

Minimising the harmonic distortions in grid connected PV system using fuzzy based Hybrid filter

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ABSTRACT

Due to uncontrolled emission of gases by the burning of resources, global warming is increasing. This is depleting the natural resources which can't be regenerated again. So every country is moving towards the renewable energy resources like solar cell, wind power etc. but country can't rely on them completely as they have many constraints. Nowadays, there is a lot of emphasis given on the solar energy conversion system so as to save the non-renewable energy resources and protect the environment at a time. In the field of power distribution by grid connected renewable energy sources, power quality is the major issue. At PCC, linear and non-linear loads are attached which affects the power quality even though MPPT with boost converter has been used. In this, harmonics in the transmission system are added which reduces power quality. So the purpose of the fuzzy logic controller is to stabilize the harmonics along with harmonics at the grid side. The filter at the grid side generates the current equal to the harmonic current but of opposite polarity and in this way, a large amount of harmonics have been filtered out. We tested the results with varying irradiation on solar cell and the results are quite good. A comparison is done with the fuzzy logic controlled system without harmonics filter and P & O controlled system without harmonics. Our proposed combination is able to reduce the 80% harmonics than P & O controlled system. This method not only improves voltage and power but also improves stability.

Keywords: PV connected grid, fuzzy logic controller, P & O controller, MPPT, Linear and non-linear loads.

Introduction

The production of clean and non-polluting energy at the consumer side with very less maintenance and having very long life is provided by the photovoltaic energy generation. Because of this advantage, the fastest growing market in the world is the photovoltaic market. But still the cost of power is very high so many researchers are finding ways to reduce this. If the energy output of the PV array is maximized then this goal can be achieved. The highest possible conversion efficiency is ensured by the inverter. The Maximum tracking point system is to operate the PV array at maximum operating point to get maximum voltage in all environmental conditions. Nowadays required amount of PV capacity is also installed in those areas where sky remains cloudy for a long time which produces varying irradiation condition for photovoltaic system. In the field of power distribution, renewable resources connected to the grid, power quality (PQ) is an issue. Linear and non-linear loads are attached at the point of coupling commonly called PCC which affects the power quality even though maximum power point tracking (MPPT) on the boost converter has been used. Various types of compensators like STATCOM, DSTATCOM, Filters, UPFC etc. have been used previously. The reference work used active shunt filter at PCC to suppress the harmonics generated by the non-linear load. Average and oscillating parts of instantaneous power are separated by Active filter controllers based on PQ theory. Active filter does not guarantee the dynamic performance. Due to this problem hybrid filter is used.

Fuzzy logic controller.

The work is focused on reducing the harmonics in PV connected grid transmission system. We adapted the method of using a set of series and parallel active filters. We are in need to transfer the maximum power with reduced harmonics in the output. So the proposed work is divided into two modules: first one is focusing on transferring the maximum power using fuzzy logic as MPPT controller and other is reducing the harmonics by the use of a set of series and parallel filters. Both modules are discussed separately in the next chapter. Since, our focus is on the fuzzy based harmonic filter at the source side so, it is necessary to know about the fuzzy logic, its history and how it is implemented.

First of all, Fuzzy logic is a problem solving method that is used in implementation of system from simple structure to huge structure or network. It acts as a firmware which means fuzzy logic can be applied to software program, hardware program or combination of both. Fuzzy logic can be used to manage partial truth, partial truth means the truth values lie between zero and one. This makes decision making easier. As

the complexity of machine is increasing, it becomes difficult to handle the machine using crisp values so at that point, fuzzy is used.

2.1 Fuzzy Inference System.

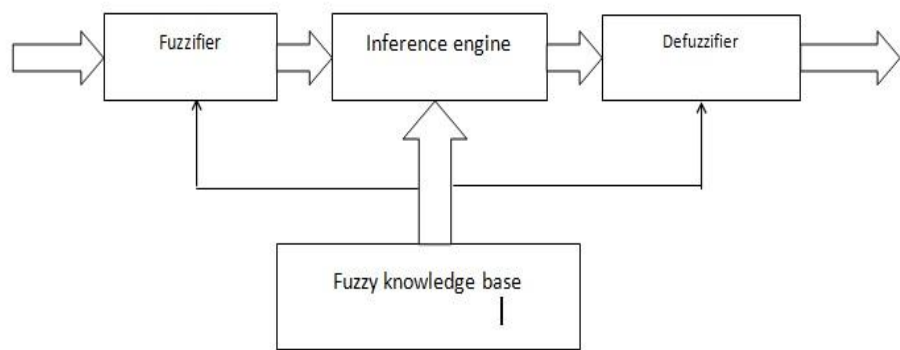


Figure 1 Schematic diagram of Fuzzy system

- Consider the three variables or inputs of fuzzy set.
- Input1: Fine of Carrier. Subsets are bad, best
- Input2: Fine of meal. Subsets are worst, good
- Input3: Tip amount. Sunsets are low, medium, high
- The first block is fuzzifier which corresponds to three variables, "service quality", " food quality", " tip amount" .
 - Second is inference engine which chooses the fuzzy operator.
 - Third is Fuzzy knowledge base which is a set of rules.
 - Fourth is Defuzzifier in which defuzzification takes place and crisp value is obtained.
 - Fifth is the Output which is the final destination.

2.2 HOW TO DESIGN FUZZY LOGIC IN MATLAB

- Step 1: Type ">>fuzzy" in the MATLAB
- Step 2: Fuzzy Inference System editor will open. Here, the input and output membership values is entered, the rule base and bushy operators are entered.

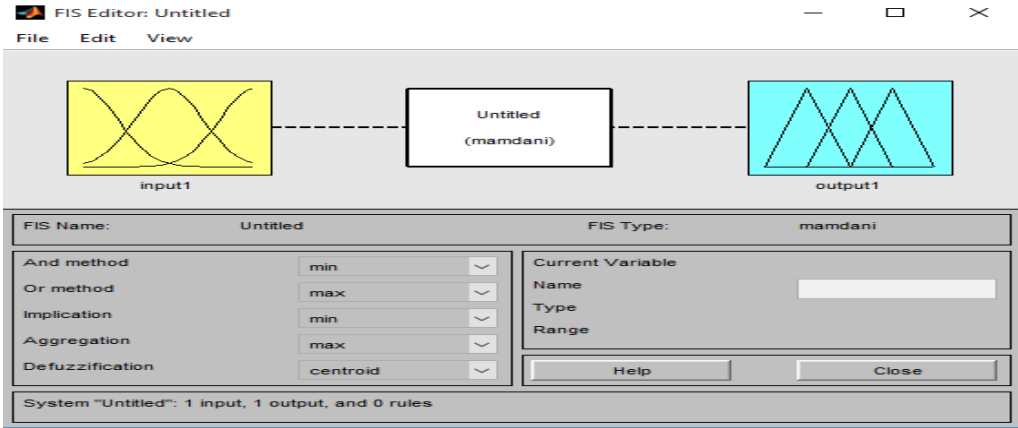


Figure 2 Fuzzy logic graphical interface of MATLAB's toolbox

The given system is Mamdani based single input single output system. The FIS editor also illustrates type of operations used, defuzzification type and aggregation type. To start. Double click on yellow enter box where membership feature editor will open.

Consider three membership features mf1, mf2, mf3 as shown in figure 3. again redefine mf1, mf2 and remove mf3. To delete mf3, click on it ,when it appears in purple color press delete button. To change the features or range of present memfership functions, click on them and then drag wherever required.

Now, again go back to FIS editor. Regulations must be defined in FIS editor. For this, double click on the white space between input and output block. This will open the rule editor. Here, different number of rules can be added.

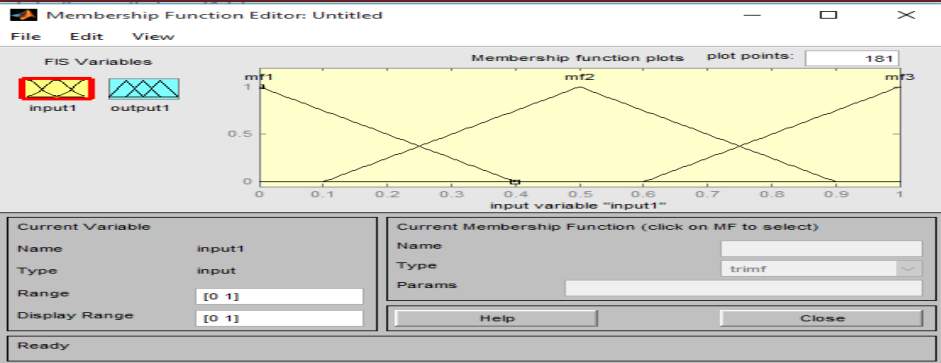


Figure 3 Membership function designing
When the different regulations are entered rule editor will look as follows:

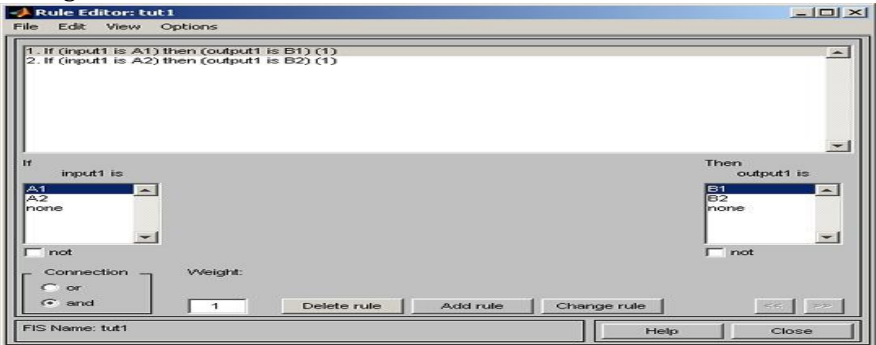


Figure 4 Fuzzy logic's Rule Editing.
Close Rule editor and FIS is now finished. It is required to export it to Simulink Model. In FIS editor, click on File option then export and then to workspace.

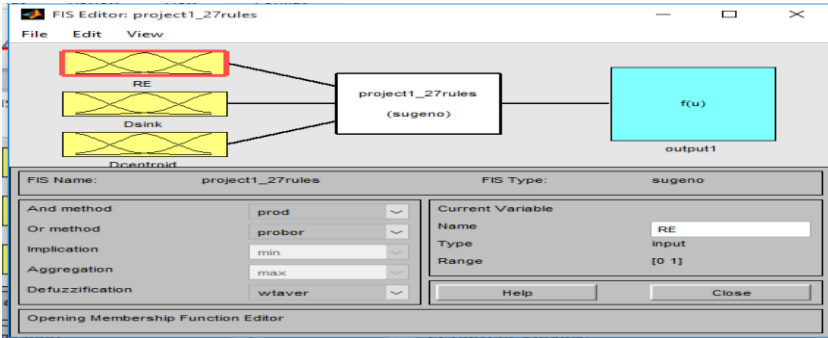


Figure 5 Fuzzy System to evaluate the output of a path in WSN with three inputs

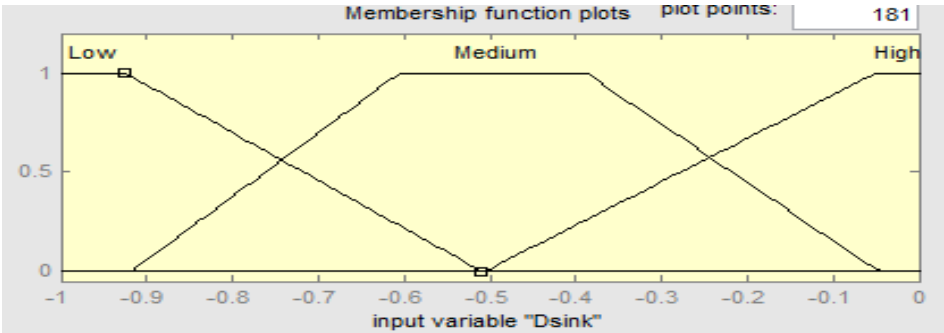


Figure 6 Membership function of Data sinks

Input parameter Data sink as displayed in Fig. 6 is having three membership capabilities named as Low, Medium and high. The size is showing the entire values in percent. The membership perform types are

considered as trapezoidal for all of the membership capabilities. The boundaries are certainly outlined for the entire membership capabilities.

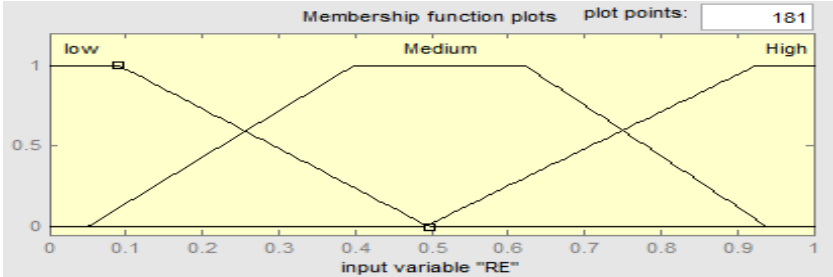


Figure 7 Membership function of Residual energy
This input parameter is having three trapezoidal membership functions: Low, Medium and High

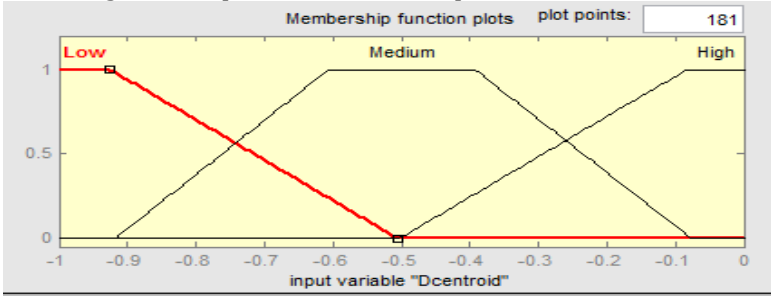


Figure 8 Membership function of Dcentriod.
Figure 8 shows the membership of Dcentriod method of defuzzyfication. This is all about the fuzzy logic. After this fuzzy based controller is designed using the previously given criteria. After this, the duty cycle occurred from fuzzy Perturb and Observation method is given to the boost converter. The power from the boost converter is compared with normal perturb and observation. The dc voltage level must be increased by the proposed work. The generated voltage is given to VSC and the active power filter connected at the load end.

3 Modelling and simulations.

To operate the system in balanced condition their voltage and frequency must be synchronised. A Voltage Source inverter at the coupling point fulfils this purpose. PV array changes the due to change in irradianations or other environmental conditions which can disturb the synchronisation of PV grid module, so a proper power generation system at PV side must be managed which can cope up with these changes. So we used fuzzy logic controlled MPPT boost converter to manage these changes. A single PV cell can generate only a power upto 3 W at 0.5-0.6 volts. This much less power can't be used to supply to grid. So we used an array of cells with 5*66 cells. 5 rows and 66 columns of PV cells are used to make an array which makes use of 330 PV cells in an array. A complete block diagram of PV connected grid is shown in figure. At the grid side controller, a PV inverter is used to convert DC into AC with complete synchronisation. Feedback controller controls the converter based on d-q theory. For three phase signals, six controlling switches are used which are fed by SPWM (sinusoidal pulse width modulation scheme).

The schematic model of voltage source controller is given in figure which is designed in ORCAD schematic. Fortunately we have a block in sim power toolbox of MATLAB which serves our purpose of controller.

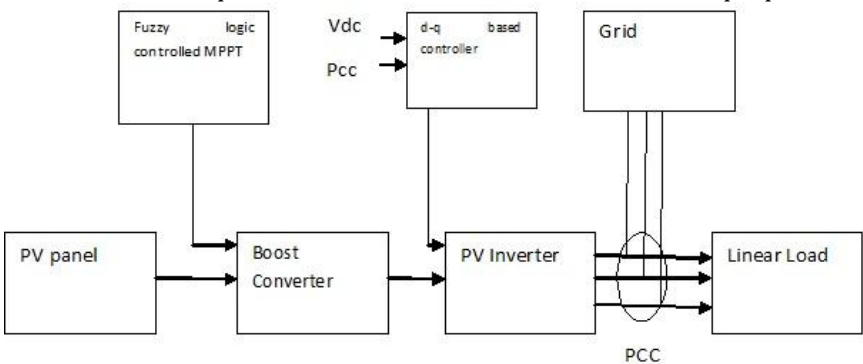


Figure 9 Complete Block diagram of PV-grid connected Systems

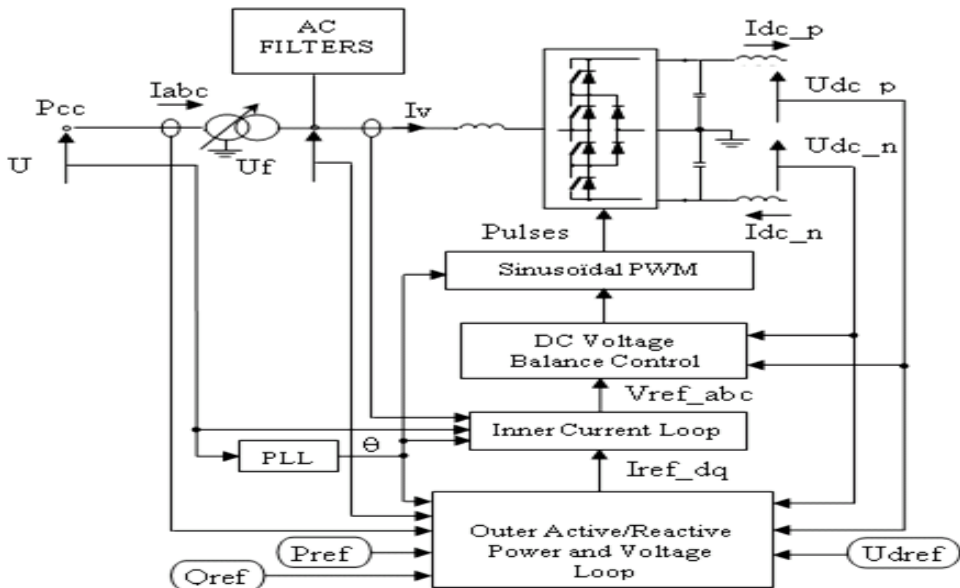


Fig. 10 Schematic model of VSC Controller for PV inverter at grid side

To manage the proper synchronisation between photovoltaic system and grid, The DC voltage at PCC must be maintained constant. In our work it is 500 Volt. The more it disturbs, the more system is in unsynchronised state. The dq controller in figure converts the current into direct axis current and quadrature axis current. The phase locked loop (PLL) provides the synchronous angle θ by measuring the system frequency for the dq transformation block. A brief mathematical formulation for controller is discussed here. After conversion of reference current into d-q part, estimation occurs as follows

The unit vectors in phase with V_a, V_b, V_c are

$$u_a = \frac{V_a}{V_m}; u_b = \frac{V_b}{V_m}; u_c = \frac{V_c}{V_m}$$

Where, V_m is magnitude of AC terminal Voltage at PCC

$$V_m = \frac{2}{3} \sqrt{V_a^2 + V_b^2 + V_c^2}$$

Here, V_a, V_b, V_c are the instantaneous Voltage at PCC

$$V_a = V_{san} - R_s I_{sa} - L_s p I_{sa}$$

$$V_b = V_{sbn} - R_s I_{sb} - L_s p I_{sb}$$

$$V_c = V_{scn} - R_s I_{sc} - L_s p I_{sc}$$

where ' p ' is the differential time operator (d/dt)

L_s is per phase source impedance

R_s is per phase source resistance

$V_{san}, V_{sbn}, V_{scn}$ are 3-phase instantaneous input supply voltage at PCC

$$V_{san} = V_{sm} \sin(\omega t)$$

$$V_{sbn} = V_{sm} \sin(\omega t - 2\pi/3)$$

$$V_{scn} = V_{sm} \sin(\omega t + 2\pi/3)$$

V_{sm} is the peak value and $\omega = 2\pi f$ is the angular frequency of the supply.

The unit vector in quadrature with V_a, V_b, V_c is obtained by using quadrature transformation of the in phase unit vectors as follows:

$$w_a = -\frac{u_b}{\sqrt{3}} + \frac{u_c}{\sqrt{3}}$$

$$w_b = \sqrt{3} \frac{u_a}{2} + \frac{(u_b - u_c) \times 2}{\sqrt{3}}$$

$$w_c = -\sqrt{3} \frac{u_a}{2} + \frac{(u_b - u_c) \times 2}{\sqrt{3}}$$

The voltage error at PCC is V_{er} which is explained below

$$V_{er}(n) = V_{ref}(n) - V_m(n)$$

$$I_{smq}^*(n) = I_{smq}^*(n-1) + k_p (V_{er}(n) - V_{er}(n-1)) + k_i V_{er}(n)$$

Here, k_p and k_i are proportional constant and integral constant. The superscript (*) represents reference quantity.

$$I_{saq}^* = I_{smq}^* w_a$$

$$I_{sbq}^* = I_{smq}^* w_b$$

$$I_{scq}^* = I_{smq}^* w_c$$

The in-phase components of reference currents are computed as follows:

$$I_{sad}^* = I_{smd}^* u_a$$

$$I_{sbd}^* = I_{smd}^* u_b$$

$$I_{scd}^* = I_{smd}^* u_c$$

Here, I_{smd}^* is constant source current used in load leveling.

$$I_{sa}^* = I_{sad}^* + I_{saq}^*$$

$$I_{sb}^* = I_{sbd}^* + I_{sbq}^*$$

$$I_{sc}^* = I_{scd}^* + I_{scq}^*$$

3.1 MATLAB modelling of PV array.

The equations used in PV array designing are discussed. As it is clear the designing of array is dependent upon the irradiation and temperature. For our work we have considered the room temperature as fixed and irradiation intensity is changed. The main parameters of PV model are : photo-generated current I_{ph} , diode saturation current, parallel resistance and series resistance. The parameters value of SunPower SPR-305WT module is used which is extracted from the database of website solardesinedtool.com. In appendix 1 parameters values of this module are provided.

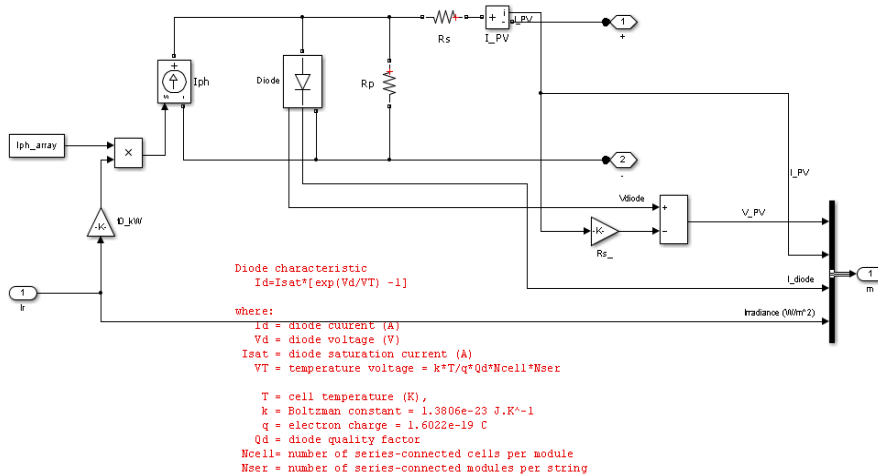


Figure 11 PV array module designed in MATLAB

In the proposed work, 66 strings of moduled are connected in parallel and 5 strings are connected in series to form PV array. The designing of Photovoltaic array

3.2 Modelling of Grid

The grid designing is quite simple and does not requires many specific parameters. The model of utility grid is shown below which is made using MATLAB. It comprises of 19KM feeder with 2MW load at the 14KM distance. 30MW load is connected at the generating point.

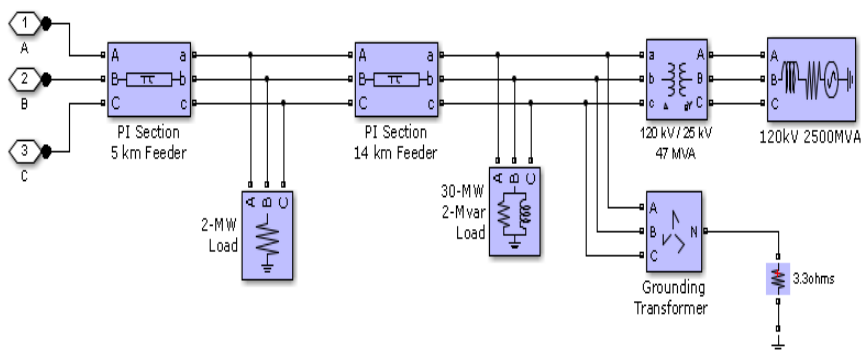


Figure 12 Utility grid designed in MATLAB

3.3 Modelling of Complete PV grid model with P&O controlled boost converter

A comparison of proposed work is shown with previous algorithms whose models are also designed with MATLAB.. The proposed work consists of three sub models each for P&O MPPT control, Fuzzy P&O MPPT control, Proposed filtered fuzzy MPPT control. It is divided into three sub models each for P&O MPPT control, Fuzzy P&O algorithm control and proposed filtered fuzzy MPPT control.. As discussed earlier, MPPT controlleras. The difference in model between the conventional P&O and fuzzy P&O designing. The model with harmonic filters in series and shunt.The shunt filter is a combination of three different filters and designed using R,L and C. This filter is applied at the load side of the system and filter out the harmonics. This harmonic filter basically acts as a current generator and generates current equal to the harmonic current but with opposite polarity. This cancels out most of the harmonic current and this also compensates the reactive power at the same time and in this way , the aim of this dissertation is being achieved.

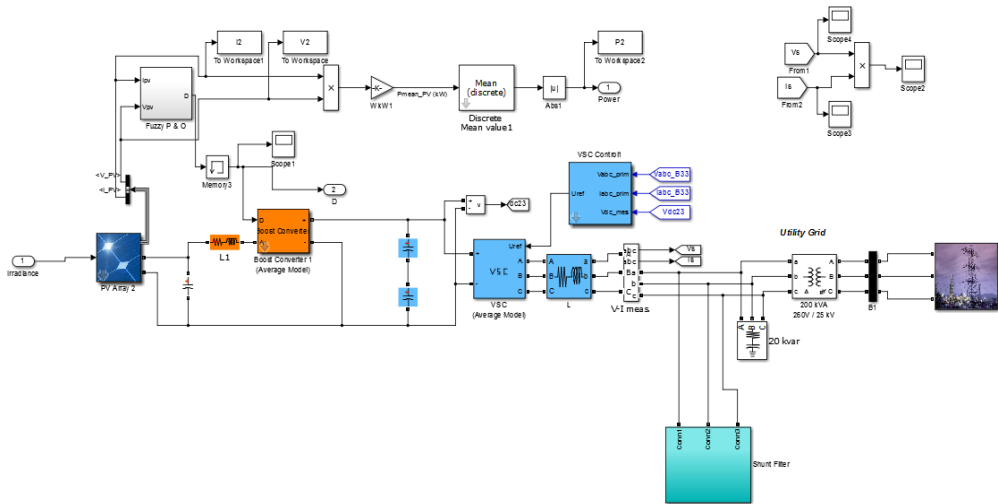


Figure 13 Complete PV grid model with P&O controlled boost converter

4 . Results & Discussions.

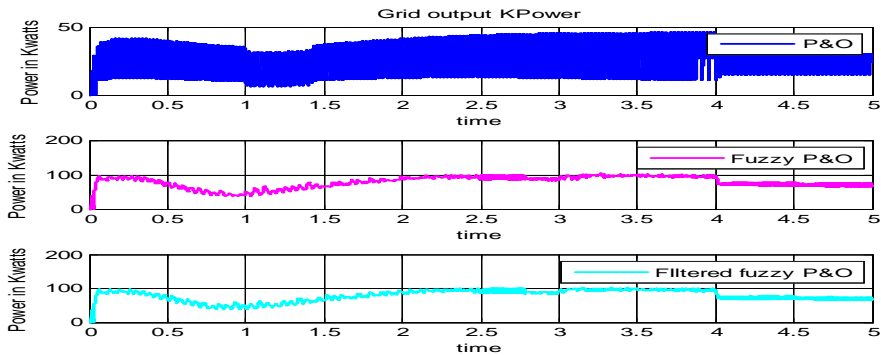


Fig. 14 Grid Output power for P&O, fuzzy P&O and filtered fuzzy P&O controller

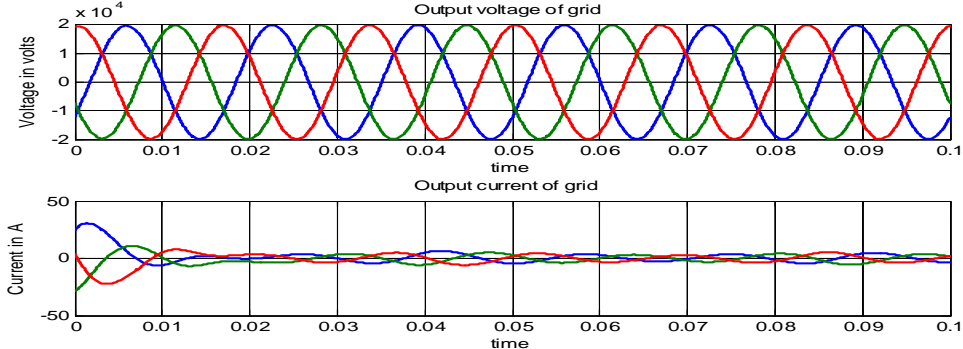


Figure 15 Output current and voltage of grid in case of proposed method

For a given input if proposed model is executed than comparative curve between three methods are P&O, fuzzy P&O and filtered fuzzy P&O, is obtained. The MPPT control is used to set up the power and so is done by fuzzy controlled in this proposal. The filtered output is also plotted along with non-filtered fuzzy logic MPPT control signal. The magnitude in both cases doesn't make any difference as both models are using same fuzzy controller, but the ripples in later one are reduced as calculated by total harmonic distortion, the tool available in MATLAB. The grid current in filtered and non filtered case is also compared then subdivided into three parts as shown below according to the proposed work.

The hysteresis analysis is done by Finite Fourier Transform (FFT). The THD value in all three cases.

P&O controlled, without harmonic control	Fuzzy controlled, without harmonic control	Fuzzy controlled, with harmonic control
62.64%	15.80%	12.52%

Table 1 THD comparison of all three cases

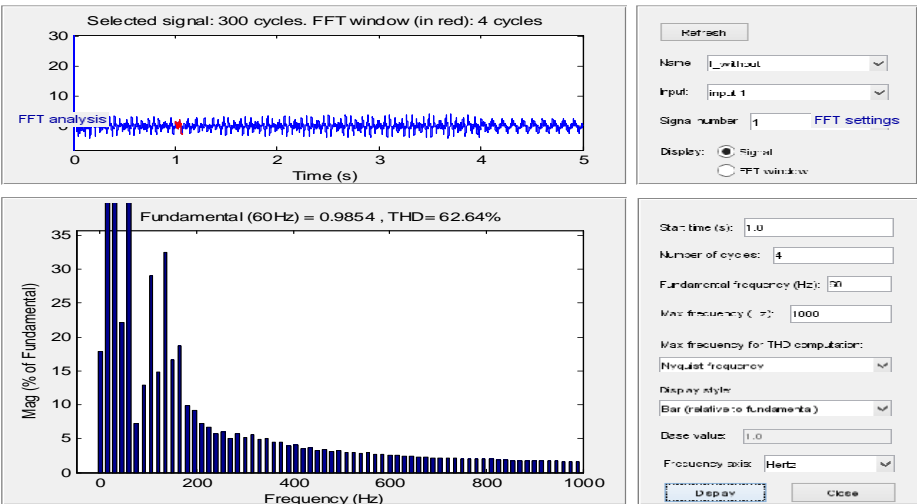


Figure 16 Hysteresis analysis for P& O controlled case without harmonic controlling

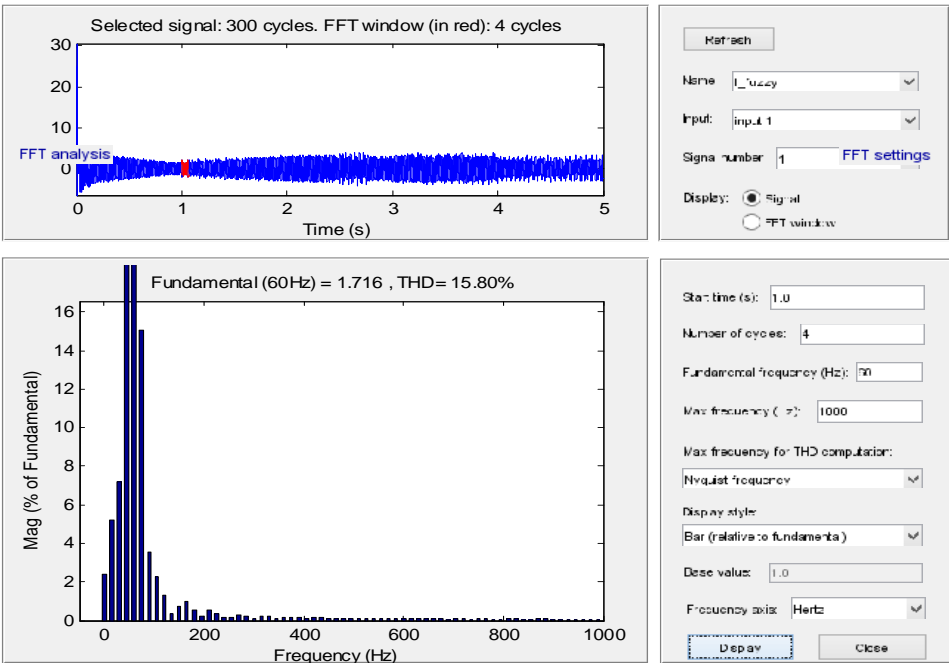


Figure 17 Hysteresis analysis for fuzzy controlled case without harmonic controlling

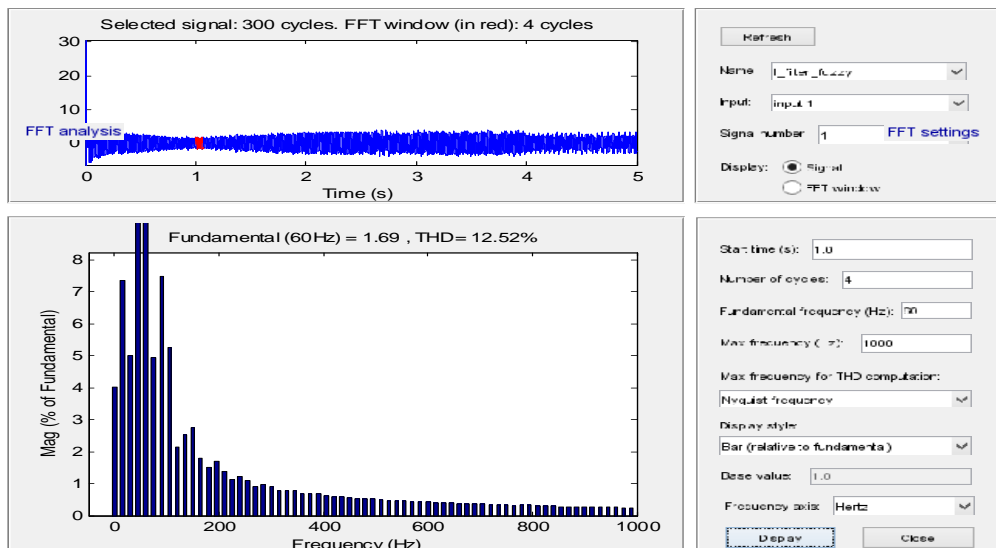


Figure 18 Hysteresis analysis for fuzzy controlled case with harmonic controlling

As is clear from the figures an improvement in ripples reduction with fuzzy logic is 84.20% and using harmonic filter this reduction is 87.78% .From the P&O controller and from fuzzy controller with no harmonic control, it is 15.80%. Our proposed combination of fuzzy controlled MPPT with harmonic filter is giving the best

5. Conclusions

This work focused on minimising the harmonic distortions in PV array connected grid transmission system by the used of more advanced fuzzy logic and harmonic filters. Three cases are considered in the work: 1. P&O controlled PV connected grid without harmonic filter 2. Fuzzy controlled PV connected grid without harmonic filter 3. Fuzzy controlled PV connected grid with harmonic filter. The magnitude and less ripples are observed in 3rd case, though power magnitude is not different in the fuzzy controlled MPPT and without filter as boost method is same but the last one is giving more stable output than second case. The system is tested with variable solar irradianations and with linear load. The synchronisation of whole system is judged by the DC coupling voltage. It should remain fix at 500 Volt. By these methods, it is disturbed in the range of 600-400 Volt but stable at 400 Volt at the end of simulations. Least fluctuations are observed with harmonic controlled method. We are able to get a reduction of 80% harmonics from P&O control and 20.76% from fuzzy logic alone. The Electric generation of 99.56 KW is also achieved From given PV Array whereas P&O controller has generated just 56.228 KW of power. In this way, the MPPT fuzzy controller with harmonic filter has excellent performance in reducing ripples in the output and providing the quality in power distribution system.

6. References

1. Jayasankar V N, Gururaj M V and Vinatha U., "A study on hybrid Renewable Energy Source interface to the non-ideal grid at distribution level with power quality improvements," *2016 IEEE 6th International Conference on Power Systems (ICPS)*, New Delhi, 2016, pp. 1-5.
2. R. Haste, A. Matre and S. L. Shaikh, "Power quality improvement in grid connected renewable energy sources at distribution level," *2014 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2014]*, Nagercoil, 2014, pp. 496-502.
3. R. Zamora; A. K. Srivastava, "Multi-Layer Architecture for Voltage and Frequency Control in Networked Microgrids," in *IEEE Transactions on Smart Grid* , vol.PP, no.99, pp.1-1.
4. M. Singh, V. Khadkikar, A. Chandra and R. K. Varma, "Grid Interconnection of Renewable Energy Sources at the Distribution Level With Power-Quality Improvement Features," in *IEEE Transactions on Power Delivery*, vol. 26, no. 1, pp. 307-315, Jan. 2011.
5. S. K. Khadem, M. Basu and M.F. Conlon, "Power Quality in Grid connected Renewable Energy Systems: Role of Custom Power Devices," *International Conference on Renewable Energies and Power Quality (ICREPQ'10)* Granada (Spain), 23rd to 25th March, 2010.
6. A. S. Shirbhate and S. D. Jawale, "Power quality improvement in PV grid connected system by using active filter," *2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS)*, Nagercoil, 2016, pp. 388-395.

7. K. R. Suja and I. J. Raglend, "Power quality improvement in grid connected wind energy system using STATCOM," *2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET)*, Kumaracoil, 2012, pp. 259-266
8. Sandipan Patra, Ankur, Modem Narayana, Soumya R. Mohanty, and Nand Kishor, "Power Quality Improvement in Grid-connected Photovoltaic-Fuel Cell Based Hybrid System Using Robust Maximum Power Point Tracking Controller," *Electric Power Components and Systems*, 00(00):1-16, 2015.
9. Wajahat Ullah Tareena, Saad Mekhilefa, Mehdi Seyedmahmoudianb, Ben Horanb, "Active power filter (APF) for mitigation of power quality issues in grid integration of wind and photovoltaic energy conversion system," *Renewable and Sustainable Energy Reviews*, volume 70, April 2017, Pages 635-655.
10. M. Y. Lada, I. Bugis and M. H. N. Talib, "Simulation a shunt active power filter using MATLAB/Simulink," *2010 4th International Power Engineering and Optimization Conference (PEOCO)*, Shah Alam, 2010, pp. 371-375.
11. Mouhanned Brahim, Jamel Belhadj," Performance of PV Grid-Connected System Under Grid Failure" *International Journal Of Renewable Energy Research* Mouhanned Brahim et al., Vol.3, No.4, 2013.
12. Zameer Ahmad, S.N. Singh," Modelling and Control of Grid Connected Photovoltaic System- A Review" *International Journal of Emerging Technology and Advanced Engineering*, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 3, March 2013.
13. Debendra Bahadur Raut, Ajay Bhattarai," Performance Analysis of Grid Connected Solar PV System Using Matlab/Simulink", *Rentech Symposium Compendium*, Volume 3, September 2013, pp 48-54.
14. K.Manohar, P.Sobha Rani," Mppt and Simulation for a Grid-Connected Photovoltaic System and Fault Analysis" *The International Journal of Engineering And Science (IJES)*, Volume 1 Issue 2|Pages 158-166 2012.
15. Ayaz Ahmad, Rajaji Loganathan, " Real-Time Implementation of Solar Inverter with Novel MPPT Control Algorithm for Residential Applications" *Energy and Power Engineering*, 2013, 5, 427-435.
16. Riad Kadri, Jean-Paul Gaubert, Member, IEEE, and Gerard Champenois, Member, IEEE," An Improved Maximum Power Point Tracking for Photovoltaic Grid-Connected Inverter Based on Voltage-Oriented Control" *IEEE Transactions On Industrial Electronics*, Vol. 58, No. 1, January 2011.
17. Takayoshi Kamejima¹, Vanxay Phimmason¹, Yuta Kondo¹, Masafumi Miyatake," The Optimization of Control Parameters of PSObased MPPT for Photovoltaics" *IEEE PEDS 2011*, Singapore, 5 - 8 December 2011.
18. Azuki Abdul Salani, Nik Azran Ab Hadi," Fuzzy Logic Controller For Shunt Active Power Filter," *4th International Conference On Technology and Techpreneurship*, ICE2T 2014, Malaysia, pp 256-259.
19. Oualid Aissa, Samil Moulahoum, Ilhami Lohak, Badreddine Babes and Nadis Kabache, " Analysis , Design and Real time Implementation of Shunt Active Power filters for Power Quality Improvement based on Predictive Direct Power Control," *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, pp 84-96.
20. Er. Mamatha Sandhu , Dr. Tilak Thakur , "Issues, Challenges , Causes, Impacts and Utilisation of Renewable Energy Sources- GRID INTEGRATION" , *International Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT)* 2014, pp 814-819.
21. Mohitha A.T, Shruthi M, " Design and control of renewable power system through wsn in microgrid" , *The International Journal of Engineering and Science*, Vol 4 , issue 5, page pp.25-32, 2015