%. As UPQC eliminates all kind of problems due to current harmonics.

V. CONCLUSION

The dynamic performance of three-phase PV-UPQC has been analyzed under conditions of variable irradiation and grid voltage sags/swells. It is observed that PV-UPQC mitigates the harmonics caused by nonlinear and maintains the THD of grid voltage, load voltage and grid current under limits of IEEE-519 standard. The system is found to be stable under variation of irradiation from 1000W/m^2 to 500W/m^2. It can be seen that PV-UPQC is a good solution for modern distribution system by integrating distributed generation with power quality improvement. Also ,the THD of grid current is within the limit that is lees than 5%.

VI. ACKNOWLEDGMENT

I would like to show gratitude to my guide Prof. P. D. Kulkarni for sharing their pearls of wisdom with as during research. I am also grateful to the KCES's college of engineering and Information technology, who provided expertise, labs and instruments that greatly assisted the research. At last but not the least, I am thankful to my parents who have supported me throughout.

APPENDIX

System parameters	
AC Line Voltage	415 V
Line Frequency	50 Hz
Bridge Rectifier Load with R-C	10Ω,1mF
DC-link Voltage	700V
DC-link Capacitor	9.3 mF
Shunt compensator interfacing inductor	1 mH
series compensator interfacing inductor	3.6 mH
Series Injection Transformer	5.35kVA,239.6V/69V
Rating of series compensator	5.35kVA
Rating of shunt compensator	24.8kVA
Ripple Filter	10μF, 10Ω
DC link PI controller gains	Kp=1.5,Ki=0.1
MPPT controller voltage step size	2V
MPPT Sampling time	0.03sec
Series VSC PI gains for d and q axis	Kp=-1,Ki=0
Shunt VSC hysteresis controller band	0.01A
Series VSC voltage hysteresis controller band	0.1V
PWM Switching frequency of VSC	10 kHz

REFERENCES

[1] Y. Yang, P. Enjeti, F. Blaabjerg, and H. Wang, "Wide-scale adoption of photovoltaic energy: Grid code modifications are explored in the distribution grid," IEEE Ind. Appl. Mag., vol. 21, no. 5, pp. 21–31, Sept 2015.
[2] A. M. Rauf and V. Khadkikar, "Integrated photovoltaic and dynamic voltage restorer system configuration," IEEE Transactions on Sustainable Energy, vol. 6, no. 2, pp. 400–410, April 2015.

[3] Aredes M., Heumann K., Watanabe E.H., "An universal active power line conditioner", IEEE Transactions on Power Delivery, 1998, vol. 13, pp. 545-551.
[4] S. Devassy and B. Singh, "Design and performance analysis of three phase solar pv integrated upqc," in 2016 IEEE 6th International Conference on Power Systems (ICPS), March 2016, pp. 1–6.
[5] N. Hingorani, "Introducing Custom Power," IEEE Spectrum, Vol.32, Issue: 6, June 1995,pp 41-48.
[6]K. R. Padiyar "FACTS controllers in power transmission and distribution" by new AGE international publisher, page 484
[7] S. Devassy and B. Singh, "Modified p-q theory based control of solar pv integrated upqc-s," IEEE Trans. Ind. Appl., vol. PP, no. 99, pp. 1–1, 2017.
[8] B. Singh, A. Chandra and K. A. Haddad, Power Quality: Problems and Mitigation Techniques. London: Wiley, 2015.
[9] A. Sadigh and K. Smedley, "Review of voltage compensation methods in dynamic voltage restorer DVR," in IEEE Power and Energy Society General Meeting, July 2012, pp. 1–8.
[10] H. Awad, M. H.J Bollen, "Power Electronics for Power Quality Improvements," IEEE Symp. on Industrial Electronics, 2003, vol.2 , pp.1129-1136.
[11] Shankar, Sai, Ashwani Kumar, and W. Gao. "Operation of unified power quality conditioner under different situations", IEEE Power and Energy Society General Meeting, 2011, pp. 1-10
[12]"IEEE recommended practices and requirements for harmonic control in electrical power systems," IEEE Std 519-1992, pp. 1–112, April 1993.
[13] M. Davari, S. Ale-Emran, H. Yazdanpanahi, and G. Gharehpetian, "Modeling the combination of UPQC and photovoltaic arrays with multi-input single-output dc-dc converter," in IEEE/PES Power Systems Conference and Exposition, 2009. PSCE '09., March 2009, pp. 1–7.
[14] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," IEEE Transactions on Sustainable Energy, vol. 4, no. 1, pp. 89–98, Jan 2013.
[15] Rosli Omar, Nasrudin Abd Rahim, Marizan sulaiman "Modeling and Simulation for voltage sags/swells mitigation using dynamic voltage restorer (DVR)" IEEE journal on Power Electronics Drives and Energy System.
[16] M. A. Chaudhari and Chandraprakash, "Three-Phase Series Active Power Filter as Power Quality Conditioner," IEEE International Conference on Power Electronics, Drives and Energy Systems, Dec. 2012, pp 1-6.

BIOGRAPHY

Rucha Hemant Belsare has completed Graduate degree B.E. in Electrical Engineering in 2017 from SSBT COET Bambhori, Jalgaon. She is Currently working towards Master of Technology in Electrical Power System at KCES's College of Engineering and Technology, Jalgaon, Maharashtra, India.

Prof. P. D. Kulkarni is working as Assistant professor in Electrical Engineering Dept. at K.C.E. COE & IT Jalgaon From last 6 years. He has completed his Graduate degree B.E. Electrical in 2001 from Y.C.C.E College of Engg. Nagpur and completed Masters Degree M.E. Power System in 2009 from GOVT COE Aurangabad. His research interest is power system analysis, Electrical Machines, power system grounding design & analysis.