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Grid integration of Photovoltaic System Interfaced with Artificial Intelligence based Modified Universal Power Quality conditioning system

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Abstract: Unified Power Quality Compensators (UPQC) in load side utility system is not able to fully suppress harmonics in power grid and distortion in the interface system. To enhance the operation of the UPQC, a Fuzzy based Modified Universal power quality conditioning system (Fuzzy-MUPQCS) is developed. Modified Universal power quality conditioning system (MUPQCS) is a combination of two active filters in series and one active filter in shunt. A 3ϕ voltage source inverter is also used to maintain a common DC link capacitor voltage through Photo voltaic (PV) system connected to a utility grid. Highest Power Point Tracking (HPPT) algorithm is mainly used to pull out the maximum amount of power in the PV system. In this paper, Proportional integral controller based MUPQCS (PI- MUPQCS) and Fuzzy-MUPQCS are used to analyse the load voltage and load current distortion, THD analysis, power factor measurement, grid voltage and grid current distortion in the three phase system under nonlinear load conditions. The execution of the MUPQCS based 3ϕ system and the controllers are simulated using Matlab /Simulink model.

1. Introduction

In view of climate change and environmental issues, the utility manager looks for alternate energy source. Even though the recent research says grid integration of renewable energy gives positive results, there is some drawbacks in the distribution generation (DG). The main drawbacks of renewable energy are difficult to control the voltage and frequency, increasing the short circuit current, disturbing protective equipment settings, difficult to synchronize with the power grid, increase of overvoltage and losses, increased cost of dispatching and implementation problem in urban areas [1].
Nowadays solar photovoltaic system is the preferable renewable energy source in power system. A PV system consists of battery, MPPT controller, DC-DC converter and solar panels which creates output voltage as constant at the terminal end of the PV system. The extraction of peak variable power from a photovoltaic array is obtained by Highest Power Point Tracking based Controller. There are various Maximum power point tracking algorithms such as constant voltage method, incremental conductance method, hill climbing method, open circuit voltage method, short circuit current method, ripple correlation method and P&O method have been discussed in the earlier literature. [2-9].
Power quality is the major issue in power system network due to nonlinear electrical loads. Current related power quality problems in the grid mains are unbalanced currents, reactive power burden, poor power factor, harmonics currents and an excessive neutral current in multiphase systems due to harmonics currents and unbalance currents produced by nonlinear loads. [10].

A custom power device known as unified power quality compensator (UPQC) is considered as the right option for critical and sensitive loads to compensate both voltage and current based power quality problems. The UPQC is a combined series and shunt compensators which provides a single solution for eliminating the PQ problems of voltages and currents. The entire circuit of a UPQC having two voltage source converters (VSCs) or current source converters (CSCs) joined back to back by a common DC link capacitor or an inductor in the DC bus [11].

Various compensation time domain control algorithms for unified power quality conditioners suggested in the literature are Adaptive detecting control, conductance based control, Enhanced phase locked loop based control, Neural network theory [12,13], Fuzzy control theory [12],[14],[15]. single phase DQ theory[16], single phase PQ theory[17], Instantaneous symmetrical component theory[18], instantaneous reactive power theory, synchronous reference frame theory[19], current synchronous detection method, I cos ϕ control, power balance theory[20] and PI controller based theory [11] .

Similarly various control algorithms for frequency domain is used for detection of power quality disturbance are Hilbert-Huang transformation theory[21], Empirical decomposition (EMD) theory[22], S-transform theory, wavelet transform theory[23], Kalman filter algorithm, Recursive discrete Fourier transform theory, Fast Fourier transform theory, Discrete Fourier transform theory and Fourier series theory [11].

MPPT based algorithm is implemented in [24] power system to pull out the peak value of the PV power in an interline PV source with grid system. In paper [25], PV systems bonding with an advanced UPQCS is connected to a utility grid. In the bonding system, an enhanced active filter is used [25] to produce output voltages to reduce all the supply voltage problems and to heavily reduce the grid current distortions and harmonics, even under nonlinear load and imbalanced conditions.

In this paper, to improve the power quality of the entire system a Fuzzy based Modified Universal power quality conditioning system (Fuzzy-MUPQCS) with MPPT based PV system is developed. In section 2, suggested model of MUPQCS is explained. In section 2.1 and 2.2, SRF-PI and Fuzzy control schemes for DVR and DSTATCOM are explained. Finally, in section 4, the simulation results of load voltage and load current distortion, THD analysis, power factor measurement, grid voltage and grid current distortion in the three phase system are discussed.

2. Suggested MUPQCS Integrated Solar PV system to Utility Grid

Figure 1 depict the 3ϕ system structure for combining a PV system to the utility grid through MUPQCS. In this suggested system, an enhanced active filter or Voltage Source Converter-I (VSC-I) is designed to reduce all supply voltage problems while sending the balance utility grid harmonics current to the active filter in shunt /VSC-II of the MUPQCS. During the disconnection of PV system, an VSC -III is proposed at the customer side utility grid to control the common DC link capacitor voltage. To extract the maximum power in the PV system, MPPT control technique is adopted. Also the harmonics and distortions produced by the load side VSC -III could also be absorbed by the active filter in shunt /VSC-II.

PV system in the MUPQCS is mainly used to maintain DC link capacitor voltage and inductance-capacitance filter is used to minimise the harmonics. During night time , DC bus voltage is regulated with the help of VSC-III ,which is connected in series with the injection transformer at the load side. The main advantage of using the PV fed MUPQCS is to minimise the grid end source current.

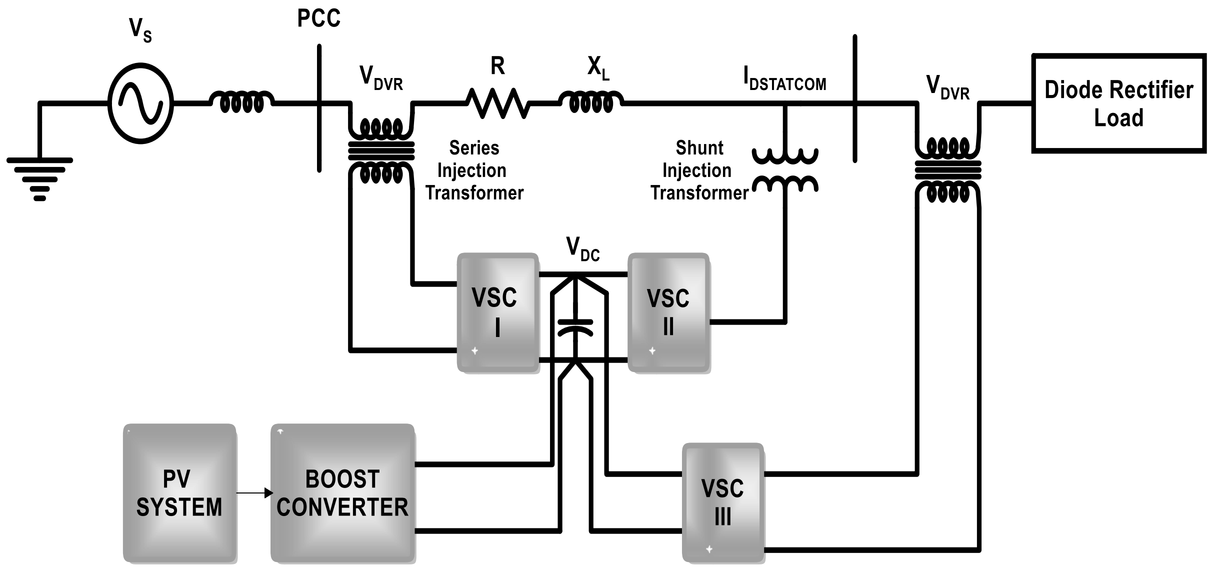


Figure 1. Schematic diagram of three phase system with PV based MUPQCS

2.1 Synchronous reference frame theory based PI Control scheme (SRF-PI) for DVR and DSTATCOM in MUPQCS

For the control of DVR and DSTATCOM part of MUPQCS, there are many number of control algorithms suggested in references. The working of DVR in MUPQCS, synchronous reference frame theory (SRF-PI) based PI control algorithms is adopted in following sections [11,26].

Figure 2 Shows the SRF-PI control algorithm for the circuit of DVR. The Park's transformation is used to transform V_{abc} to DQO. Voltage harmonics, oscillatory components and distortion are reduced by Low pass filter (LPF). The quadrature and direct axis voltages are

$$V_{Sd} = V_{dDC} + V_{dAC} \quad (1)$$

$$V_{Sq} = V_{qDC} + V_{qAC} \quad (2)$$

The DC bus voltage of DVR is maintained with PI controller.

$$V_{Loss(n)} = V_{Loss(n-1)} + K_{p1}\left(V_{de(n)} - V_{de(n-1)}\right) + K_{i1} V_{de(n)} \quad (3)$$

Where $V_{d(n)} = V^{*}_{DC} - V_{DC(n)}$ is the error between sensed DC voltage (V^{*}_{DC}) at the n^{th} sampling instant. K_{i1} and K_{p1} are the integral and proportional gains. The gain of the controller is obtained by trial and error method.

The reference customer side voltage direct axis is

$$V^{*}_{d} = V_{dDC} - V_{loss} \quad (4)$$

The reference voltage (V_L*) and load terminal voltage (V_L) of amplitude is regulated by one more PI controller. The output voltage of PI controller is reactive component of voltage (V_{qr}) which is used to control the reference value as

$$V_{qr(n)} = V_{qr(n-1)} + K_{p2}\left(V_{te(n)} - V_{te(n-1)}\right) + K_{i2} V_{te(n)} \quad (5)$$

Where, $V_{te(n)} = V^{*}_{L} - V_{L(n)}$, represents difference between actual and reference load side.

The reference customer side voltage quadrature axis is

$$V^{*}_{q} = V_{qDC} + V_{qr} \quad (6)$$

The reference customer side voltage DQO to abc frame is done by reverse park transformation. The error between reference customer side voltage and actual customer side voltage is fed to the Pulse Width Modulation Controller to gives the signal to DVR converter. [11,26].

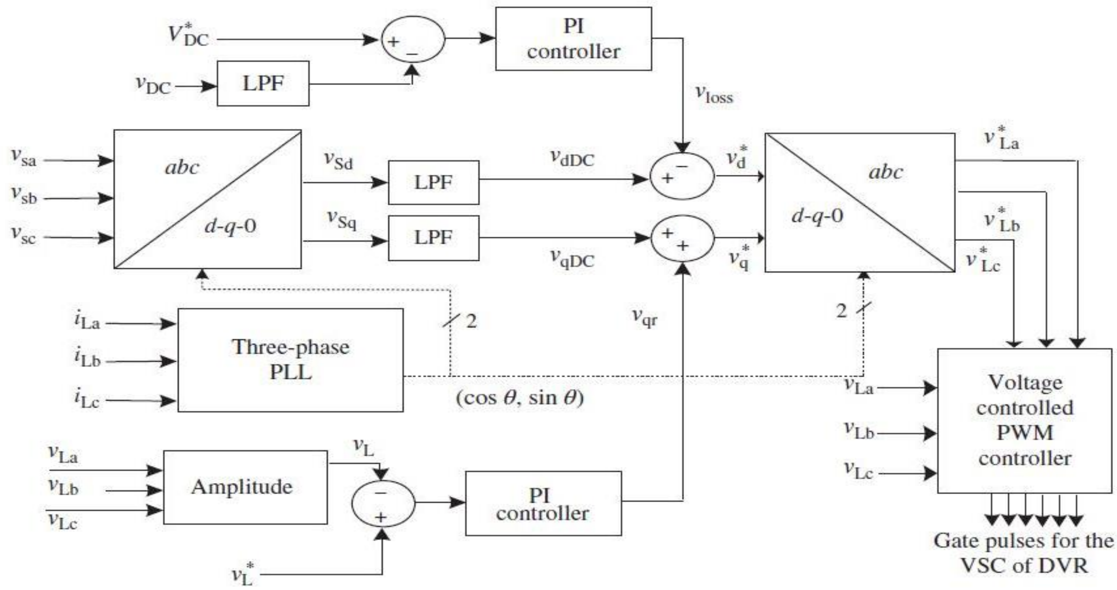


Figure 2. Control circuit of DVR in MUPQCS [11,26]

The function of DSTATCOM is to improve the power quality of source current and also said the common DC bus between DVR and DSTATCOM by absorbing active power at the time of transients. The control scheme of DSTATCOM is depicted in reference [11]. The voltage at PCC (V_{SA}, V_{SB}, V_{SC}), the load currents (i_{LA}, i_{LB}, i_{LC}) and DC bus voltage are observed as feedback signal. The load current in abc frame are transformed to the dqo frame.

2.2 Fuzzy based Control Algorithm for DVR and DSTATCOM

Figure 3 shows the Fuzzy based control circuit for DVR/DSTATCOM portion of MUPQCS. In this circuit, actual DC voltage is matched with reference DC voltage and the error voltage and change in error voltage is given as input to Fuzzy Controller.

For DSTATCOM, the output response of the fuzzy controller is given to the multiplier through limiter, the reference source current is obtained from unit amplitude generation through multiplier. The unit amplitude generation is obtained by phase locked loop. The reference source current is compared with the load current gives compensation reference current. In Hysteresis Current Controller, reference current compensation is compared with reference current the output is injected by the compensation circuit.

For DVR, output response of the fuzzy controller is given to the multiplier through limiter, the reference source voltage is obtained from unit amplitude generation through multiplier. The reference source voltage is matched with load voltage and the deviation gives the compensation reference voltage. In Hysteresis Voltage Controller, reference voltage compensation is matched with reference voltage and the output is injected by the compensation circuit. Fuzzy based control algorithm for DVR and DSTATCOM and Fuzzy Rule Table are adopted from the reference [12].

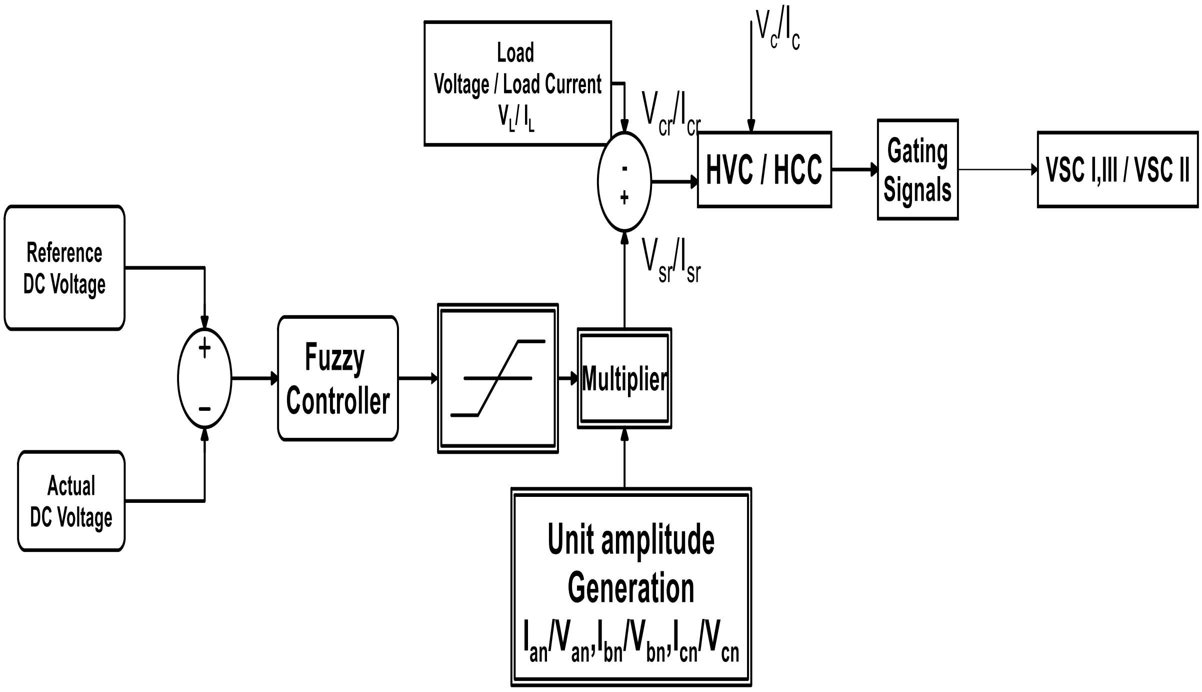


Figure 3. Fuzzy based control circuit for DVR /DSTATCOM in MUPQCS [12]

2.3 HPPT Control algorithm for PV system.

Highest power point tracking is a technique used commonly with PV systems to ensure the peak value of generated power is transferred to the load. various types of MPPT algorithms is implemented for obtaining maximum power transfer in literature. One of the popular scheme called incremental conductance method shown in Figure 4 is used as a control algorithm for PV system. In this scheme, the highest power point is obtained by comparing the impedance of the PV array and converter. Again, boost converter is tuned by varying the duty cycle [27]. The algorithm is explained in equations (7) to (9).

At the voltage source side,

$$\frac{dI_{PV}}{dV_{PV}} > -\frac{I_{PV}}{V_{PV}} \Rightarrow \text{d=d+}\Delta\text{d(i.e., increment duty cycle)} \tag{7}$$

In the current source region,

$$\frac{dI_{PV}}{dV_{PV}} < -\frac{I_{PV}}{V_{PV}} \Rightarrow \text{d=d}-\Delta\text{d(i.e., decrement duty cycle)} \tag{8}$$

At, MPP

$$\frac{dI_{PV}}{dV_{PV}} = -\frac{I_{PV}}{V_{PV}} \Rightarrow \text{d=d or }\Delta\text{d=0 (i.e., retain d)} \tag{9}$$

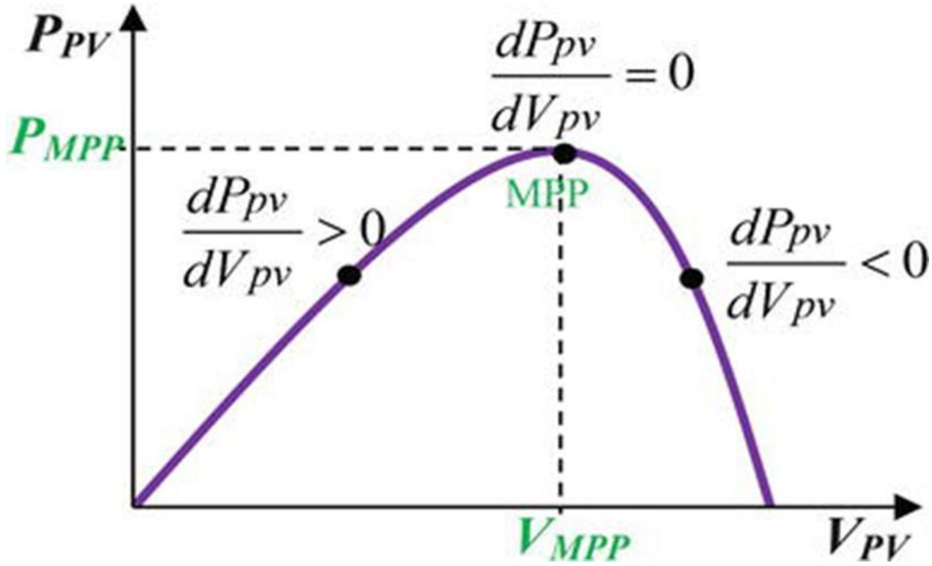


Figure 4. Incremental conductance method

3. Simulation Results and Discussion

A three phase system with PV based MUPQCS connected with diode rectifier RL load is shown in Figure 1. The MPPT controller based PV system is interfaced with the power grid. The simulated PV system consists of MPPT controller, DC-DC converter and series-parallel solar panels. Two control techniques such as PI and Fuzzy are implemented in MUPQCS. Table 2 shows the parameters of the three phase system with MUPQCS. The detailed parameters of the PV system are shown in Table 3.

Simulations were carried out with the condition of load changes from 10kW to 30kW and 100VAR to 300VAR during the time period 0.1sec to 0.15 sec in the load voltage waveforms shown in Figure 5(a). The voltage waveforms are distorted during the entire period and the magnitude is reduced in between 0.1 to 0.15 secs. After insertion of PI and Fuzzy controller in MUPQCS, the voltage sag deficiencies are compensated as depict in Figure 5(b) and 5(c). The total harmonic distortion (THD) value for voltage is reduced from 29.09% to 0.17 % and 0.03% respectively. Current in the load side is also distorted and the magnitude is increased during the period 0.1 to 0.15 sec as shown in Figure 6(a). From 6(b) and 6(c) ,it is observed that the distortion is completely suppressed and the THD is reduced from 14.61 % to 1.3% and 0.59% for PI and fuzzy controller respectively .

The power factor at the load bus is measured in the simulated model and tabulated in Table 1. From the results, it is understand that the load side power factor is increased from 0.6 to 0.8 /0.99 in the case of PI /fuzzy controller.

From Figure 7 and 8, shows the comparison performance of grid voltage and grid current with and without Fuzzy -MUPQCS. It results in a pure sinusoidal voltage and current waveform with reduction in Voltage THD from 4.56% to 0.01 % and grid current from 10.76% to 0.16 %.

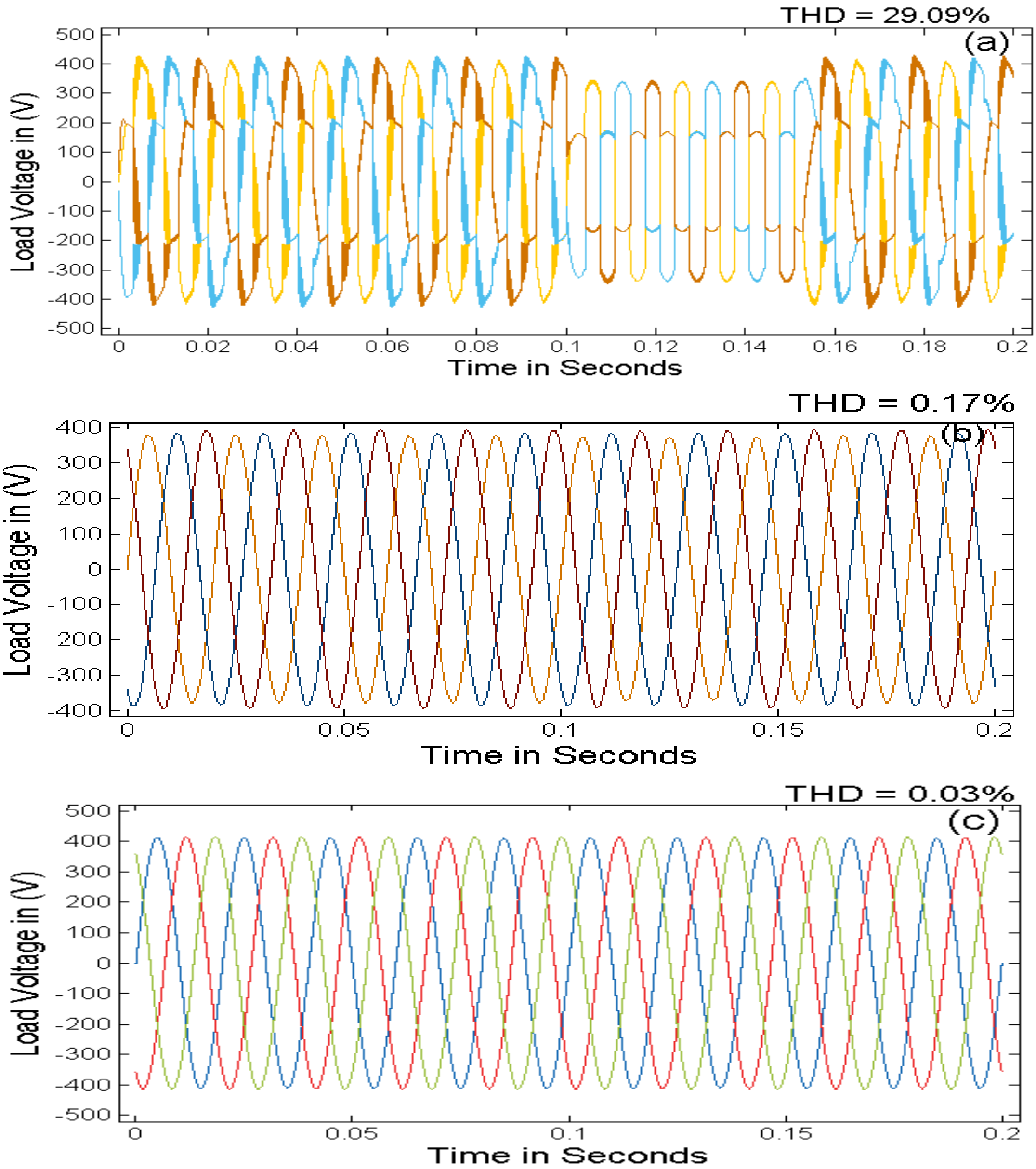
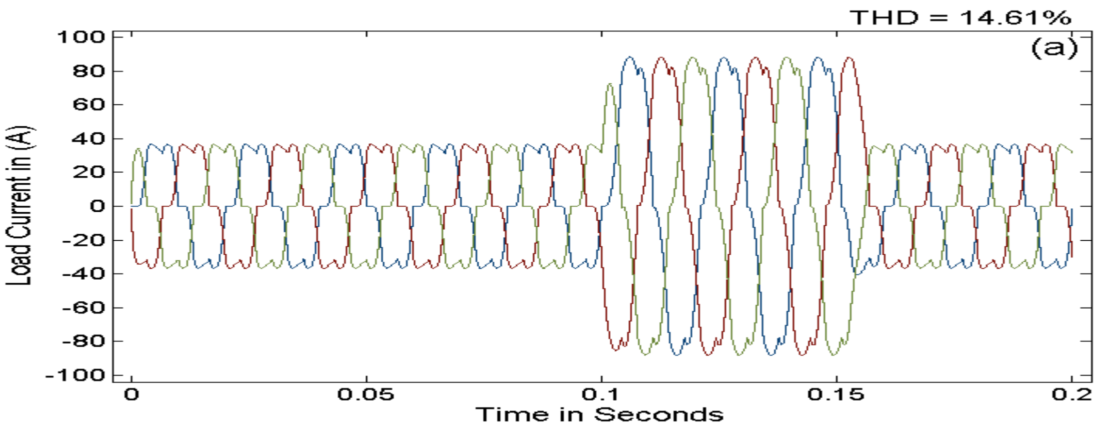
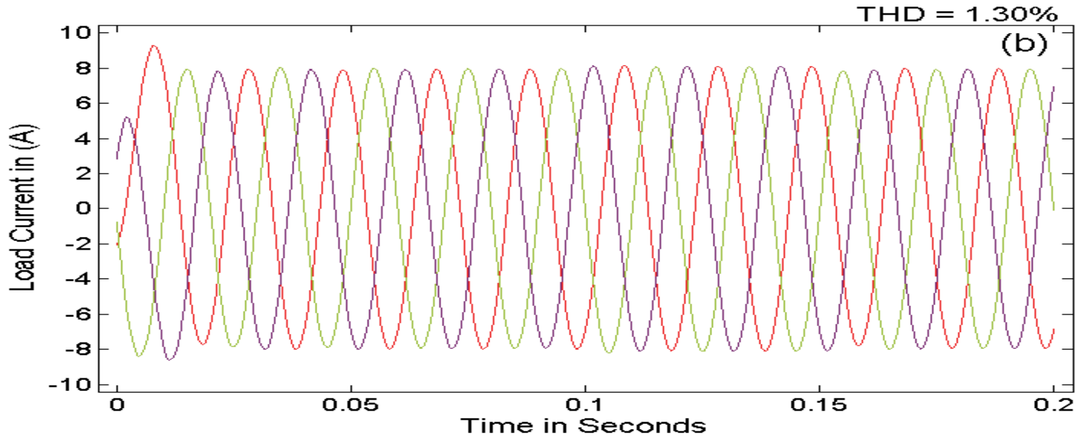


Figure 5. Simulated Load voltage waveforms (a) without MUPQCS (b) With PI-MUPQCS (c) With Fuzzy-MUPQCS





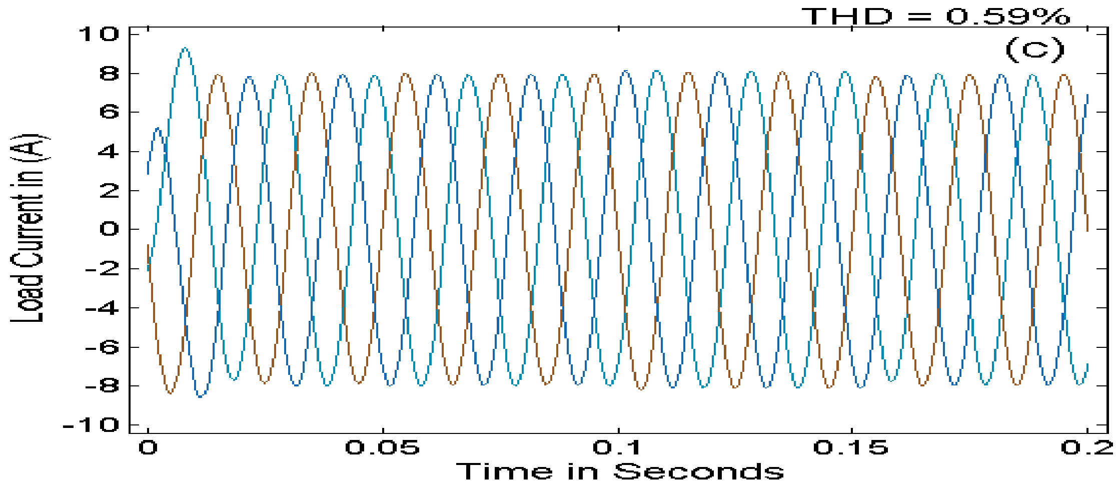


Figure 6. Simulated waveforms of Load Current (a) without MUPQCS (b) PI-MUPQCS (c) Fuzzy-MUPQCS

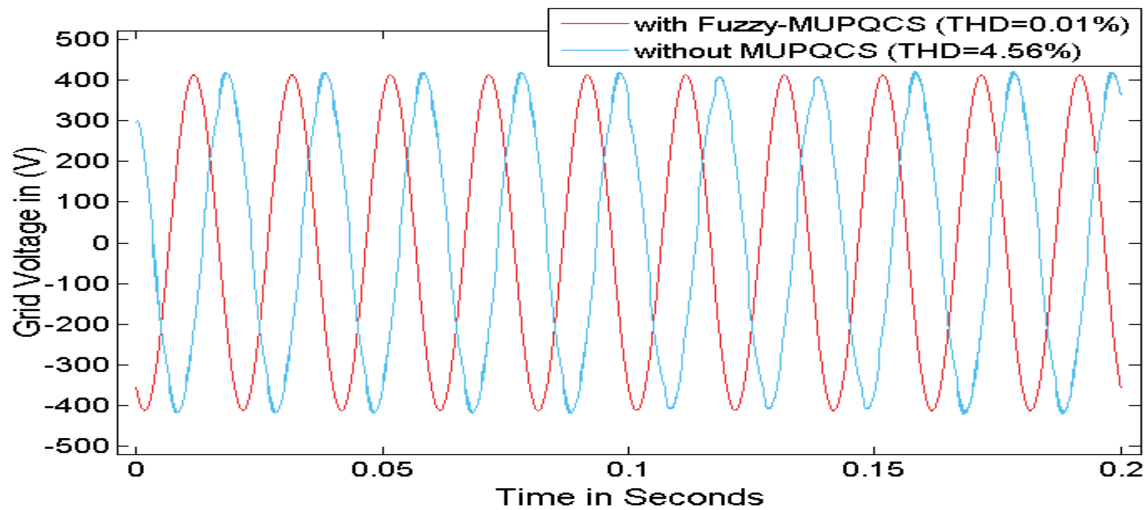


Figure 7. Measurement of Grid Voltage with and without Fuzzy-MUPQCS in three phase system containing nonlinear load.

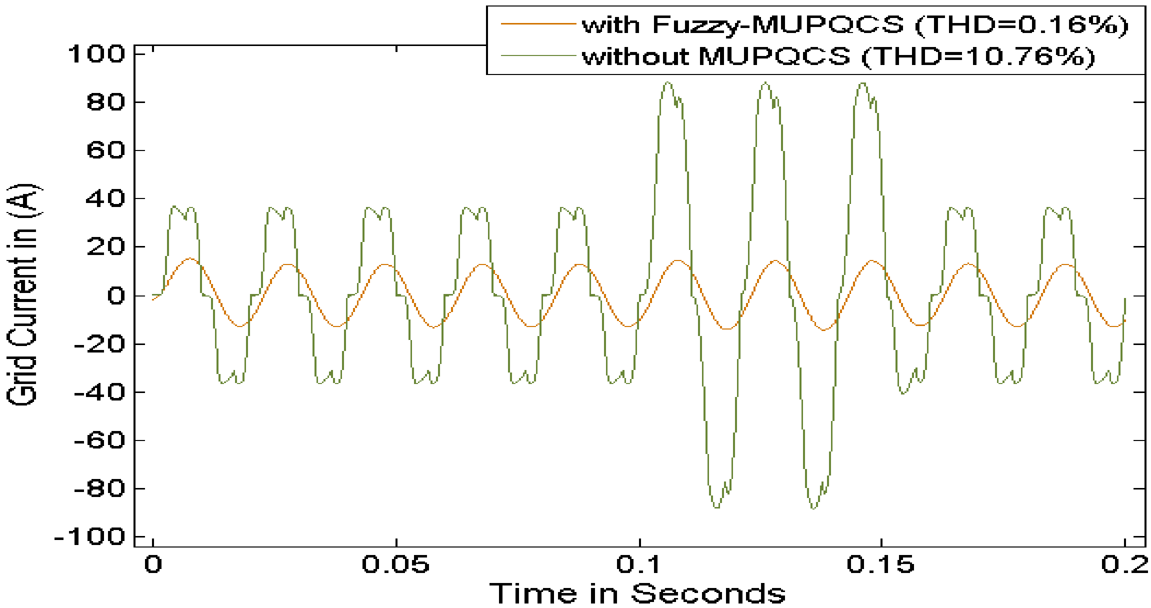


Figure 8. Measurement of Grid Current with and without Fuzzy-MUPQCS in three phase system containing nonlinear load.

Table 1. Measurement of Powerfactor in load bus

Particulars	Powerfactor
Without MUPQCS	0.6
With PI-MUPQCS	0.8
With Fuzzy-MUPQCS	0.99

Table 2. Typical Data for Three phase system and MUPQCS

Important Parameter	System Values
Grid Voltage (Peak to Peak)	415 V
Supply Frequency	50 Hz
Resistance of Distribution System	0.632 Ω
Inductance of Distribution System	4 mH
Transformer Ratio	1:1
Transformer 1 for Series Injection	50 KVA
Shunt Injection transformer	5 KVA
Series Injection transformer 2	5 KVA
PWM Switching Frequency	1 kHz
Active Load	10/30KW
Reactive Load	100/300 VAR
Inductive Filter	16.7 mH
Capacitance Filter	9.6 μF
DC capacitor	2.2 μF
DC bus voltage	700 V

Table3. Parameters of the Solar Module

Parameters	Values
Number of cells in series	96
Maximum Power	305.2W
Number of series connected module per string	5
Open circuit Voltage	64.2V
Short circuit current	5.96A
Voltage at Maximum power (V_{mp})	54.7V
Current at Maximum power (I_{mp})	5.58A
Series Resistance	0.037998Ω
Parallel Resistance	993.51 Ω
Diode saturation current I_{sat}	1.175e-8A
Light Generated Photo current I_{ph}	5.9602A
Diode quality factor Q_d	1.3

4. Conclusion

This paper proposes an Fuzzy-MUPQCS to integrate PV systems to the utility grid. The performance analysis of load voltage and load current distortion, THD, power factor, grid voltage and grid current distortion in the three phase system under nonlinear load conditions are investigated. Two control schemes such as PI and Fuzzy are implemented in the MUPQCS system. A 3ϕ voltage source inverter is also used to maintain a common DC link capacitor voltage through photovoltaic system. Highest Power Point Tracking algorithm is used to draw out the peak power in the PV system connected to a utility grid. The simulated results clearly gives the conclusion that the Fuzzy-MUPQCS is the best custom power device for compensating voltage sag, suppressing excess load current, minimising THD and improving the value of power factor. Also it results in a pure sinusoidal current with low value of THD in the grid end.

5. References

[1] Gharehpetian G B and Mohammad Mousavi Agah S 2017 *Distributed Generation Systems Design, Operation and Grid Integration* (US: Elsevier)

[2] Logeswarana T and SenthilKumar A 2014 A Review of Maximum Power Point Tracking Algorithms for Photovoltaic Systems under Uniform and Non-Uniform irradiances *4th Int. Conf. on Advances in Energy Research Energy Procedia* **54** 228 – 235

[3] Esram T, Kimball J W, Krein P T, Chapman P L and Midya P 2006 Dynamic maximum power point tracking of photovoltaic arrays using ripple correlation control *IEEE Trans. of Power Electronics* **21** 1282–1291

[4] Bidyadhar Subudhi and Raseswari Pradhan 2013 A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems *IEEE Trans. on Sustainable Energy* **4** 89-98

[5] Subudhi B and Pradhan R 2011 Characteristics evaluation and parameter extraction of a solar array based on experimental analysis *in Proc. 9th IEEE Power Electronics and Drives System Singapore* 340-344

[6] Moacyr Aureliano Gomes de Brito, Luigi Galotto, Jr., Leonardo Poltronieri Sampaio, Guilherme de Azevedo e Melo and Carlos Alberto Canesin 2013 Evaluation of the Main MPPT Techniques for Photovoltaic Applications *IEEE Trans. on Industrial Electronics* **60** 1156-1167

[7] Masoum M A S, Dehbonei H, and Fuchs E F 2002 Theoretical and experimental analyses of photovoltaic systems with voltage and current based maximum power point tracking *IEEE Trans. on Energy Conversion* **17** 514–522
[8] Pakkiraiah B and Durga Sukumar G 2016 Research Survey on Various MPPT Performance Issues to Improve the Solar PV System Efficiency *J. of Solar Energy Hindawi* 1-20
[9] Yue M and Wang X 2014 A revised incremental conductance MPPT algorithm for solar PV generation systems *Computational Engineering Finance and science*
[10] Ewald F Fuchs and Masoum M A S 2015 *Power Quality in Power System and Electrical Machines* (Amsterdam: Elsevier)
[11] Singh B, Chandra A and Al-Haddad K 2015 *Power Quality Problems and Mitigation Techniques* (UK:John Wiley & Sons)
[12] Moleykutty George 2007 Artificial Intelligence Based Three-Phase Unified Power Quality Conditioner *J. of Computer Science* **3** 465-477
[13] Vinnakoti S and Kota V R 2019 Performance analysis of ANN-based multilevel UPQC under faulty and overloading conditions *Int. J. of Ambient Energy* in press 1-21
[14] Dixon J W, Contardo J M, Moran L A, 1999 A Fuzzy-controlled active front-end rectifier with current harmonic filtering characteristics and minimum sensing variables *IEEE Trans. on Power Electronics* **14** 724-729
[15] Jain S K, Agarwal P and Gupta H O 2002 Fuzzy logic controlled shunt active power filter for power quality improvement *IEE Proc. on Electrical power applications* **149** 317-328
[16] Vinod Khadkikar and Ambrish Chandra 2012 Control of single-phase UPQC in synchronous d-q reference frame *IEEE 15th Int. Conf. on Harmonics and Quality of Power* 378-383
[17] Yash Pal , Swarup A and Bhim Singh 2010 A comparison of single-phase p-q theory and UVT based control algorithms for single-phase UPQC *Annual IEEE India Conf. (INDICON)*
[18] Haque M T, Ise T and Hosseini S H 2002 A novel control strategy for unified power quality conditioner (UPQC) *IEEE 33rd Annual IEEE Power Electronics Specialists Conf.* 94-98
[19] Pramod S M, Shruti K P and Joshi S K 2012 Flexible 3P4W system using UPQC with combination of SRF and P-Q theory based control strategy *22nd Australasian Universities Power Engineering Conf. (AUPEC)*
[20] Jampana B, Veeramalla R and Askani J 2016 Power Quality Enhancement Using Power Balance Theory Based DSTATCOM *Advances in Electrical and Electronic Engineering* **14** 1-10.
[21] Kiruthiga B, Narmatha Banu R and Devaraj D 2020 Detection and classification of power quality disturbances or events by adaptive NFS classifier *Soft Computing Springer* **24** 10351-10356
[22] Erinc Karatoprak and Serhat Seker 2019 An Improved Empirical Mode Decomposition Method Using Variable Window Median Filter for Early Fault Detection in Electric Motors, *Mathematical Problems in Engineering* 1-9
[23] Bhim Singh, Shahani D T, Chinmay Jain and Raj Kumar 2016 Dual-Tree Complex Wavelet Transform Based Control Algorithm for Power Quality Improvement in a Distribution System *IEEE Trans. on Industrial Electronics* **64** 764-772
[24] Habeebullah Sait H and Arul Daniel S 2011 New control paradigm for integration of photovoltaic energy sources with utility network *Int. J. of Electric Power Energy System* **33** 86-93
[25] Bijan Rahmani, Weixing Li, Guihua Liu 2015 An Advanced Universal Power Quality Conditioning System and MPPT method for grid integration of photovoltaic systems *Electrical Power and Energy Systems* **69** 76-84
[26] Marshall Arockia Dass Philip and Peer Fathima Abdul Kareem 2020 Power Conditioning Using DVR under Symmetrical and Unsymmetrical Fault Conditions *European J. of Electrical Engineering* **22** 179-191
[27] Chetan Singh Solanki 2011 *Solar Photovoltaic fundamentals technologies and applications* (New Delhi: PHI learning)