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Fuzzy Logic Controlled PV Based Boost Converter Fed Shunt Active Power Filter with Maximum Power Point Tracking

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ABSTRACT

High source current harmonics is a major problem faced by Electrical Engineers in power systems. Shunt Active Filter is a popular device in FACTS family generally used to reduce the source current harmonics. The non linear loads in a multi bus system demand reduction in the harmonics so that the line losses and heat can be reduced. The objective of this work is to reduce harmonics in the lines. This paper proposes single Boost converter fed fuzzy logic controlled shunt active filter system to improve the power quality and to obtain maximum power from PV system. A three phase rectifier with large capacitor is considered with non linear load. The simulation studies are performed in MATLAB/SIMULINK for PI and FLC controlled systems and they are compared. The Simulink results obtained show reduction in current THD. The FL controller is observed to show better characteristics than other controllers.

Key wards: Shunt Active Power Filter(SAPF), Fuzzy Lozic Controller(FLC), Preportional & Intigral controller(PI), Maximum Power Point Tracking (MPPT)

I. INTRODUCTION

Power quality is affected by the use of SMPS in laptops and television sets. Shut active filter may be used to the harmonic distortion. The current supplied by SAPF can be controlled by varying the pulse width applied to the devices of SAPF.

Conventionally PI or PID controllers are used for this purpose but suffer from frequent tuning of their parameters for different load and disturbance conditions. In this paper a fuzzy logic controller is designed and replaced for PI controller. A fuzzy controller is knowledge based and can adopt to the situation. Moreover its design is free from mathematical modeling. The dynamic response of the controller is effective compared to conventional controllers.

Real time implementation of adaptive fuzzy hysteresis based current controlled technique for SAF is given by Panda [1]. The instantaneous theory and its use for power quality enhancement is given by Akagi [2,3]. An indirect method of control of power filter for changing loads is given by Bhimsingh[4]. The instantaneous reactive power compensator having switching devices with capacitor is presented by Kanzawa[5]. A detailed review of SAF with respect to control method and circuits is presented by Bhimsingh[6]. Selection of best location for SAF in multi bus distribution system is given by maron[7]. An approach to assess the performance of utility interactive PV system is given by Abouzahr[8]. The generalized design of high performance SAF with output LCL filter is given by Tang[9]. An improved control algorithm of SAF for voltage regulation and harmonic elimination and power factor correction is depicted by

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Haddad[10]. A procedure based on voltage and current transfer matrices is derived in [12] which proposes a method to find the optimum point of connection for shunt active power filters, in improving the compensation effectiveness. Stability analysis based on the phase margin of open-loop transfer functions is done in [13] with the focus on the control method of the shunt active filter. In[14], a high-capacity three-phase four-wire grid-connected PV system based on Boost converter + dual-level four-leg inverter is proposed, and stability of the unified control is discussed with the help of Bode plots of open loop gain for current and voltage loops. A comparative study of various PV fed Active filters configurations and their control method in a three-phase, four-wire distribution system is done in [15]. To investigate parameters such as power output, total harmonic distortion, phase imbalance and neutral conductor current under both uniform and non-uniform radiation conditions. a predictive control technique using Fuzzy controller is proposed in [16] where in A Fuzzy logic control algorithm is applied for MPPT.

Lot of research on single stage PV grid-connected system with power quality improvement has been done so far but not many studies are available on two-stage high-power system. In this paper, a novel high capacity grid-connected PV system based on single Boost converter fed active filter is proposed, which allows a wide range of input voltage for better control objective.

In this two-stage topology the roles of each power stage will be clear the first stage, Boost converter, to achieve maximum power point tracking (MPPT) control, control of output voltage of PV arrays stable, and the second stage, VSI inverter, responsible for grid injection and active filtering. As for as control of VSI converter is concern generalized PQ theory is used for generation of reference currents generation. Fuzzy rules are implemented for FLC to control the harmonics using SAF and its response is compared with conventional PI controlled system.

The problem formulation involves deriving maximum power from PV using constant voltage method. The pulse width applied to the boost converter is adjusted to obtain constant power from PV system.

II. SYSTEM DESCRIPTION

Block diagram of an existing system with shunt active filter is shown in Fig.2.1. where in a source is Supplying a non linear load and a shunt active filter installed for mitigation of source current harmonics

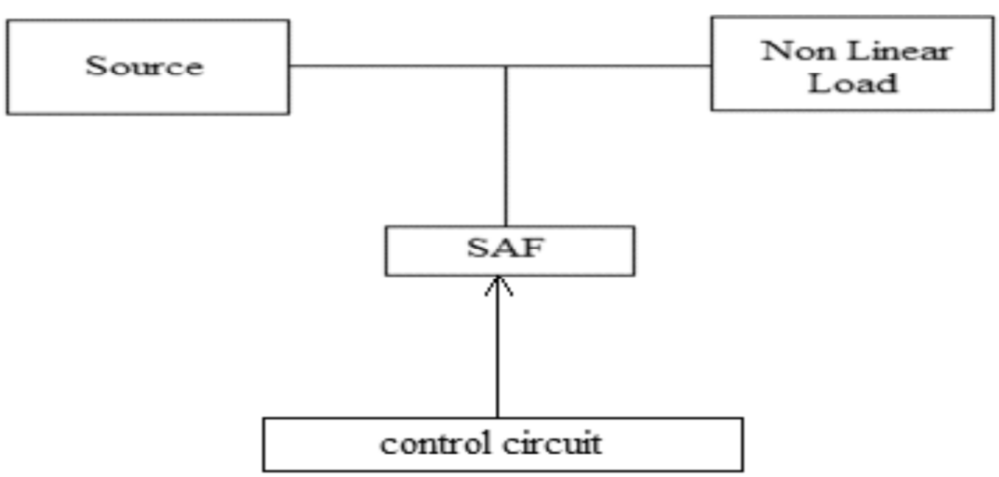

Figure 2.1: Block Diagram of Existing System

In the proposed system shunt active filter is introduced and it is powered from PVarray and a boost converter as shown in Fig.2.2

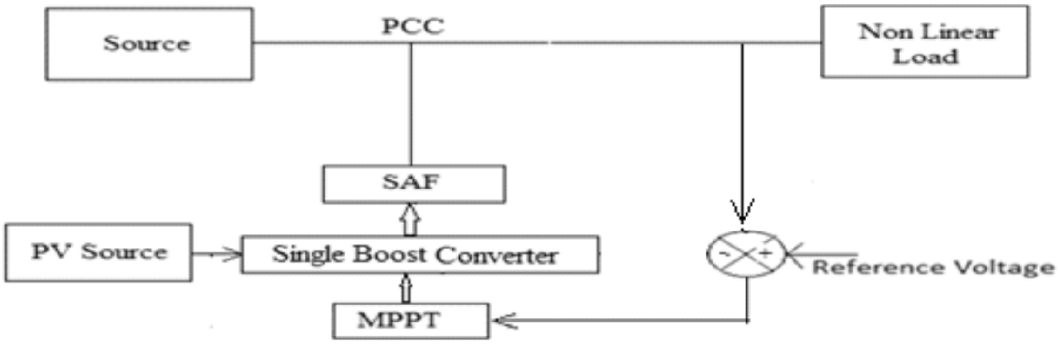

Figure 2.2: Block Diagram of Proposed SBFCSAF System

III. CONTROL OF BOOST CONVERTER AND SAPF

Control of Boost Converter

Boost Converter control is used to control the output voltage of PV arrays so that maximum power can be transferred. Because it always works in continuous current mode. The inductor current can be reduced by using large inductance

The relationship between input and output voltage of Boost converter are related as follows:

$$V_{DC} = V_{PV}/(1 - D) \tag{3.1}$$

When MPPT algorithm detects that it needs to increase V_{PV}, *D* should be reduced and to decrease $V_{PV,}$ *D* should be increased.

Values of L & C of boost converter are obtained as follows:

$$L = \frac{V_{DC}.D}{f\ \Delta_I} \tag{3.2}$$

$$C = \frac{D}{2\,fR} \tag{3.3}$$

Control of SAPF

Instantaneous reactive power theory or p-q theory is used for controlling the three leg VSI inverter. This theory was proposed by Akagi in 1984 and consists of transformation of source voltages in to three axis α-β-0 frame using power invariant transformation matrix C.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = C \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}; \quad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = C \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Where

$$C = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \tag{3.4}$$

The generalized instantaneous active and reactive powers are then defined in terms of these α-β-0 components as

$$p = v \cdot i = v_a i_a + v_b i_b + v_c i_c = v_0 \; i_0 + v_\alpha i_\alpha + v_\beta i_\beta \tag{3.5}$$

$$q = \begin{bmatrix} q_0 \\ q_\alpha \\ q_\beta \end{bmatrix} = v \times i = \begin{bmatrix} \begin{vmatrix} v_\alpha & v_\beta \\ i_\alpha & i_\beta \end{vmatrix} \\ \begin{vmatrix} v_\beta & v_0 \\ i_\beta & i_0 \end{vmatrix} \\ \begin{vmatrix} v_0 & v_\alpha \\ i_o & i_\alpha \end{vmatrix} \end{bmatrix} \tag{3.6}$$

$$q = \| q \| = \sqrt{q_0^2 + q_\alpha^2 + q_\beta^2} \tag{3.7}$$

The instantaneous three-phase active power has two components:

the instantaneous zero-sequence active power p_o, and the instantaneous active power due to positive and negative sequence components, $p_{\alpha\beta}$

$$\begin{aligned} p &= p_0 + p_{\alpha\beta} \\ p_0 &= v_0 \; i_0 \\ p_{\alpha\beta} &= v_\alpha i_\alpha + v_\beta i_\beta \end{aligned} \tag{3.8}$$

Each power component has, in turn, a mean value or dc component and an oscillating value or ac component. For the system shown in Fig. 2.1, the power components required by the load are

$$p_L = \overline{p_L} + \widetilde{p_L}\,; \quad q_L = \overline{q_L} + \widetilde{q_L} \tag{3.9}$$

From eqs. 3.2 and 3.3 and taking into the vectors u and q orthogonal (u.q=0) the current can be calculated by inverse transformation as

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_0^2 + v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_0 & 0 & v_\beta & -v_\alpha \\ v_\alpha & -v_\beta & 0 & v_0 \\ v_\beta & v_\alpha & -v_0 & 0 \end{bmatrix} \begin{bmatrix} p \\ q_0 \\ q_\alpha \\ q_\beta \end{bmatrix} \tag{3.10}$$

The objective of the p–q strategy is to get the source to give only the constant active power demanded by the load, $p_s = \overline{p}L_{\alpha\beta} + \overline{p}L_0$. In addition, the source must deliver no zero-sequence active power, $i_{sRf0} = 0$ so that the zero-sequence component of the voltage at the PCC does not contribute to the source power (i.e., $v_0 = 0$). The reference source current in the α-β-0 frame is therefore

$$\begin{bmatrix} i_{sRf\,0} \\ i_{sRf\,\alpha} \\ i_{sRf\,\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_0 & 0 & v_\beta & -v_\alpha \\ v_\alpha & -v_\beta & 0 & v_0 \\ v_\beta & v_\alpha & -v_0 & 0 \end{bmatrix} \times \begin{bmatrix} \overline{p}L_{\alpha\beta} + \overline{p}L_0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$= \frac{\bar{p}L_{\alpha\beta} + \bar{p}L_0}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} 0 \\ v_\alpha \\ v_\beta \end{bmatrix} \tag{3.11}$$

Design of DC Link Voltage PI Controller

The three phase reference currents (peak value) for the control of active filter are generated in accordance with the PI controller error between the average dc bus voltage Vdc (n) and its reference value Vdcref (n) of the active filter. The dc bus voltage error Ve (n) at nth sampling instant is

$$v_e(n) = v_{dcref}(n) - v_{dc}(n) \tag{3.12}$$

This error signal Ve (n) is processed in PI controller and output K (n) at nth sampling instant is expressed as

$$k(n) = k(n-1) + k_p\{v_e(n) + v_e(n-1)\} + k_i\{v_e(n)\} \tag{3.13}$$

where Kp and Ki are the gains of the PI controller.

IV. PROPOSED FUZZY CONTROL ALGORITHM

In order to implement the control Scheme of a SAF in a closed loop, the DC capacitor voltage V_{dc} is sensed and then compared with the reference value V_{dcref}. The error e(n) = $V_{dcref} - V_{dc}$ and derivativeof error signal 'de(n)' are used as inputs for fuzzy processing. The output of the fuzzy controller after a limit is used for pulses generation of boost converter.

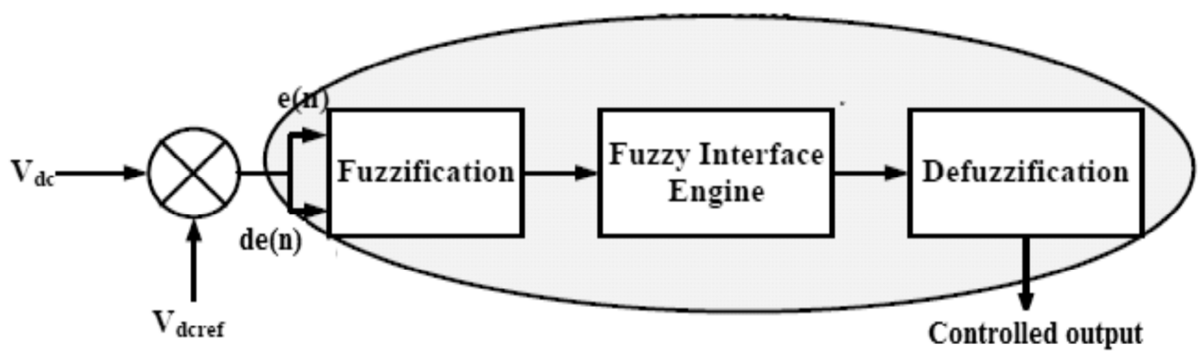

Figure 4.1: Fuzzy Control Scheme

Fig. 4.1 shows the Scheme of Fuzzy control. The control action is determined from the evaluation of set of simple linguistic rules. The error *e* and change of error *de* are used as inputs to Fuzzy system. To convert these numerical variables into linguistic variables, the three member ship functions mf1, mf2, mf3 as shown in Fig. 4.2 are used for both the inputs 'e' and 'de'.

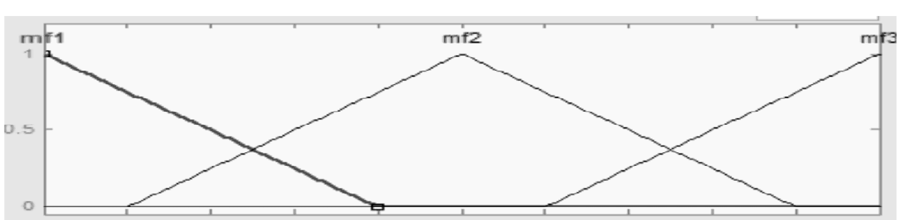

Figure 4.2: Member ship Functions for inputs e and de

V. SIMULATION RESULTS AND DISCUSSION

Simulation studies are done using SIMULINK and the results are discussed in this section. The SIMULINK model of open loop system is shown in Fig. 5.1.

Table 1
Parameters used for simulation

Parameter	*Value*	*parameter*	*value*
Supply voltage	415v(peak/phase)	Source inductance	30mH
Frequency	50HZ	Load resistance	100ohm
Source Resistance	1 ohm	Load inductance	1H
Filter inductance	10mH/phase	Panel sh.ckt current	5.15A
Panel open circuit voltage	230v	Panel current at MPP	4.95A
Panel voltage at MPP	230v	No of series cells in a unit	56
No of units in parallel	4		

The line impedance split into two parts is shown in figure. The output of PV is boosted and it is applied to the capacitor of the Active Filter.

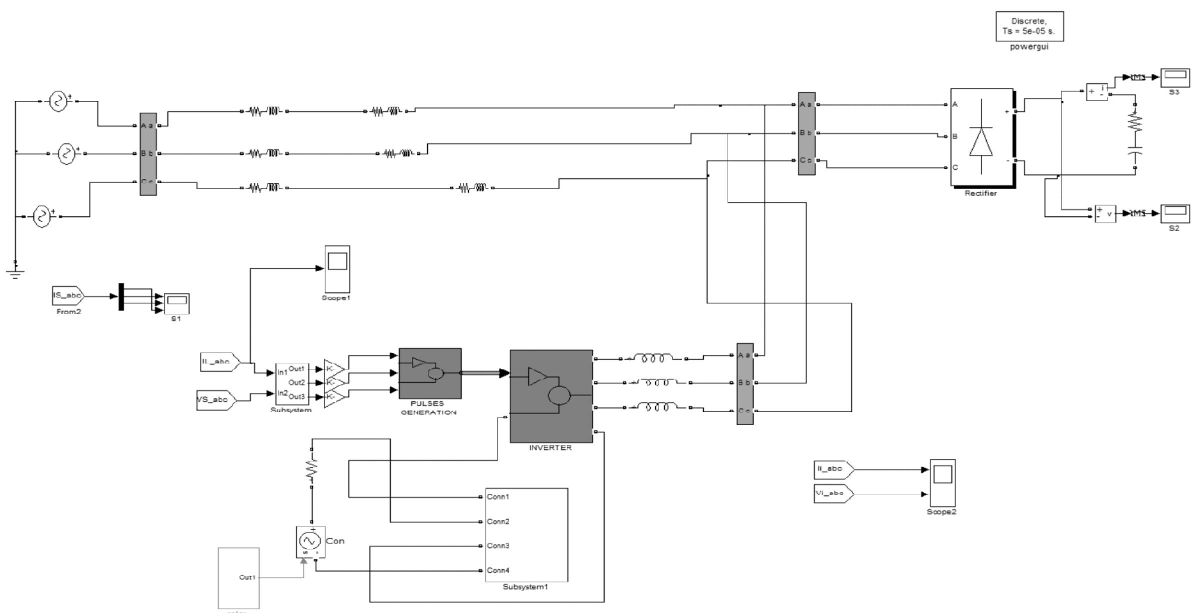

Figure 5.1: Simulink Model of open loop System

The PV power output is dependent on solar irradiation and this effect is considered by varying the input insolation from 1000 to 900 at t=0.2 sec. Due to this the out put voltage of PV array is reduced as shown in Fig 5.2 and the corresponding change in output voltage of boost converter is shown in Fig. 5.3.

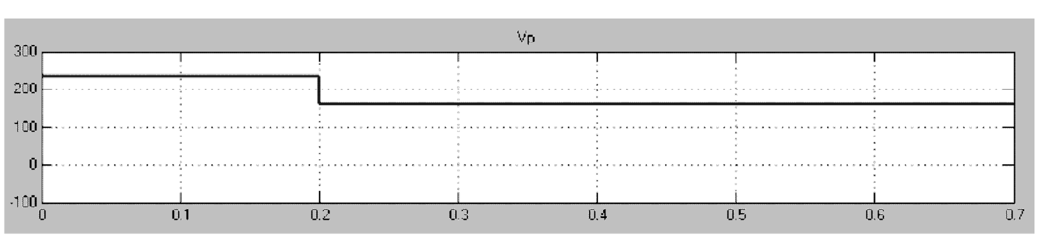

Figure 5.2: Change in output voltage of PV source

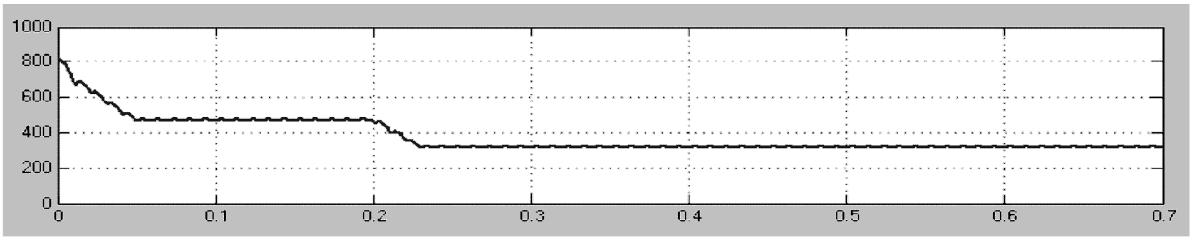

Figure 5.3: Change in Boost Converter voltage

The voltage and current of non linear load is also dropped due to this decrement in solar power and are shown in Fig 5.4 and 5.5 respectively where in it can be observed that current is reduced to 3A and gets settled.

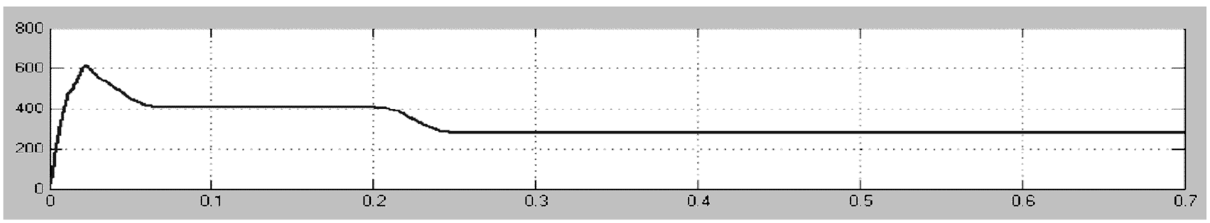

Figure 5.4: Output Voltage of Non linear load

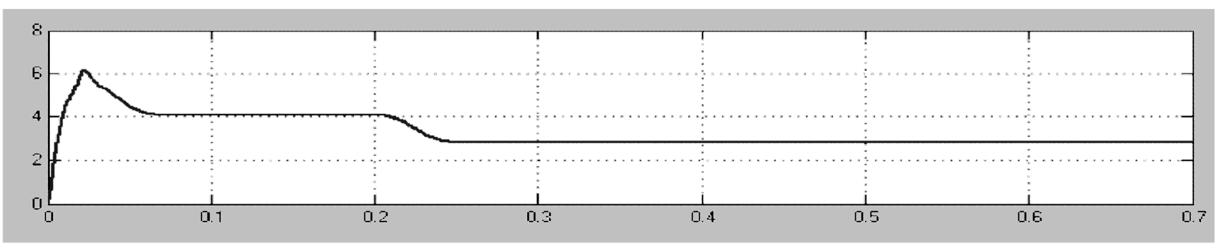

Figure 5.5: Output Current of Non linear load

The closed loop system with PI controller is shown in Figure 5.6

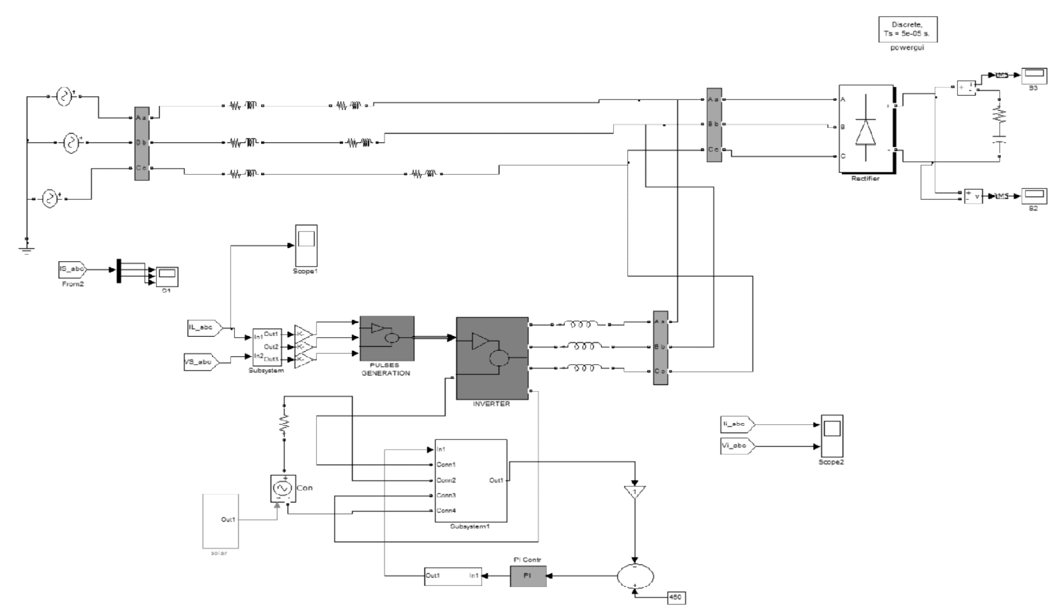

Figure 5.6: Closed loop system with PI controller

The output voltage of solar system is shown in Fig.5.7 and is observed that it decreases from 240V to 160V.

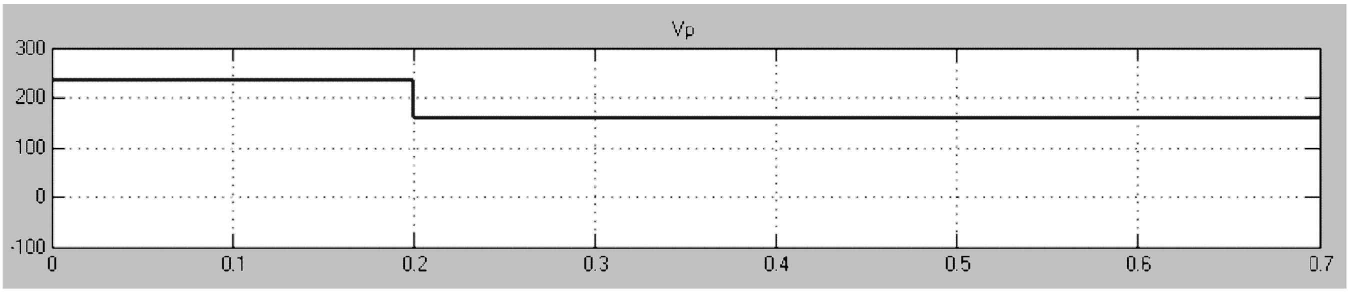

Figure 5.7: Output voltage of PV system

The voltage of boost converter is shown in Figure 5.8 and this value decreases to 450V. The RMS output voltage and current of non linear load are shown in Figures 5.9 and 5.10 respectively. It can be observed from load current that its value increases to 4Amp.

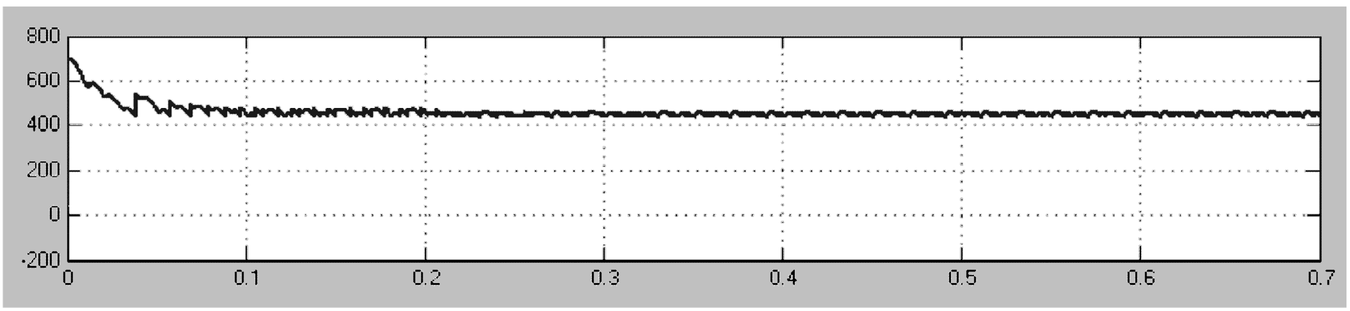

Figure 5.8: Output voltage of boost converter

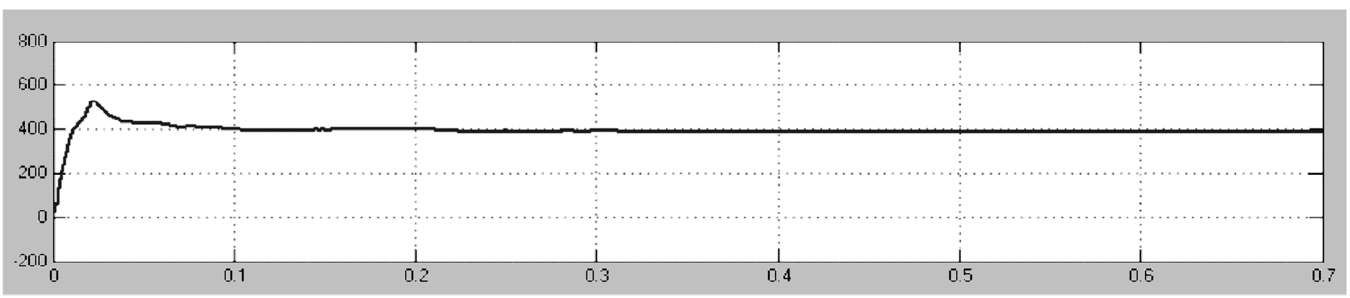

Figure 5.9: Voltage of non linear load

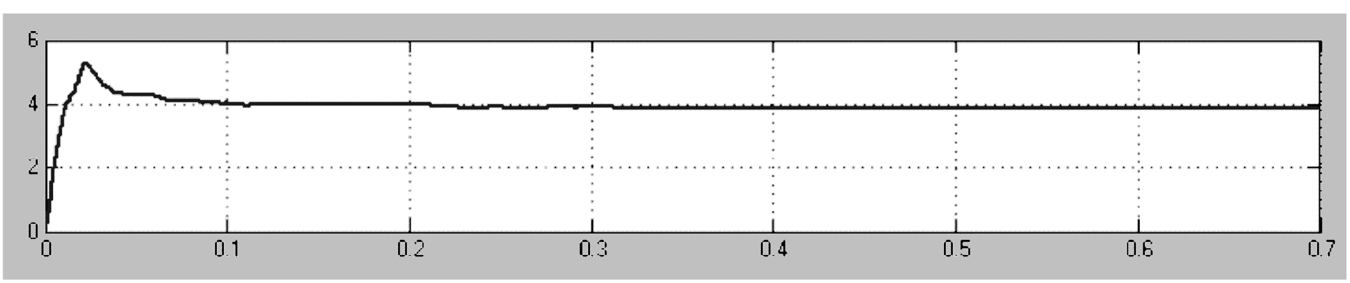

Figure 5.10: Output current of non linear load

The source current wave form of all the three phases is shown in Fig. 5.11. The source current THD was observed to be 6.05% as shown in THD spectrum of Fig.5.12

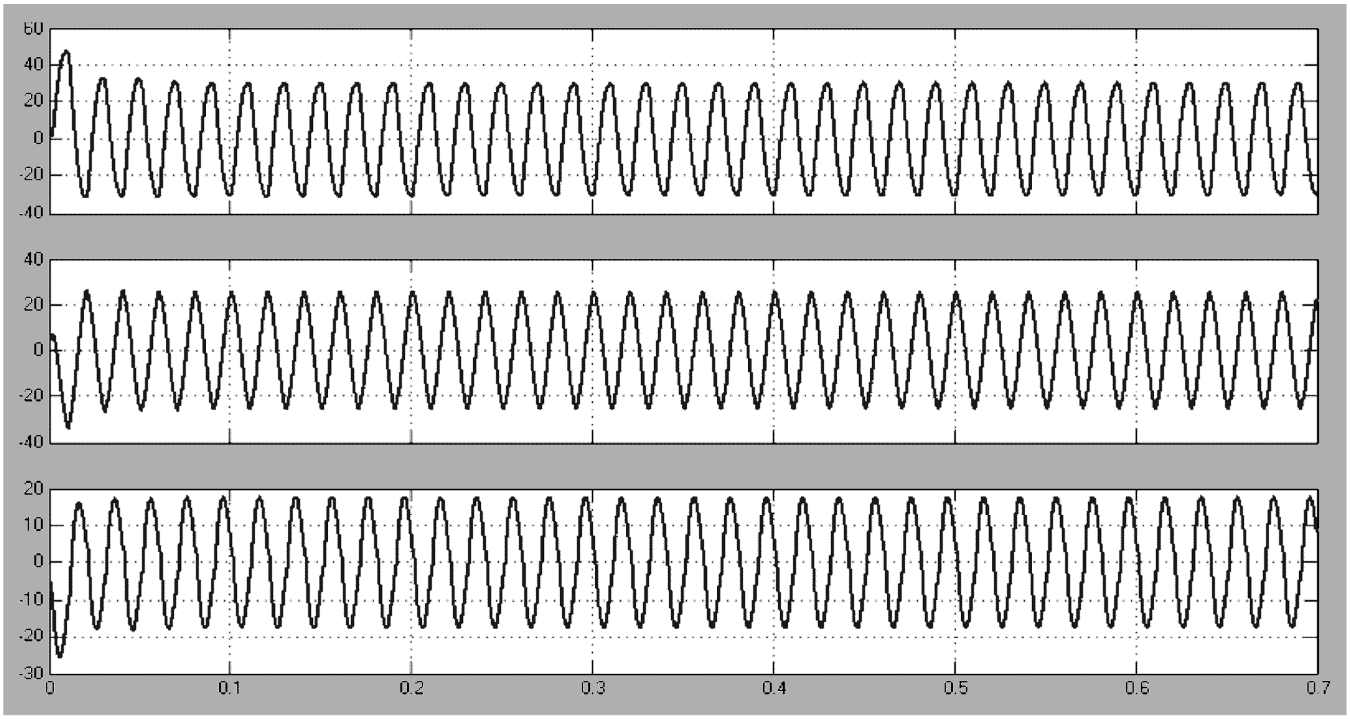

Figure 5.11: Source Current Waveform

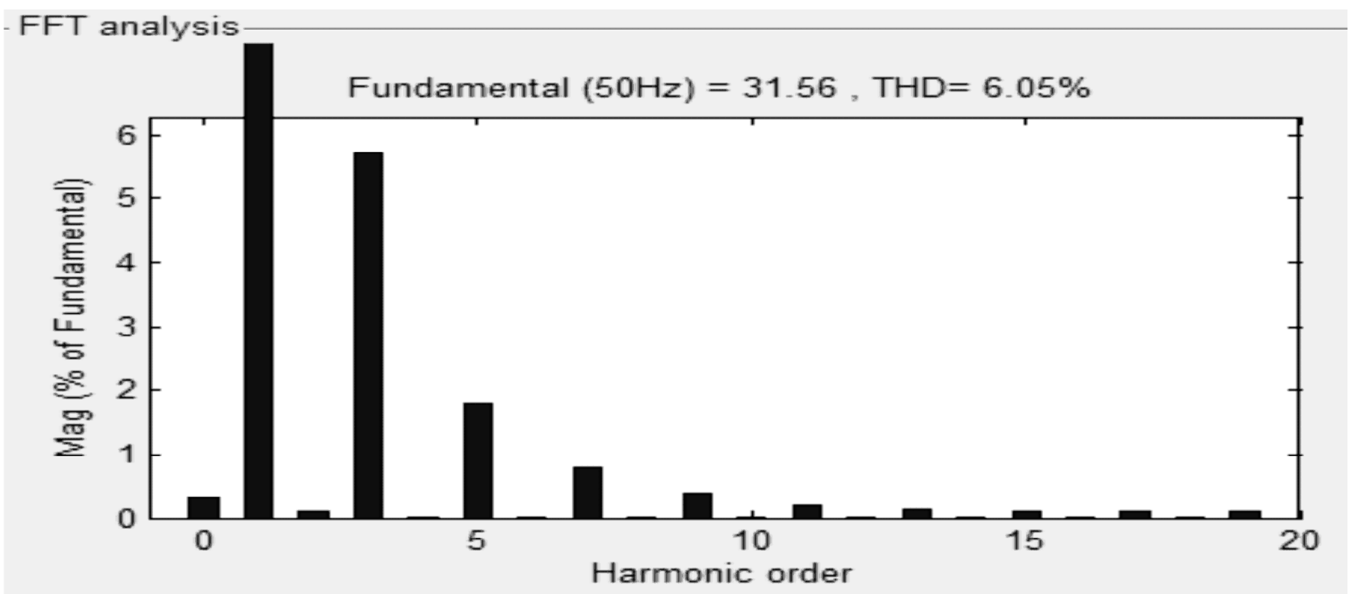

Figure 5.12: THD Spectrum of Source Current

The closed loop system with fuzzy controller is shown in Fig.5.13 and the corresponding results are presented in Fig.5.14. The PI controller is replaced by fuzzy logic controller.

The source current wave form and its THD spectrum for this case are shown in Figure.5.15. The THD was observed to be decreased to 4.73% and it is lower when compared to PI controlled system.

From these results it is evident that the transition from high voltage to low voltage due to the decrement in PV insolation is smoother in Fuzzy logic controller as the dynamic response due to fuzzy logic controller is better compared to PI controller.

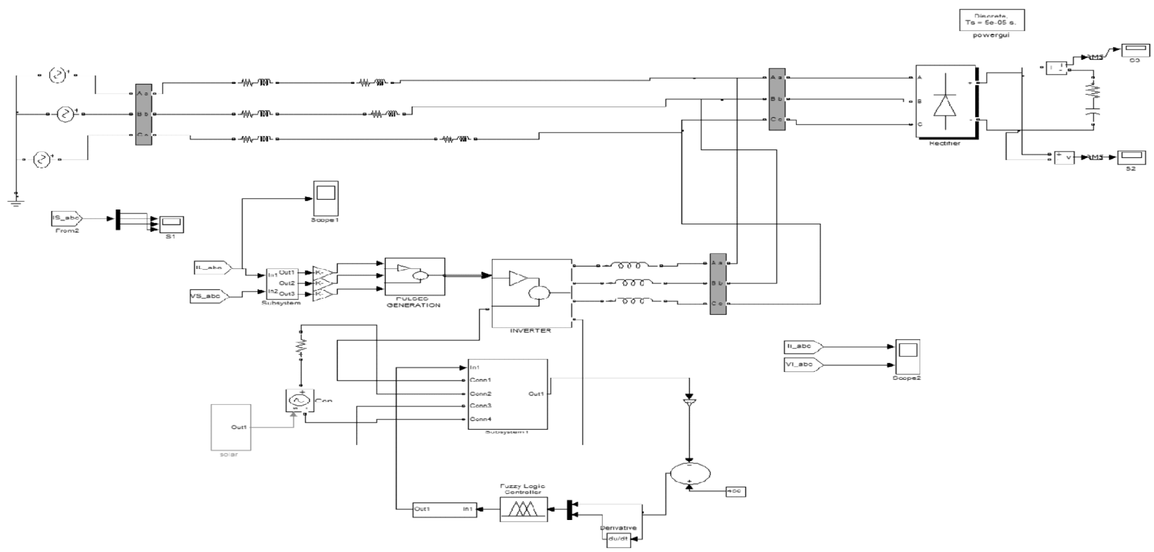

Figure 5.13: Closed loop Controlled System

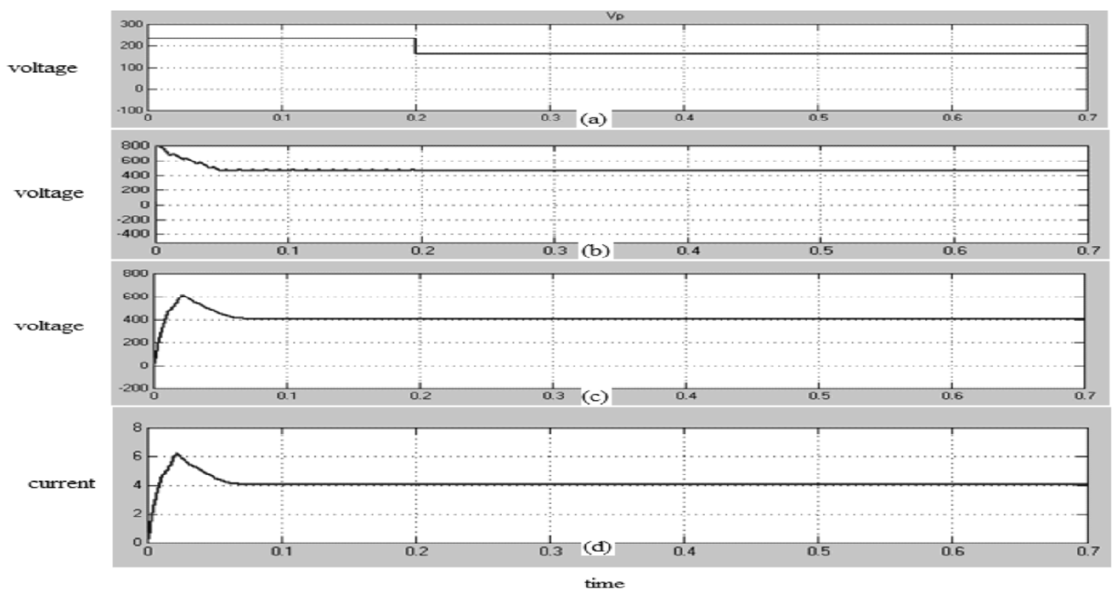

Figure 5.14: (a) PV source voltage, (b) voltage of boost converter, (c) voltage & (d) current of non linear load

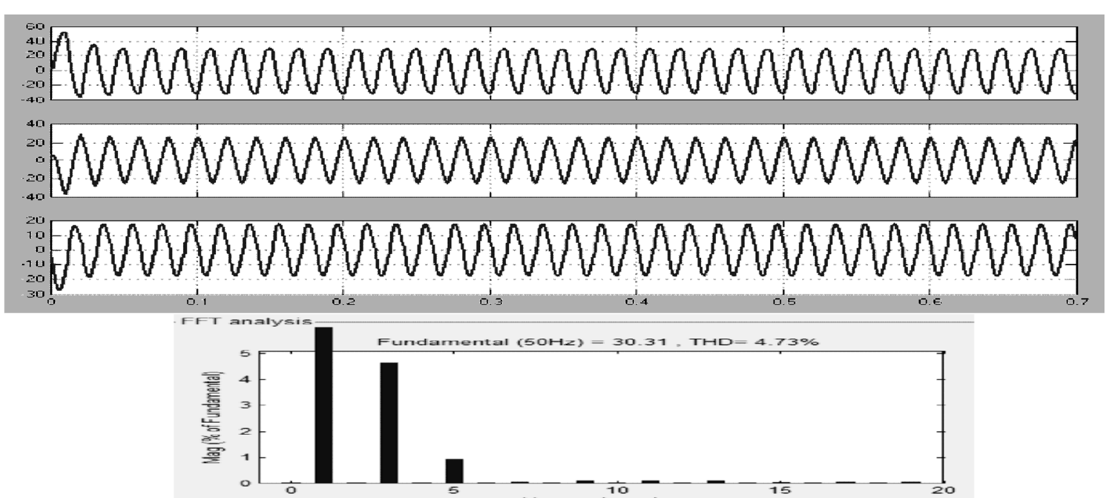

Figure 5.15: Source Current Waveform & THD Spectrum

The summary of time domain parameters is shown in Table 2. The settling time is reduced to 0.5 sec and steady state error is reduced to 1.8V.

Table 2
Summary of time domain parameters

Controller	*Peak time (s)*	*Setting time (s)*	*Steady state error (V)*
PI	0.22	0.23	15
Fuzzy	**0.05**	**0.5**	**1.8**

Table 3
THD comparison

Controller	*THD*
PI	6.05%
Fuzzy	**4.73%**

From the summary in the Table 2, it is clear that peak time, settling time and steady state error are drastically reduced by using FL controlled SAF. The THD is reduced by 1.3% by replacing PI with FLC. The THD comparison is shown in Table 3.

VI. CONCLUSION

The Active filter systems controlled by PI and FLC for supplying PV power to grid are modeled and simulated using SIMULINK. The simulation results of closed loop system with PI and FLC are presented. The results indicate that the response of FLC controlled system is smoother than PI controlled system. The peak time is reduced by 0.17 sec and steady state error is reduced by 14.2V. The advantages of FLC controlled system are improved dynamic response and reduced steady state error. The disadvantages of proposed system are requirement of PV source and boost converter. This work has reviewed the performance of PI & FLC. The results obtained in this paper are clear examples of improvement in dynamic response of SAF system.

The scope of the present work is to compare PI and FL controlled systems. PV controlled SAF with Two inductor Boost Converter (ILBC) will be investigated in future.

REFERENCES

[1] Y. Suresh A.K. Panda and M. Suresh “Real-time implementations of adaptive fuzzy hysteresis-band current control technique for shunt active power filter” Vol. 5, Iss. 7, pp. 1188–1195, IET Power Electronics, 2012.

[2] H. Akagi, E. Watanabe, M. Aredes “Instantaneous Power Theory and Applications to Power Conditioning: (Wiley-IEEE Press, 2007).

[3] M.H. Rashid “Power Electronics Handbook: Devices, Circuits, and Application”, (Elsevier Inc., Section Edition, 2007).

[4] Bhim Singh, and Vishal Verma “An Indirect Current Control of Hybrid Power Filter for Varying Loads” IEEETransactions on Power Delivery, Vol. 21, No. 1, pp. 178- 184, January 2006.

[5] H. Akagi, Y. Kanzawa, and A. Nabae “Instantaneous reactive power compensators comprising switching devices without energy Components” IEEE Transactions on Industrial Applications, Vol. 20, No. 3, pp. 625–630, 1984.

[6] Bhim Singh, Kamal Al-Haddad, and Ambrish Chandra “A Review of Active Filters for Power Quality Improvement” IEEE Transactions on Industrial Electronics, Vol. 46, No. 5, pp. 60 – 71, October 1999.

[7] L. T. Morán, J. J. Mahomar, and J. R. Dixon,”Careful connection- selecting the best point of connection for shunt active power filters in multibus power distribution systems” *IEEE Industry Applications Magazine*,pp. 43- 50, Mar- Apr 2004.

[8] I. Abouzahr and R. Ramakumar, “An approach to assess the performance of utility-interactive photovoltaic systems,” *IEEE Trans. Energy Convers.*, Vol. 8,No. 2, pp. 145–153, Jun.1993.

[9] Y. Tang, P. C. Loh, P. Wang, F. H. Choo, F. Gao, and F. Blaabjerg,"Generalized Design of High Performance Shunt Active Power Filter With Output LCL Filter" *IEEE Transactions on Industrial Electronics*, Vol. 59, No.3, pp. 1443- 1452, March 2012.

[10] Ambrish Chandra, Bhim Singh, B. N. Singh, and Kamal Al-Haddad, "An Improved Control Algorithm of Shunt Active Filter for Voltage Regulation,Harmonic Elimination, Power-Factor Correction, and Balancing of Nonlinear Loads" *IEEE Transactions on Power Electronics*, Vol. 15, No. 3, pp. 495 -507, May 2000.

[11] H. Akagi, New Trends in Active Filters for Power Conditioning" *IEEE Transactions on Industry Applications*, Vol 32, No 6, pp. 1312- 1322,December 1996.

[12] Luis Morán T, José Mahomar J," Selecting The Best Point Of Connection For Shunt Active Filters In Multi-Bus Power Distribution Systems" 0-7803-7420-7/02/$17.00 © 2002 IEEE.

[13] Hirofumi Akagi, "Control Strategy and Site Selection of a Shunt Active Filter for Damping of Harmonic ropagation in Power Distribution Systems" IEEE Transactions on Power Delivery, Vol. 12, No 1, January 1997.

[14] Jing Li, Fang Zhuo," A Grid-Connected PV System with Power Quality Improvement Based on Boost + Dual-Level Four-Leg Inverter".

[15] H. Patel, V. Agarwal, "Investigations into the performance of photo voltaics-based active filter configurations and their control schemes under uniform and non-uniform radiation conditions" IET Renew. Power Gener., 2010, Vol. 4, Iss. 1, pp. 12–22.

[16] Hamad, M.S, Fahmy, A.M, and Abdel-Geliel, M, "Power Quality Improvement of a Single-Phase Grid-Connected PV System with Fuzzy MPPT Controller" 978-1-4799-0224-8/13/$31.00 ©2013 IEEE.