# FUZZY CONTROLLED SHUNT ACTIVE FILTER TO REDUCE HARMONICS USING SOLAR PV SYSTEM

Payal V. Dhatrak[1], Nilesh Chamat[2]

[1] PG Scholar, Electrical Engineering Department, Ballarpur Institute of Technology, Ballarpur, Maharashtra, India

[2] Head of Department, Electrical Engineering Department, Ballarpur Institute of Technology, Ballarpur, Maharashtra, India

## ABSTRACT

*The development of new energy sources is continuously enhanced because of the critical situation of the chemical industrial fuels such as oil, gas and others. Thus, the renewable energy sources have become a more important contributor to the total energy consumed in the world. In fact, the demand for solar energy has increased by 20% to 25% over the past 20 years. The market for PV systems is growing worldwide. In fact, nowadays, solar PV provides around 4800 GW. Between 2004 and 2009, grid connected PV capacity reached 21 GW and was increasing at an annual average rate of 60%. In order to get benefit from the application of PV systems, research activiti es are being conducted in an attempt to gain further improvement in their cost, efficiency and reliability.*

*Renewable energy resources such as solar and wind energies are becoming advantageous compared to the conventional sources of power production in many ways like they are eco-friendly, available in a huge amount, non-depletable, etc. But the only drawback is that their outputs depend upon the climatic conditions. Wind -Photovoltaic Hybrid System (WPHS) utilization is becoming popular due to the increasing energy costs and decreasing prices of turbines and PV panels. However to make up for the drawbacks back -up power is often necessary.*

*This methodology also presents the implementation of a generalized photovoltaic model using Matlab/Simulink software package, which can be representative of PV cell, module, and array for easy use on simulation platform. The proposed model is designed with a user-friendly icon and a dialog box like Simulink block libraries. This makes the generalized PV model easily simulated and analyzed in conjunction with power electronics for a maximum power point tracker. Taking the effect of sunlight irradiance and cell temperature into consideration, the output current and power characteristics of PV model are simulated and optimized using the proposed model. This enables the dynamics of PV power system to be easily simulated, analyzed, and optimized.*

*This method present, the active filtering capability that can be incorporated in grid connected photovoltaic systems by proper control of the grid interfacing inverter. Fuzzy logic controller is used for generating the reference signals to control the inverter so that the system feeds the available photovoltaic energy into the grid, provides reactive power compensation and harmonic elimination of the loads connected at the point of common coupling. The controller is tested in MA TLAB/SIMULINK for linear and nonlinear loads. The simulation results demonstrate the efficient working of grid connected photovoltaic system as Shunt Active Filter.*

**Keyword: -** *Fuzzy logic controller, shunt active filter*

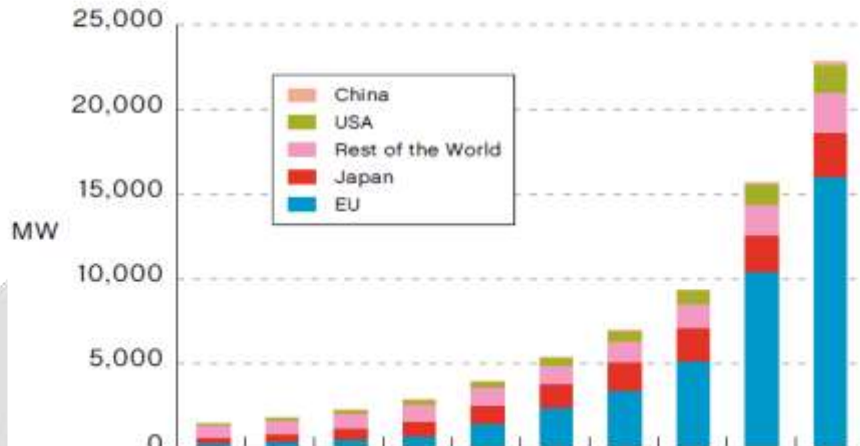
---

## 1. INTRODUCTION

The solar photovoltaic (PV) industry has grown since the oil crises of the 1970s, but has especially been in rapid development in recent years. According to the International Energy Agency (IEA) [1], the world PV industry has developed at average annual growth rates of 15% to 20% from 1991 to 2007 - a growth rate comparable to that of the semiconductor and computer industries. In the recent 10-year period from 2000 to 2009, world cumulative installed PV power has been increasing from 1,428 MW to 22,893 MW (see Fig. 1.1), with an average annual growth rate 36.7%, making it the world's fastest-growing energy technology [2]. The rapid growth rate is mainly due to the need for alternatives to fossil fuel-based electricity generation, concerns over the global environment, reduced photovoltaic costs, and interests in distributed energy sources to improve power system reliability [3-4].

For instance, during the past decades, thanks to the new discovered materials, devices and fabrication methods, as well as improved solar-cell efficiency and reliability, the cost of photovoltaic has been reduced by several orders of magnitude. According to the International Energy Agency (IEA) [1], PV system costs in reported countries has come down from 16 USD per watt in 1991 to 8 USD per watt in 2007.

For the next several decades, the PV industry has the capability to keep a double digit annual growth. In a solar PV roadmap of IEA [5-6], it is estimated that by 2050, the solar PV power will supply around 11% of global electricity generation and reduce 2.3 Gigatonnes (Gt) of CO2 emissions per year. As a leading role in world PV industry, the U.S. photovoltaic industry roadmap [3] has a long-term goal for 10% of U.S. peak electricity generation capacity by 2030 be supplied by PV power. It is reasonable to predict that the PV industry has the potential to play a significant role in world electricity generation in the future.




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| China | 19 | 30 | 45 | 55 | 64 | 68 | 80 | 100 | 145 | 305 |
| USA | 139 | 168 | 212 | 275 | 365 | 479 | 624 | 831 | 1,173 | 1,650 |
| ROW | 763 | 826 | 913 | 1,000 | 1,044 | 1,051 | 1,235 | 1,422 | 1,870 | 2,347 |
| Japan | 318 | 452 | 637 | 860 | 1,132 | 1,422 | 1,708 | 1,919 | 2,149 | 2,633 |
| EU | 189 | 286 | 422 | 633 | 1,319 | 2303 | 3,282 | 5,088 | 10,340 | 15,958 |

**Fig-1:** Historical development of world cumulative PV power installed in main Geographies [2]

## 2. SIMULATION MODEL & RESULTS

### 2.1. MATLAB Simulation model

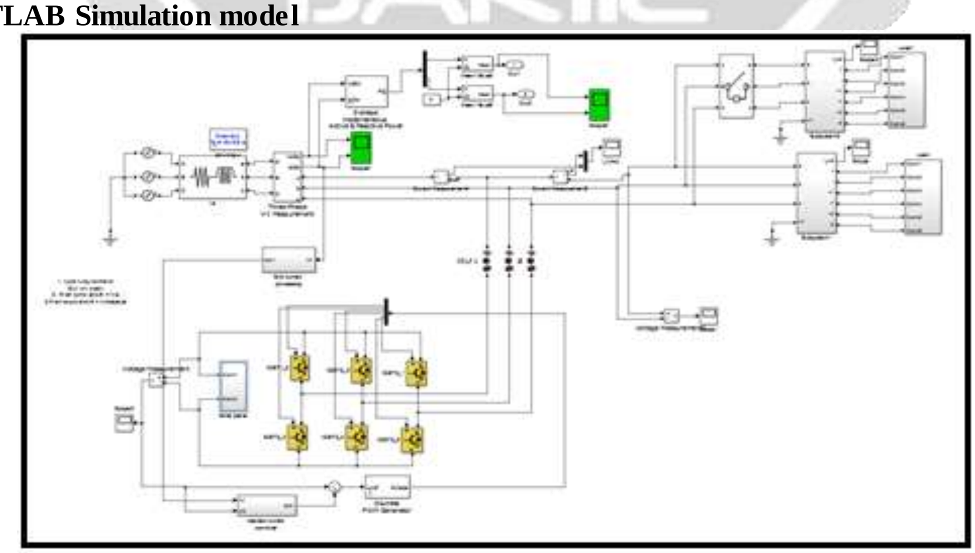


**Fig-2:** MATLAB Simulation model of proposed system

**2.2. Designing of control rules**

Computational methods determine the computational efficiency, processor memory requirement and processing time. The fuzzy control rules based on membership function defining or relate input variables to output variables. The number and type of MF determines the computational efficiency of fuzzy control technique. The determination of MFs depends on the designer's experience and knowledge. The shape decision of MFs affects how well a fuzzy system rules approximate a function.

Triangles or triangular membership function (TMF) have been frequently used in several applications of FLC. TMF are preferred due to simplicity, easy implementation, symmetrical along the axis. Figure 6.3 shows the MFs relating input and output linguistic variables. The number of linguistic variables is directly related to the accuracy of approximating function and plays an important role for input-output mapping. However, some limits have to consider while designing number of linguistic variables in view of accuracy and complexity of FLC.

The error e and change of error ce at nth sampling instant are used as input of FLC and can be written as

$$e = V_{dc,ref} - V_{dc}$$

$$ce(n) = e(n) - e(n-1)$$

The output of FLC with limiter is considered as amplitude of derived reference current ( ∗Ism ). In this paper seven triangular membership functions have been chosen for representing numerical variables into linguistic variables [15], viz., NL (negative large), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), PL (positive large). The spacing between MFs may be equal or unequal; it is set here for cover a band of load current with good accuracy. After this rules formation as knowledge base, different inference mechanisms have been developed for defuzzify fuzzy rules. In this paper, authors apply Mamdani's max-min inference method to get an implied fuzzy set of tuning rules. Finally center of mass method is used defuzzify the implied control variables. The above can be summarized as for implementing FLC:

(1) First, scaling factors consist of the normalization gain for input and de-normalization gain is selected properly.

(2) Rules decision based on accuracy and complexity.

(3) Fuzzification, implication using mamdani's operator and finally defuzzification to get desired output.

Fig. 4 shows the block diagram of the proposed FLC scheme with shunt active filter. The designed rules for knowledge base are shown in Table 6.1. The top row and left column of the matrix indicate the fuzzy sets of the variables e and ce.

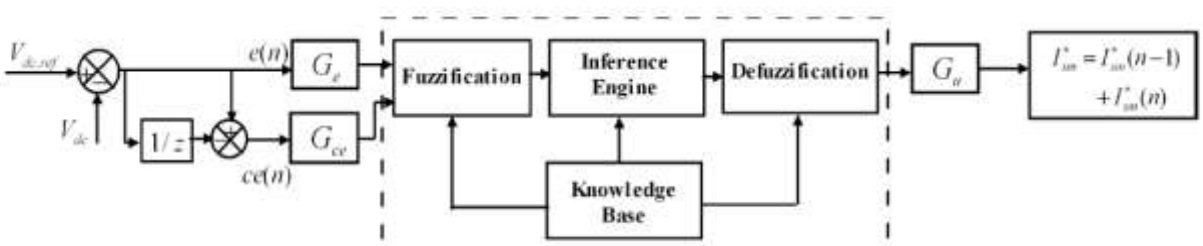



**Fig-3:** Fuzzy logic controller model for shunt active filtering and inverter controlling

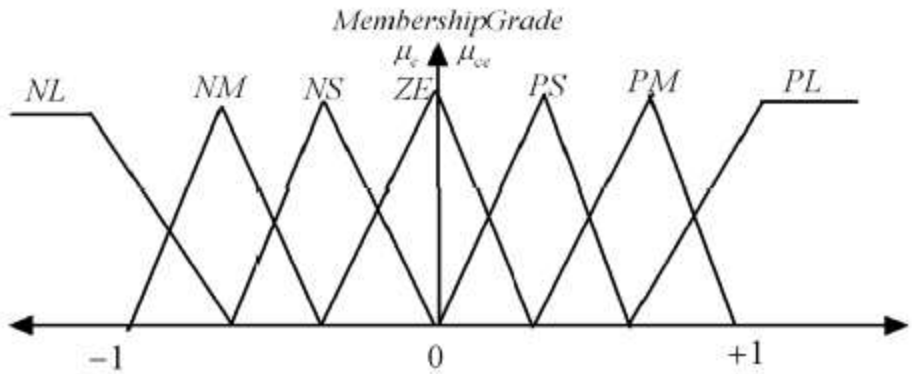
Computational methods determine the computational efficiency, processor memory requirement and processing time. The fuzzy control rules based on membership function defining or relate input variables to output variables. The number and type of MF determines the computational efficiency of fuzzy control technique. The determination of MFs depends on the designer's experience and knowledge.

The shape decision of MFs affects how well a fuzzy system rules approximate a function. Triangles or triangular membership function (TMF) have been frequently used in several applications of FLC TMF are preferred due to simplicity, easy implementation, symmetrical along the axis. Figure 4 shows the MFs relating input and output linguistic variables. The number of linguistic variables is directly related to the accuracy of approximating function and plays an important role for input-output mapping. However, some limits have to consider while designing number of linguistic variables in view of accuracy and complexity of FLC. The error e and change of error ce at nth sampling instant are used as input of FLC and can be written as [14]:

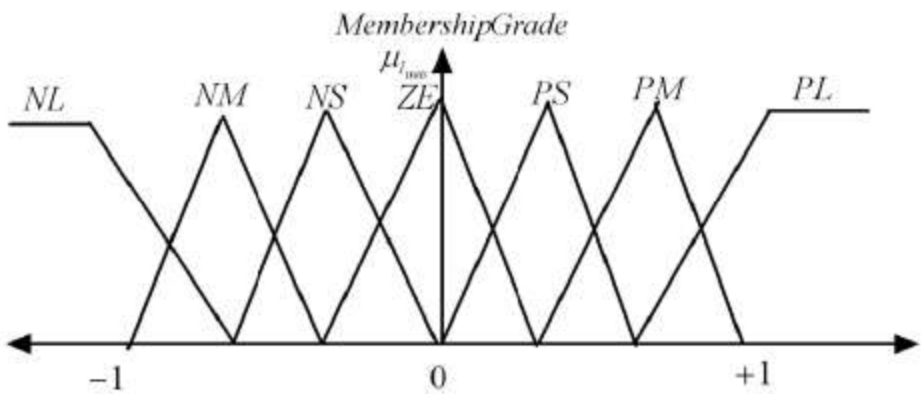
$$e = V_{dc,ref} - V_{dc}$$

$$ce(n) = e(n) - e(n-1)$$

The output of FLC with limiter is considered as amplitude of derived reference current ( ∗Ism ). In this paper seven triangular membership functions have been chosen for representing numerical variables into linguistic variables , viz., NL (negative large), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), PL (positive large). The spacing between MFs may be equal or unequal; it is set here for cover a band of load current with good accuracy. After this rules formation as knowledge base, different inference mechanisms have been developed for defuzzify fuzzy rules. In this paper, authors apply Mamdani's max-min inference method to get an implied fuzzy set of tuning rules. Finally center of mass method is used defuzzify the implied control variables.




(a) error 'e' and change in error 'ce'




(b) change in reference output current

**Fig-4:** Triangular shaped membership function used in fuzzification

The output of FLC with limiter is considered as amplitude of derived reference current ( Ism ). In this paper seven triangular membership functions have been chosen for representing numerical variables into linguistic variables [15], viz., NL (negative large), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), PL (positive large). The spacing between MFs may be equal or unequal; it is set here for cover a band of load current with good accuracy. After this rules

formation as knowledge base, different inference mechanisms have been developed for defuzzify fuzzy rules. In this paper, authors apply Mamdani¡¯s max-min inference method to get an implied fuzzy set of tuning rules. Finally center of mass method is used defuzzify the implied control

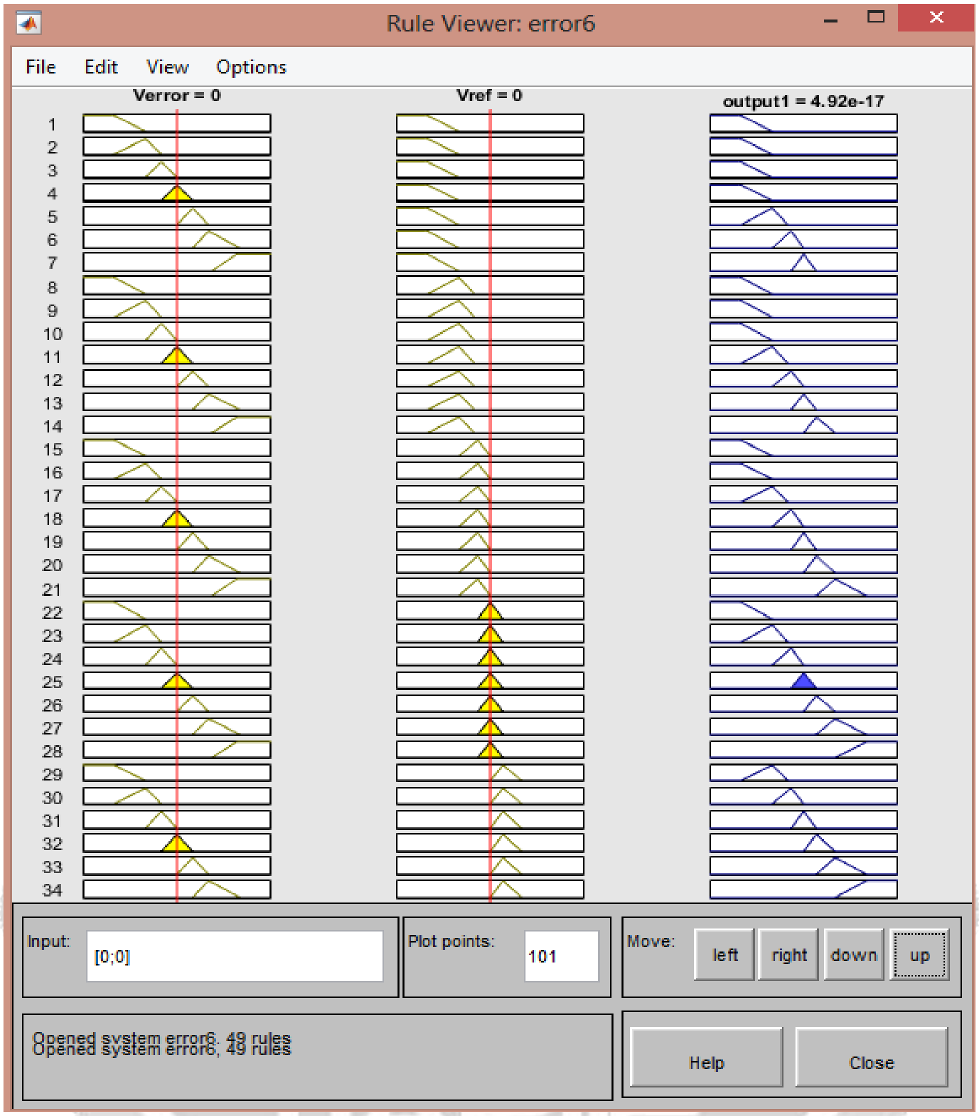



**Fig-5:** Fuzzy logic rule base for controlling inverter circuit

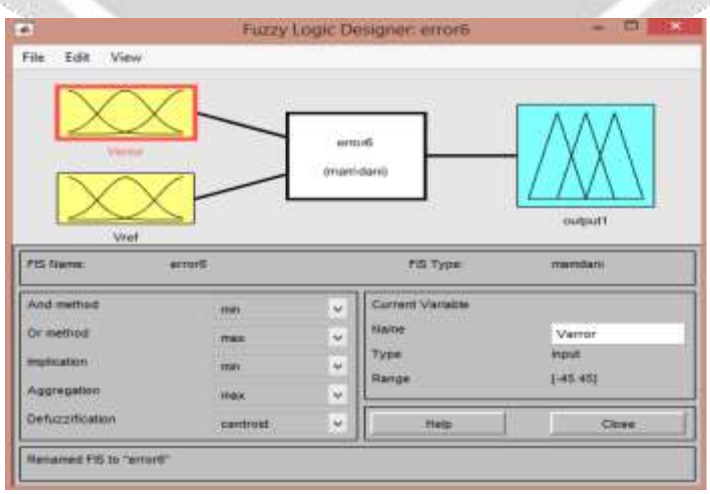



**Fig-6:** Fuzzy logic GUI in fuzzy logic toolbox using MATLAB simulink

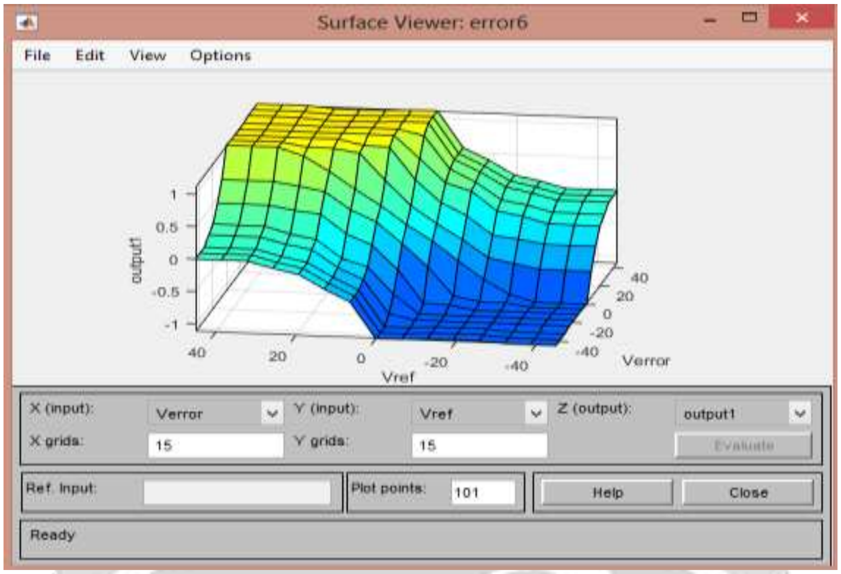



**Fig-7:** Fuzzy logic surface viewer (Rule base surface logic)

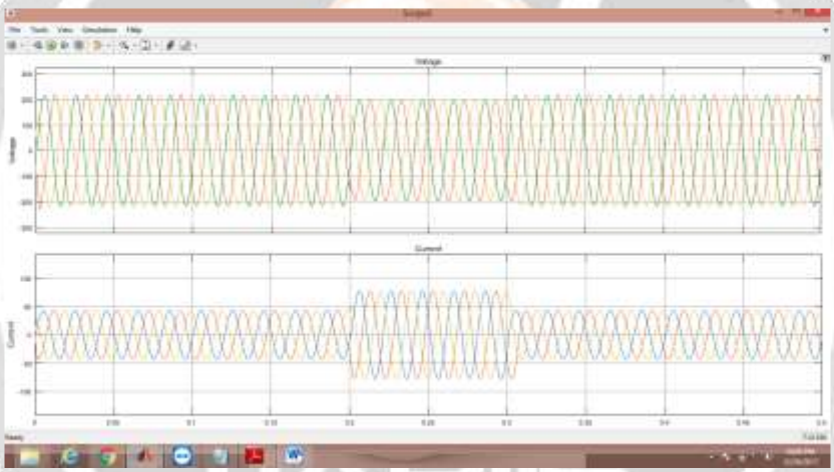


**Fig-8:** Grid power system Source voltage and current

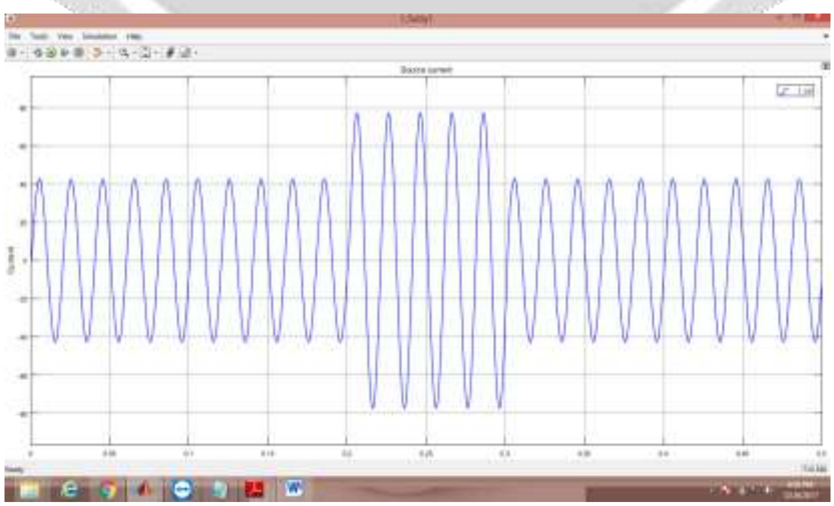


**Fig-9:** Solar PV system generated Source current

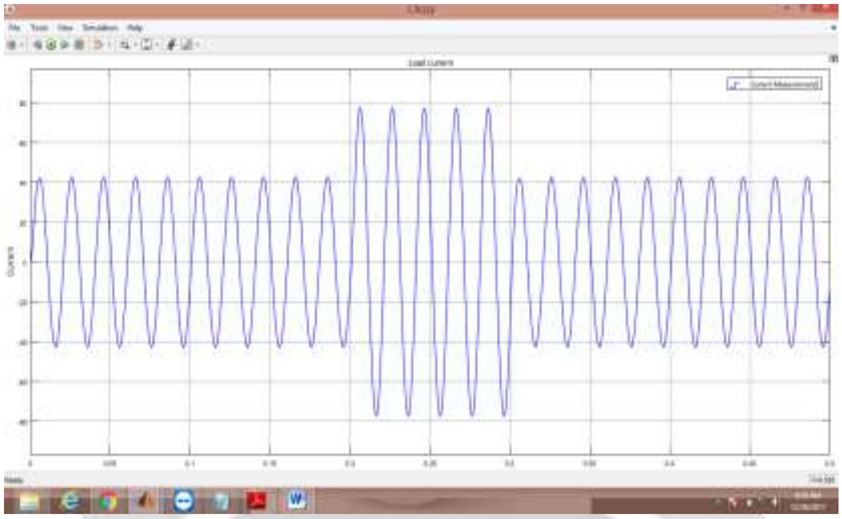


**Fig-10:** Solar PV system connected load current

**Fig-11:** Active power and reactive power

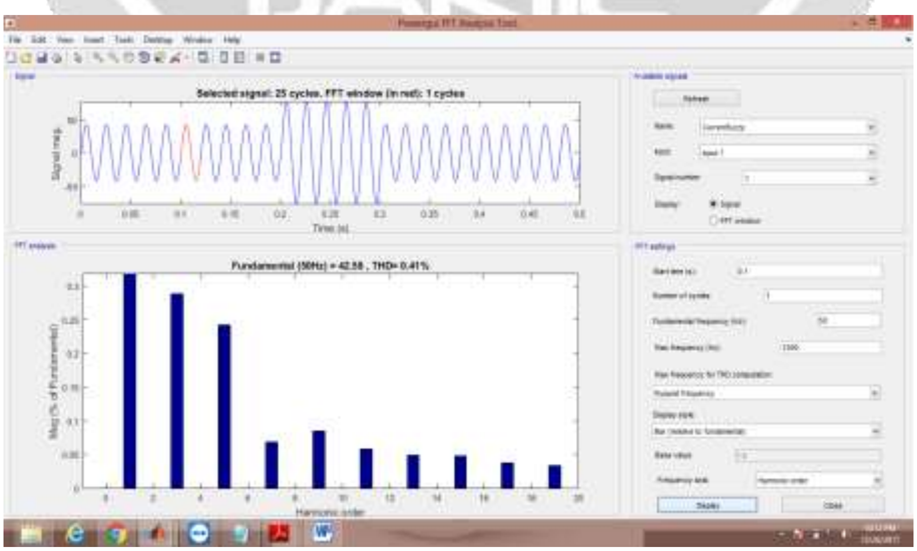



**Fig-12:** FFT analysis on solar pv system (THD) Total Harmonics Distortion = 0.41%

## 3. CONCLUSION

The application of grid connected photovoltaic system as shunt active filter is demonstrated in the paper. The performance of the system is tested with linear and non-linear loads in software. The interfacing inverter of the SPY system provides harmonic elimination and reactive power compensation to the local loads in addition to real power support. The PV power is used to feed the local loads and the extra power available is pumped into the grid. When the PV power available is not sufficient to meet the local loads, extra power required to satisfy load demand is taken from the grid.

The source voltage and current are made to be in phase in the system with linear inductive load. Tn the system feeding nonlinear loads, the harmonics in the grid side are eliminated and the THD is maintained within limits.

A 36W PV module is modelled and simulated with varying irradiation and temperature. A boost converter is designed and simulated. To control the gate pulse of the high frequency switch of the boost converter MPPT algorithm are used. Both the MPPT methods that is P&O and Income methods are used for maximum PowerPoint tracking. The Porter and Observer algorithm is simple in operation and required less hardware as compared to Incremental Conductance Method but in this method the power loss is little more as compared to the Incremental Conductance Method due to the output of the PV array oscillate around the MPP. Similarly the Incremental Conductance Method has better control and smaller oscillation but the hardware requirement is more. The Incremental Conductance Method achieve its steady state value earlier than P&O method. There are many merits and demerits of the two method. Therefore all the features should be taken into account to choose a better control algorithm. In this project for comparing these two algorithms three series model and six parallel model is taken and simulated in Matlab/Simulink. From the simulation result it is observed that both the method give nearly same result. So the P&O method is chosen for the grid synchronization purpose because of its simplicity and easy implementation. A dynamic model of wind turbine is model and simulated. PMSG is used in this paper as a wind generator due to its self excitation capabilities and requires less maintain. A 6kW out power is generated from the PMSG. A greed side VSI is used to synchronize the wind-PV hybrid system. The various waveform of this system were obtained by using the software Matlab/Simulink.

## 4. REFERENCES

[1] Jeyraj Selvaraj, Nasrudin A. Rahim, “Multilevel Inverter For Grid-Connected PV System Employing Digital PI Controller”, IEEE Transactions On Industrial Electronics, vol. 56, No. 1, pp. 149-158 , 2009.

[2] Renewable Energy Policy Network for the 21st Century (REN21), “Renewable 2010 Global Status Report”, Deutsche Gesellschaftfür Technische Zusammenarbeit (GTZ) GmbH, pp. 19, 2010.

[3] Savita Nema, R.K. Nema, Gayatri Agnihotri, “MATLAB/Simulink based study of photovoltaic cells / modules / array and their experimental verification”, International journal of Energy and Environment, vol.1, No.3, pp.487-500, 2010.

[4] Huan-Liang Tsai, Ci-Siang Tu, Yi-Jie Su, “Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK”, Proceedings of the World Congress on Engineering and Computer Science WCECS, San Francisco, USA, 2008.

[5] Francisco M, González-Longatt, “Model of Photovoltaic Module in Matlab™”, 2do congresoı beroamerı cano de estudıantes de ıngenıeríaeléctrı ca, electrónıca y computacıón pp.1-5, 2005.

[6] S. Rustemli, F. Dincer, “Modeling of Photovoltaic Panel and Examining Effects of Temperature in Matlab/Simulink”, Electronics and Electrical Engineering, ISSN 1392-1215, no. 3(109), pp. 35-40, 2011.

[7] Kinal Kachhiya, Makarand Lokhande, Mukesh Patel, “MATLAB/Simulink Model of Solar PV Module and MPPT Algorithm”, Proceedings of the National Conference on Recent Trends in Engineering and Technology, 2011.

[8] I.H. Atlas, A.M. Sharaf, “A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment”, International Conference on Clean Power, pp. 341-345, 2007.

[9] S. Liu and R. A. Dougal, “Dynamic multiphysics model for solar array”, IEEE Tram. Energv Conversion, Vo1.17, No.2, pp.285-294,
June 2002

[10] 1. A. Cow and C.D. Manning, “Development of a photovoltaic array model for me in power-electronics simulation studies”, IEE Proc. Elecrr. Power Appl., Vol. 146, Na.2, pp.193-200, March 1999

[11] H. Yamarhita, K.Tamahashi, M. Michihim., A. Tsuyoshi, K. Amako, and M. Park, “A novel Simulation technique of the PV generation system using red weather conditions”, in 2002 Proc. Power Conversion Con!, V01.2, pp. 839 444, April 2002

[12] G.A. Vokas, A.V. Machias, and J.L. Souflis, “Computn modeling and parameters estimation for solar cells”, h 1991 Proe Medirerranean Elecrrorechnicol Con/, v0l.l. pp. 206 -209, May 1991
[13] Shell Solar Product Information Sheets.
[14] L.A.C Lopes and Lienhardt, A.-M. “A simplified nonlinear power source for simulating PV panels”. Power Electronics Specialist, 2003. PESC’03. IEEE 34th Annual Conference on, Volume 4, pp. 1729- 1734.15-19 June 2003.
[15] B. Kroposki, R. DeBlasio, “Technologies for the New Millennium: Photovoltaics as a Distributed Resource”. Power Engineering Society Summer Meeting, 2000. IEEE, Vol. 3, p.p. 1798 – 1801,16-20 July 2000
[16] A. Hansen, P. Lars, H. Hansen and H. Bindner. “Models for a Stand- Alone PV System”. Risø National Laboratory, Roskilde, December 2000, ISBN 87-550-2776-8. [Online]. Available: http://www.risoe.dk/rispubl/VEA/ris-r-1219.htm
[17] G. Walker, "Evaluating MPPT converter topologies using a MATLAB PV model," Journal of Electrical & Electronics Engineering, Australia, IEAust, vol.21, No. 1, 2001, pp.49-56.
[18] Lorenzo, E. (1994). Solar Electricity Engineering of Photovoltaic Systems. Artes Graficas Gala, S.L., Spain.
[19] CIGRE TF38.01.10 “Modeling New Forms of Generation and Storage”, November 2000.
[20] J. A. Gow, C. D. Manning “Development of a photovoltaic array model for use in powerelectronics simulation studies,” IEE Proceedings on Electric Power Applications, vol. 146, no. 2, pp. 193-200, March 1999.
[21] S. W. Angrist, , Direct Energy Conversion, Allyn and Bacon, Inc., 4th edition, 1982, pp. 177-227.
[22] O. Wasynczuk, “Dynamic behavior of a class of photovoltaic power systems,” IEEE Transactions on Power Apparatus and Systems, vol. PAS-102, no. 9, 1983, pp. 3031-3037.
[23] J. C. H. Phang, D. S. H. Chan, and J. R. Philips, “Accurate analytical method for the extraction of solar cell model parameters,” Electronics Letters, vol. 20, no. 10, 1984, pp.406-408.
[24] C. C. Hua and C. M. Shen, “Study of maximum power tracking techniques and control of dc-dc converters for photovoltaic power system,” Proceedings of 29th annual IEEE Power Electronics Specialists Conference, vol. 1, 1998, pp. 86-93.
[25] J. A. Gow and C. D. Manning, “Development of a photovoltaic array model for use in power-electronics simulation studies,” IEE Proceedings- Electric Power Applications, vol. 146, no. 2, 1999, pp. 193-199.