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Design and Performance Analysis of a Three-Phase Single Stage Solar Photovoltaic Integrated Unified Power Quality Conditioner (PV-UPQC)

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Abstract– This paper deals with the design and performance analysis of a three-phase single stage solar photovoltaic integrated unified power quality conditioner (PV-UPQC). The PV-UPQC consists of a shunt and series connected voltage compensators connected back-to-back with common DC-link. The shunt compensator performs the dual function of extracting power from PV array apart from compensating for load current harmonics. An improved synchronous reference frame control based on moving average filter is used for extraction of load active current component for improved performance of the PV- UPQC. The series compensator compensates for the grid side power quality problems such as grid voltage sags/swells. The compensator injects voltage in-phase/out of phase with point of common coupling (PCC) voltage during sag and swell conditions respectively. The proposed system combines both the benefits of clean energy generation along with improving power quality. The steady state and dynamic performance of the system are evaluated by simulating in MATLAB-Simulink under a nonlinear load. The system performance is then verified using a scaled down laboratory prototype under a number of disturbances such as load unbalancing, PCC voltage sags/swells and irradiation variation.

Keywords — *Power Quality, shunt compensator, series compensator, UPQC, Solar PV, MPPT.*

I. INTRODUCTION

With the advancement in semiconductor technology, there is an increased penetration of power electronic loads. These loads such as computer power supplies, adjustable speed drives, switched mode power supplies etc. have very good efficiency, however, they draw nonlinear currents. These nonlinear cur- rents cause voltage distortion at point of common coupling particularly in distribution systems. There is also increasing emphasis on clean energy generation through installation of rooftop PV systems in small apartments as well as in commercial buildings [1], [2]. However, due to the intermittent nature of the PV energy sources, an increased penetration of such systems, particularly in weak distribution systems leads to voltage quality problems like voltage sags and swells, which eventually instability in the grid [3]– [7]. These voltage quality problems also lead to frequent false tripping of power electronic systems, malfunctioning and false triggering of electronic systems and increased heating of capacitor banks etc [8]– [10]. Power quality issues at both load side and grid side are major problems faced by modern distribution systems. Due to the demand for clean energy as well as stringent power quality requirement of sophisticated electronic loads, there is need for multifunctional systems which can integrate clean energy generation along with power quality improvement. A three phase multi-functional solar energy conversion system, which compensates for load side power quality issues has been proposed in [11], [12]. A single-phase solar PV inverter along with active power filtering capability has been proposed in [13], [14]. Major research work has been done in integrating clean energy generation along with shunt active filtering. Though shunt active filtering has capability for both load voltage regulation, it comes at the cause of injecting reactive power. Thus shunt active filtering cannot regulate PCC voltage as well as maintain grid current unity power factor at same time. Recently, due to the stringent voltage quality requirements for sophisticated electronics loads, the use of series active filters has been proposed for use in small apartments and commercial buildings [15], [16]. A solar photovoltaic system integrated along with dynamic voltage restorer has been proposed in [17]. Compared to shunt and series active power filters, a unified power quality conditioner (UPQC), which has both series and shunt compensators can perform both load voltage regulation and maintain grid current sinusoidal at unity power factor at same time. Integrating PV array along with UPQC, gives the dual benefits of clean energy generation along with universal active. The integration of PV array with UPQC has been reported in [18]– [20]. 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. With the increased emphasis on distributed generation and microgrids, there is a renewed interest in UPQC systems [21], [22].

Reference signal generation is a major task in control of PV- UPQC. Reference signal generation techniques can be broadly divided into time-domain and frequency domain techniques [8]. Time domain techniques are commonly used because of lower computational requirements in real-time implementation. The commonly used techniques include instantaneous reactive power theory (p-q theory), synchronous reference frame theory (d-q theory) and instantaneous symmetrical com- ponent theory [23]. The main issue in use of synchronous reference frame theory-based method is that during load unbalanced condition, double harmonic component is present in the d-axis current. Due to this, low pass filters with very low cut off frequency is used to filter out double harmonic component. This results in poor dynamic performance [24]. In this work, a moving average filter (MAF) is used to filter the d-axis current to obtain fundamental load active current. This gives optimal attenuation and without reducing the bandwidth of the controller [25]. Recently, MAF has been applied in improving performance of DC-link controllers as well as for grid synchronization using phase locked loop (PLL). [26], [27].

In this paper, the design and performance analysis of a three- phase PV-UPQC are presented. An MAF based d-q theory-based control is used to improve the dynamic performance during load active current extraction. The main advantages of the proposed system are as follows,

- Integration of clean energy generation and power quality improvement.
- Simultaneous voltage and current quality improvement.
- Improved load current compensation due to use of MAF in d-q control of PV-UPQC.
- Stable under various dynamic conditions of voltage sags/swells, load unbalance and irradiation variation.

The performance of the proposed system is analysed extensively under both dynamic and steady state conditions using MATLAB-Simulink software. The performance is then experimentally verified using a scaled down laboratory prototype under various conditions experienced in the distribution system such as voltage sags/swells, load unbalance and irradiation variation.

II. Unified Power Quality Conditioner (UPQC)

The Unified Power Quality Conditioner (UPQC) is a multifunctional power conditioner that may be used to adjust for several power source voltage disturbances, voltage variations, and to prevent harmonic load current from entering the power system [28]. It is a specialised power gadget intended to reduce the effects of disturbances on the performance of sensitive loads. UPQC is made up of two voltage-source inverters with a common dc connection that may be single-phase, three-phase three-wire, or three-phase four-wire [29]. In the series active power filter (APF), one inverter is controlled as a variable voltage source, while another inverter is controlled as a variable current source in the shunt active power filter (APF). The Active Filter in series adjusts for voltage supply irregularities (e.g., including harmonics, imbalances, sag, swell, flickers, negative and zero sequence components). The shunt filter adjusts for load current distortions (such as those generated by harmonics or imbalances), reactive power, and dc link voltage control [30].

III. System Configuration and Design of UPQC

Figure 1 shows the design of the PV-UPQC. The topology is designed particularly for a 3ph system. The system configuration contained series converters and shunt converters with back-to-back connection having DC-bus in between them. At load end the shunt converters are normally connected. Solar Photovoltaic array will be directly interconnected with a common DC-link capacitor of the UPQC via a diode with reverse blocking capability to avoid the current to flow in reverse direction. The series converter is normally operated in voltage mode of control and it will compensate the grid voltage sags/swells. Through interfacing inductors, a shunt converter and a series converter are interconnected to a network or an electrical grid. A series connected injection transformer can be operated for injecting a voltage signal generated by a series connected compensator to an electrical grid system. Ripple filters will filter out the harmonics which are generating because of the frequent action of switching of the converters. Here a nonlinear load is used containing a bridge rectifier connected to a voltage-fed load.

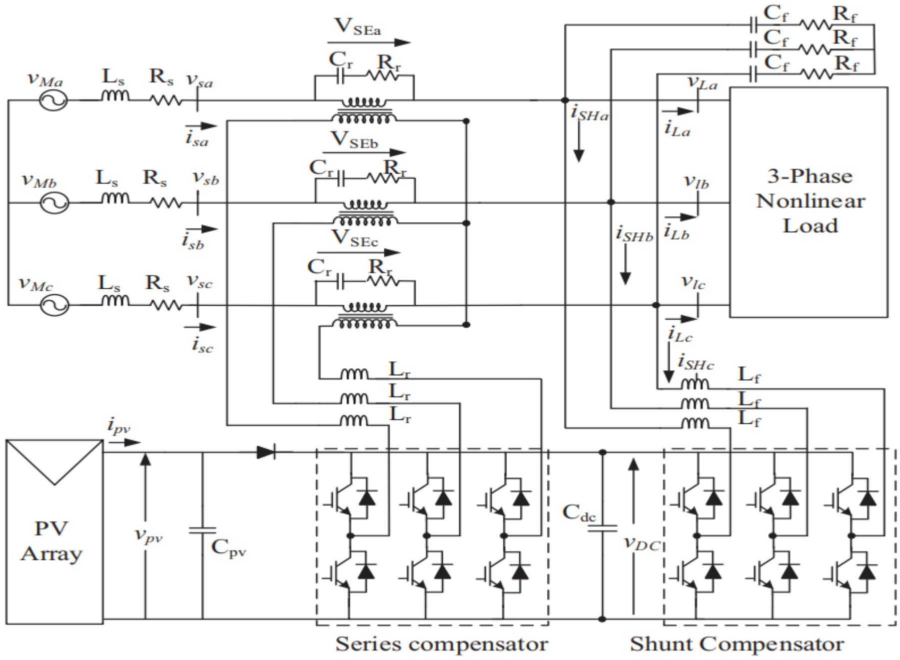

Figure 1: System Configuration of PV-UPQC

A. Basics of design configuration of PV-UPQC

The steps in designing the PV-UPQC starts from correct sizing of the solar photovoltaic array, voltage level of DC- Link, capacitor of a DC-link. The sizing of shunt converter should be properly selected as it must resolves the maximum amount of power output available from the solar Photovoltaic array along with compensation of reactive power as well as current harmonics. As photovoltaic solar array is exactly interconnected with system through a common DC link of the UPQC, hence while selecting the size of PV array it should be ensure the MPP voltage should matches with the required voltage at DC link. While selecting the power rating important condition to be considered such that, during normal conditions, a photovoltaic array should supply the load active power as well as it must feeds back the power into an electricity grid. The other building blocks are an interfacing inductor connected to the series as well as shunt compensators, the series injecting transformer connected with a series connected compensator.

IV. SIMULATION RESULTS AND DISCUSSION

Figure 2 shows the MATLAB Model of PV Integrated UPQC system. By performing simulation study in MATLAB software, a steady state as well as dynamic system behavior of Solar PV-UPQC can be examined. A load having nonlinear nature is used which comprises of 3Ph diode bridge connected rectifier connected with R-L load. A stepping size for simulation study is taken as 1e-6s. There are different dynamic conditions occurring in the system which may be voltage sag and voltage swells at PCC end and variation in the Photovoltaic irradiation.

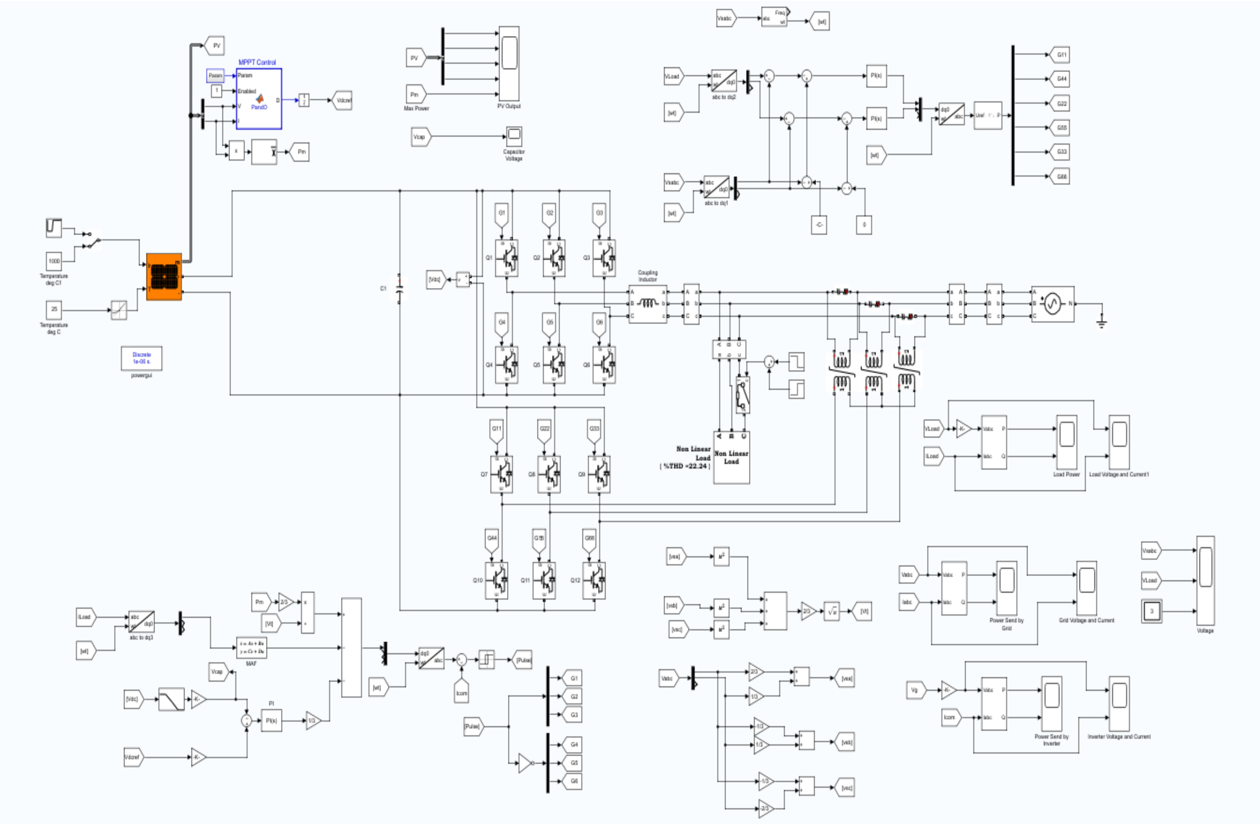

Figure 2: MATLAB Model of PV Integrated UPQC system

Table 1: Simulation Parameters

Simulation Parameters	Values
Maximum Power (W)	213.15
Cells per module (Ncell)	60
Open circuit voltage Voc (V)	36.3
Short-circuit current Isc (A)	7.84
Voltage at maximum power point Vmp (V)	29
Current at maximum power point Imp (A)	7.35
Parallel Strings	18
Series-connected modules per string	25

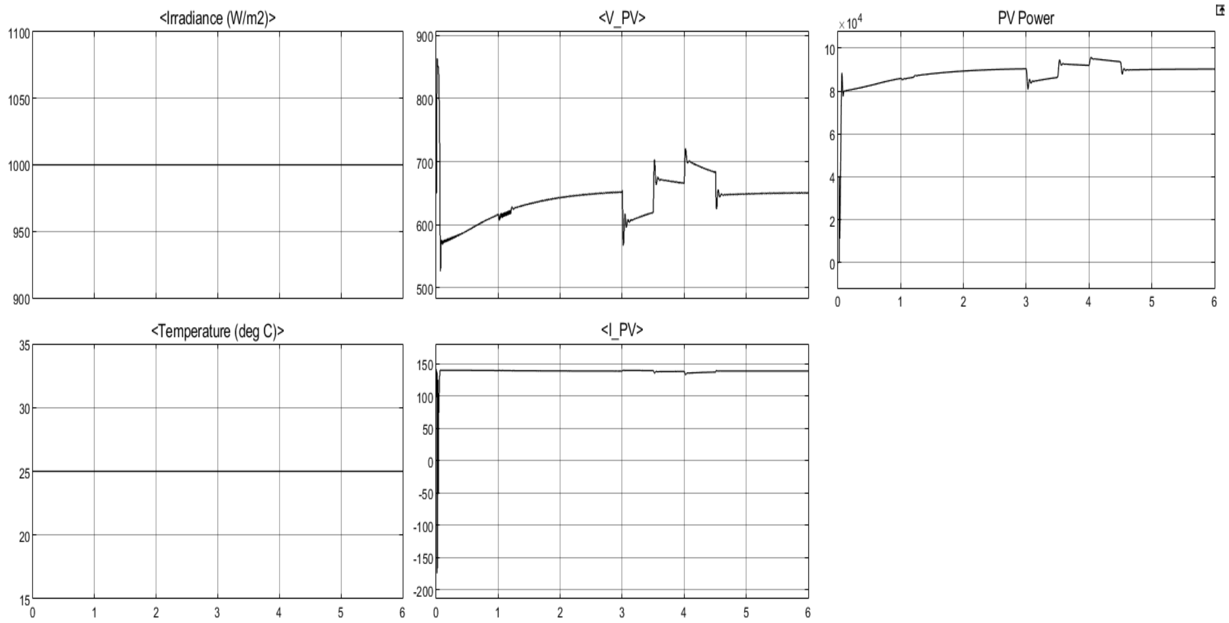

Figure 3: Irradiance, Temperature, Voltage-PV, Current-PV & Power-PV V/s Time in (S)

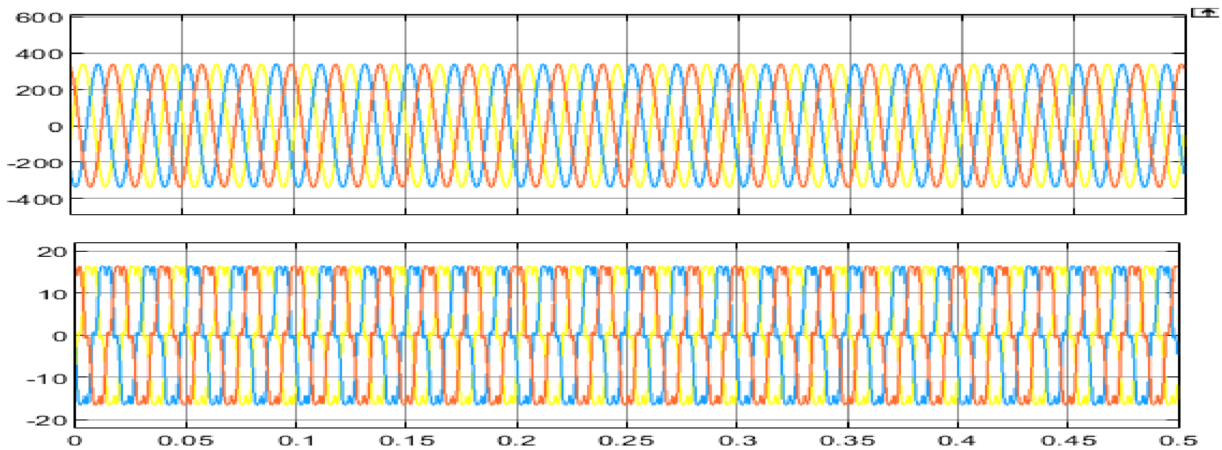

Figure 4: Load Voltage and Current V/s Time in (S)

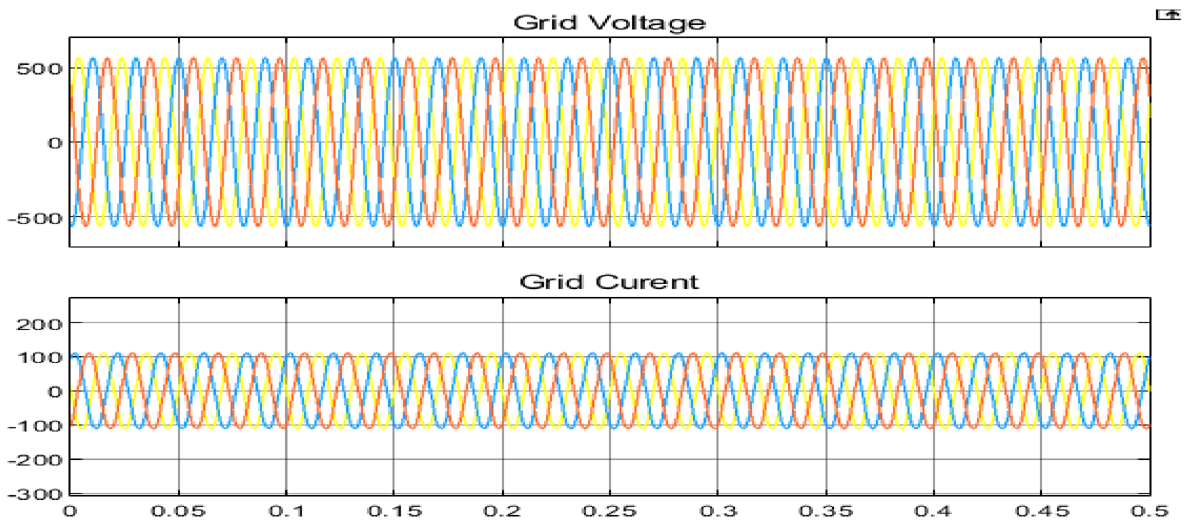

Figure 5: Grid Voltage and Grid Current V/s Time in (S)

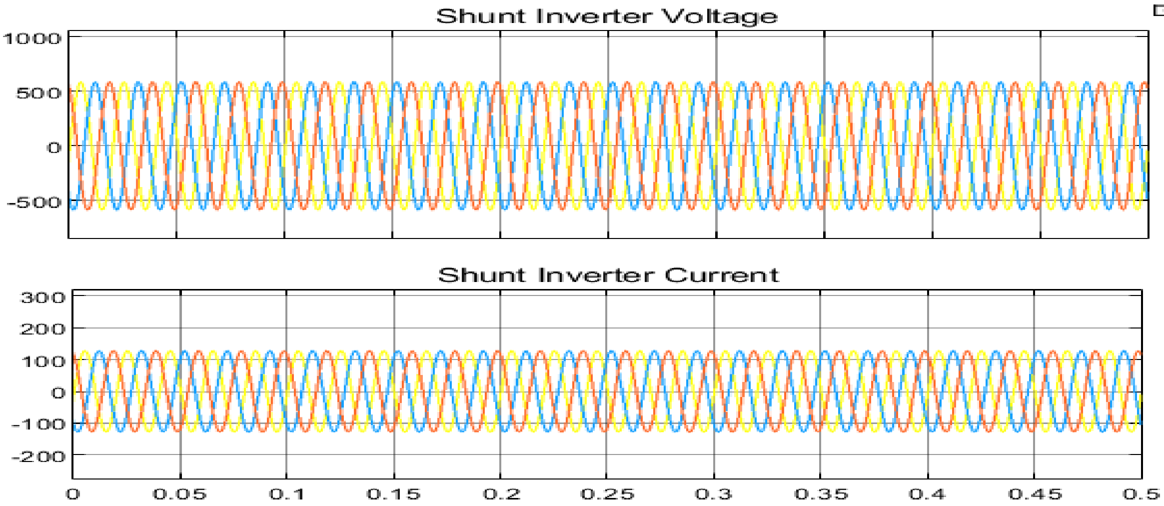

Figure 6: Shunt Inverter Voltage and Shunt Inverter Current V/s Time in (S)

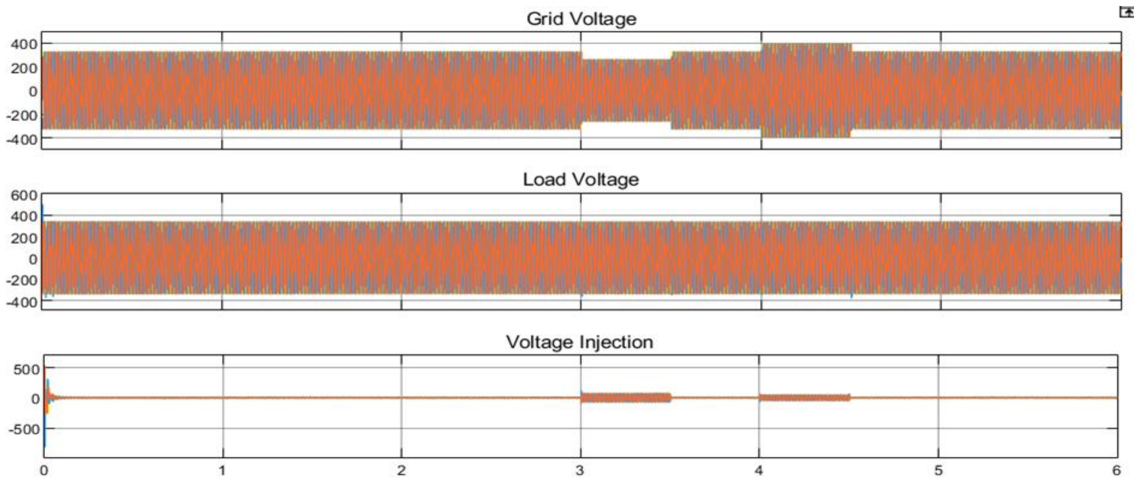

Figure 7: Grid Voltage, Load Voltage and Voltage Injection V/s Time in (S)

CONCLUSION

The design and dynamic performance of three-phase PV- UPQC have been analyzed under conditions of variable irradiation and grid voltage sags/swells. The performance of the system has been validated through experimentation on scaled down laboratory prototype. It is observed that PV- UPQC mitigates the harmonics caused by nonlinear load and maintains the THD of grid current under limits of IEEE-519 standard. The system is found to be stable under variation of irradiation, voltage sags/swell and load unbalance. The performance of d-q control particularly in load unbalanced condition has been improved through the use of moving average filter. It can be seen that PV-UPQC is a good solution for modern distribution system by integrating distributed generation with power quality improvement.

References

[1] B. Mountain and P. Szuster, “Solar, solar everywhere: Opportunities and challenges for australia’s rooftop pv systems,” IEEE Power and Energy Magazine, vol. 13, no. 4, pp. 53–60, July 2015.

[2] A. R. Malekpour, A. Pahwa, A. Malekpour, and B. Natarajan, “Hier- archical architecture for integration of rooftop pv in smart distribution systems,” IEEE Transactions on Smart Grid, vol. PP, no. 99, pp. 1–1, 2017.

[3] 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.

[4] M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, “An approach for online assessment of rooftop solar pv impacts on low-voltage distribution networks,” IEEE Transactions on Sustainable Energy, vol. 5, no. 2, pp. 663–672, April 2014.

[5] J. Jayachandran and R. M. Sachithanandam, “Neural network-based control algorithm for DSTATCOM under nonideal source voltage and varying load conditions,” Canadian Journal of Electrical and Computer Engineering, vol. 38, no. 4, pp. 307–317, Fall 2015.

[6] A. Parchure, S. J. Tyler, M. A. Peskin, K. Rahimi, R. P. Broadwater, and M. Dilek, “Investigating pv generation induced voltage volatility for customers

sharing a distribution service transformer," IEEE Trans. Ind. Appl., vol. 53, no. 1, pp. 71–79, Jan 2017.

[7] E. Yao, P. Samadi, V. W. S. Wong, and R. Schober, "Residential demand side management under high penetration of rooftop photovoltaic units," IEEE Transactions on Smart Grid, vol. 7, no. 3, pp. 1597–1608, May 2016.

[8] B. Singh, A. Chandra and K. A. Haddad, Power Quality: Problems and Mitigation Techniques. London: Wiley, 2015.

[9] M. Bollen and I. Guo, Signal Processing of Power Quality Disturbances. Hoboken: Johm Wiley, 2006.

[10] P. Jayaprakash, B. Singh, D. Kothari, A. Chandra, and K. Al-Haddad, "Control of reduced-rating dynamic voltage restorer with a battery energy storage system," IEEE Trans. Ind. Appl., vol. 50, no. 2, pp. 1295– 1303, March 2014.

[11] B. Singh, C. Jain, and S. Goel, "ILST control algorithm of single- stage dual purpose grid connected solar pv system," IEEE Trans. Power Electron., vol. 29, no. 10, pp. 5347–5357, Oct 2014.

[12] R. K. Agarwal, I. Hussain, and B. Singh, "Three-phase single-stage grid tied solar pv ecs using PLL-less fast CTF control technique," IET Power Electronics, vol. 10, no. 2, pp. 178–188, 2017.

[13] Y. Singh, I. Hussain, B. Singh, and S. Mishra, "Single-phase solar grid- interfaced system with active filtering using adaptive linear combiner filter-based control scheme," IET Generation, Transmission Distribution, vol. 11, no. 8, pp. 1976–1984, 2017.

[14] T.-F. Wu, H.-S. Nien, C.-L. Shen, and T.-M. Chen, "A single-phase inverter system for pv power injection and active power filtering with nonlinear inductor consideration," IEEE Trans. Ind. Appl., vol. 41, no. 4, pp. 1075–1083, July 2005.

[15] A. Javadi, A. Hamadi, L. Woodward, and K. Al-Haddad, "Experimental investigation on a hybrid series active power compensator to improve power quality of typical households," IEEE Trans. Ind. Electron., vol. 63, no. 8, pp. 4849–4859, Aug 2016.

[16] A. Javadi, L. Woodward, and K. Al-Haddad, "Real-time implementation of a three-phase thseaf based on vsc and p+r controller to improve power quality of weak distribution systems," IEEE Transactions on Power Electronics, vol. PP, no. 99, pp. 1–1, 2017.

[17] A. M. Rauf and V. Khadkikar, "Integrated photovoltaic and dynamic voltage restorer system configuration," IEEE Transactions on Sustain- able Energy, vol. 6, no. 2, pp. 400–410, April 2015.

[18] S. Devassy and B. Singh, "Design and performance analysis of three- phase solar pv integrated upqc," in 2016 IEEE 6th International Con- ference on Power Systems (ICPS), March 2016, pp. 1–6.

[19] K. Palanisamy, D. Kothari, M. K. Mishra, S. Meikandashivam, and I. J. Raglend, "Effective utilization of unified power quality conditioner for interconnecting PV modules with grid using power angle control method," International Journal of Electrical Power and Energy Systems, vol. 48, pp. 131 – 138, 2013.

[20] 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.

[21] S. K. Khadem, M. Basu, and M. F. Conlon, "Intelligent islanding and seamless reconnection technique for microgrid with upqc," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 3, no. 2, pp. 483–492, June 2015.

[22] J. M. Guerrero, P. C. Loh, T. L. Lee, and M. Chandorkar, "Advanced control architectures for intelligent microgrids;part ii: Power quality, energy storage, and ac/dc microgrids," IEEE Transactions on Industrial Electronics, vol. 60, no. 4, pp. 1263–1270, April 2013.

[23] B. Singh and J. Solanki, "A comparison of control algorithms for dstatcom," IEEE Transactions on Industrial Electronics, vol. 56, no. 7, pp. 2738–2745, July 2009.

[24] B. Singh, C. Jain, S. Goel, A. Chandra, and K. Al-Haddad, "A multifunc- tional grid-tied solar energy conversion system with anf-based control approach," IEEE Transactions on Industry Applications, vol. 52, no. 5, pp. 3663–3672, Sept 2016.

[25] S. Golestan, M. Ramezani, J. M. Guerrero, and M. Monfared, "dq-frame cascaded delayed signal cancellation- based pll: Analysis, design, and comparison with moving average filter-based pll," IEEE Transactions on Power Electronics, vol. 30, no. 3, pp. 1618–1632, March 2015.

[26] R. Pea-Alzola, D. Campos-Gaona, P. F. Ksiazek, and M. Ordonez, "Dc- link control filtering options for torque ripple reduction in low-power wind turbines," IEEE Trans. Power Electron., vol. 32, no. 6, pp. 4812– 4826, June 2017.

[27] S. Golestan, M. Ramezani, J. M. Guerrero, F. D. Freijedo, and M. Mon- fared, "Moving average filter based phase-locked loops: Performance analysis and design guidelines," IEEE Trans. Power Electron., vol. 29, no. 6, pp. 2750–2763, June 2014.

[28] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," IEEE Trans- actions on Sustainable Energy, vol. 4, no. 1, pp. 89–98, Jan 2013.

[29] 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.

[30] A. Rauf and V. Khadkikar, "An enhanced voltage sag compensation scheme for dynamic voltage restorer," IEEE Trans. Ind. Electron., vol. 62, no. 5, pp. 2683–2692, May 2015.