

Fuzzy Controller Based Grid Integration of Hybrid Solar Photovoltaic and DFIG Wind Energy System to Improve Power Quality

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Abstract: This paper is focused on grid integration of a hybrid photovoltaic (PV) and doubly fed induction generator (DFIG) based wind energy system. An intelligent controller was developed to generate maximum power from the above renewable energy sources and to solve the grid integration issue while improving the generated power quality. This paper has three major parts. The first pertains the design of a fuzzy logic controller to maximize power point tracking of photovoltaic power system and to generate maximum power under various weather conditions. The second part explains the design of a fuzzy logic controller for DFIG based wind energy conversion system to improve the system performance. The third part integrates the above two renewable energy sources and develop a hybrid fuzzy logic controller for solving grid integration issues and improving the power quality. The proposed system simulation results are evaluated with IEEE 1547 standard for showing the effectiveness of the system. The fuzzy controller has been developed for maximum power point tracking for 10 KW photovoltaic power systems and analysed with various weather conditions.

Keywords: PV, DFIG, Grid, Fuzzy, Power Quality, Hybrid.

1 Introduction

Due to the deficiency of inorganic resources and amplification of environmental pollution, nations all over the biosphere pays more care to the growth of renewable energy. As Solar Photovoltaic and Wind power play a significant role in renewable energy, there has been increasing interest in the analysis of PV and wind power in power system [1]. The solar photovoltaic based power generation is playing a major role to meet consumer demand. Nowadays the researchers have developed an advanced configurations of PV power conversion systems and MPPT controllers. The main advantage of solar photovoltaic power is its ability of generating electricity from sunlight without environmental collateral damage, less maintenance, no noise and 15 - 25 % efficiency. A common arrangement for large wind turbines is based on the DFIG with back-to-back converters between the AC grid and the rotor windings. The main advantage of the

DFIG is its ability to change operational speed with only 20 - 30 % of the generated power passing through the power converters. The conventional controllers do not perform well in a DFIG system. Therefore, in this paper, fuzzy logic controller has been designed for DFIG control systems and is based on rotor current vector control with d-q decoupling [2][3]. In a characteristic hybrid energy system, the primary energy resource is at a lower availability level while the subordinate one is usually at a higher availability level. For the occasion, in the winter seasons, the wind speed is generally highly available while the solar radiation is at its lowest intensity. During the night hours, sunlight cannot be used for power generation, whereas the wind energy can be successfully used. Hence, simultaneous utilization of multiple energy resources significantly improves to meet consumer load demands [4]. In this study, the objective function is to improve the power quality of the hybrid system as a function of PV and Wind parameters. To achieve this

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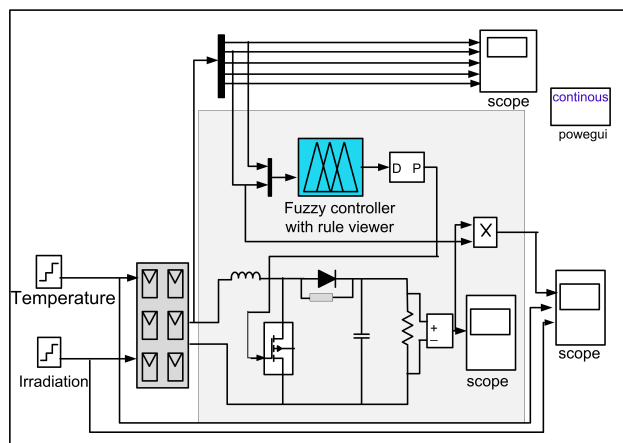


Fig. 1: Fuzzy based MPPT controller simulation model for 10KW PV system Design of Fuzzy Logic Controller.

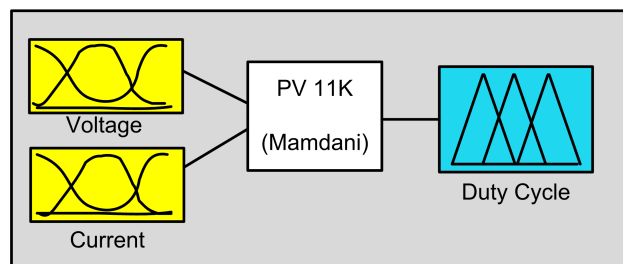


Fig. 2: Fuzzy controller structure for MPPT controller.

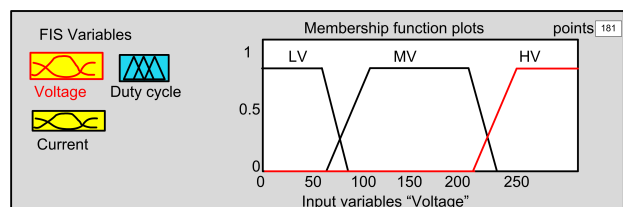


Fig. 3: Fuzzy input membership function of PV voltage.

fuzzy logic controller has been developed for hybrid PV and DFIG wind energy system and synchronized with power grid for improving the power quality.

This paper is organized as follows. The maximum power point tracking of PV system using Fuzzy logic controller is presented in Section II. Then, in Section III, the design of the DFIG wind energy system and rotor current control by using fuzzy controller is implemented. In Section IV, a discussion of implementation of fuzzy controller based grid integration of hybrid PV / DFIG and finally in Section V, the conclusion of research work is presented.

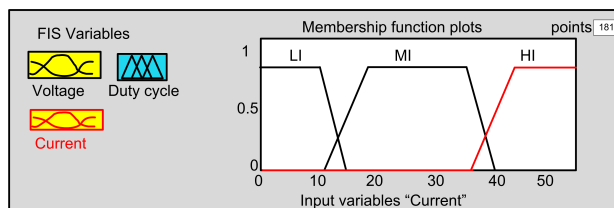


Fig. 4: Fuzzy input membership function of PV current

2 MPPT Controller for PV system

The Maximum power point tracking algorithm is playing a very essential role in renewable energy sources for generating maximum power at various weather conditions. The solar photovoltaic system generates electricity with respect to falling of sunlight on modules. The sunlight irradiance is nonlinear characteristics that intermittent availability cause solar PV modules unable to generate maximum power [1]. In literate survey, different types of MPPT controllers based on Perturb and Observe (P&O) algorithm, Incremental Conductance algorithm, Feedback voltage and current, feedback power algorithm etc are designed and verified [4][5]. In this paper, the fuzzy logic controller based on MPPT algorithm has been developed and simulated in MATLAB environment and compared with conventional controller. The boost converter based PV MPPT system has been developed in MATLAB as shown in fig 1.

The fuzzy logic controller has been developed with two inputs and one output functions [4] [6] such as PV voltage, PV current and duty cycle of the PV boost converter as shown in fig 2. The fuzzy PV voltage input membership function is classified into three ranges such as low voltage, medium voltage and high voltage as presented in fig 3. The fuzzy PV current input membership function is classified into three ranges namely low current, medium current and high current as presented in fig 4. The fuzzy duty cycle output membership function is classified into three ranges that are low duty cycle, medium duty cycle and high duty cycle as presented in fig 5. The fuzzy membership function are designed based on the trapezoidal method for Fuzzification process and used centroid method for defuzzification process. The fuzzy rules are formed based on input data and analysis duty cycle various condition such as low input, medium input and high input are presented in fig 6 to fig 8. The fuzzy rules surface waveform presented in fig 9.

The proposed fuzzy control based PV MPPT controller has been simulated at various climatic conditions such as various irradiance and various temperature ranges. To carry out the simulation the different irradiance values like 250 W/m², 500 W/m², 750

Table 1: Fuzzy Vs INC MPPT algorithm

Irradiance	Inc Conductance	Fuzzy Logic
1000 W/M ²	9662 W	10039 W

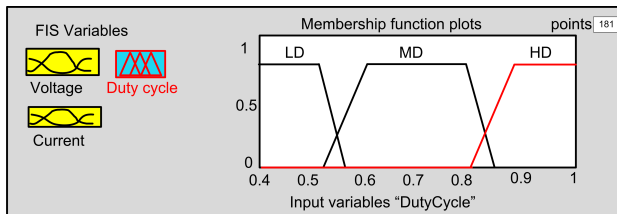


Fig. 5: Fuzzy output membership function for duty cycle of boost converter

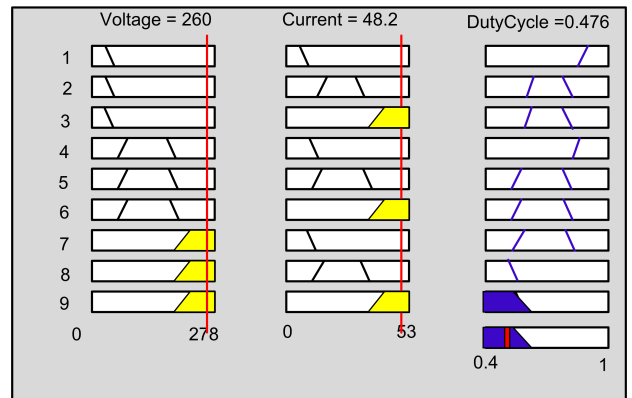


Fig. 8: Fuzzy rules based system for MPPT controller (high membership function)

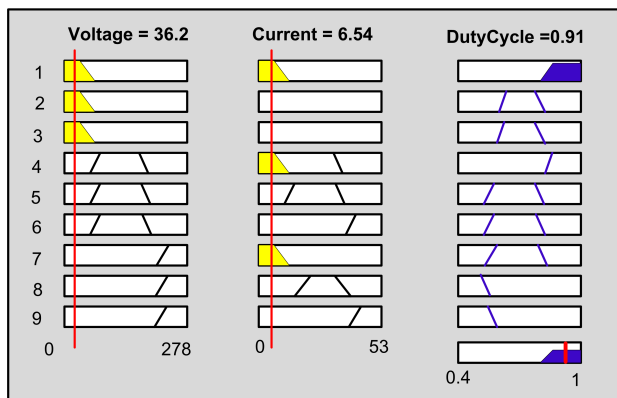


Fig. 6: Fuzzy rules based system for MPPT controller (lower membership function)

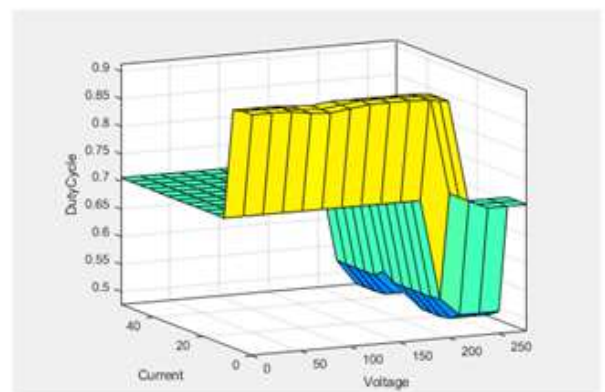


Fig. 9: Fuzzy rules surface system for MPPT controller

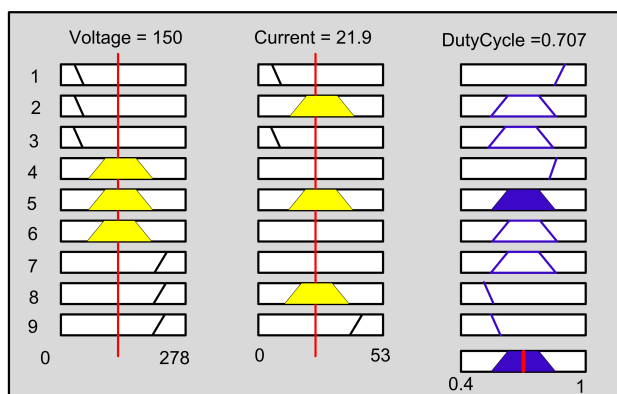


Fig. 7: Fuzzy rules based system for MPPT controller (medium membership function)

W/m² and 1000 W/m² are considered. The irradiance of 250 W/m² is set during the period 0 to 0.05 sec. This gives PV power of 1800 W. Similarly during interval 0.05 sec to 0.1 sec irradiance was increased to 500 W/m², which will produce PV power of 3000 W. Later during 0.1 sec to 0.15 sec irradiance of 750 W/m² was set to give PV power of 6000 W. Finally Irradiance of 1000 W/m² was set to give PV power of 10 KW. The temperature values varied and set to 25⁰C, 26⁰C, 28⁰C and 29⁰C during the intervals 0 to 0.05 sec, 0.05 to 0.1 sec, 0.1 sec to 0.15 sec and 0.15 to 0.2 sec respectively. The above weather conditions are applied in proposed simulation model and analysis the PV output power waveform as shown in fig 10. The PV boost converter voltage and

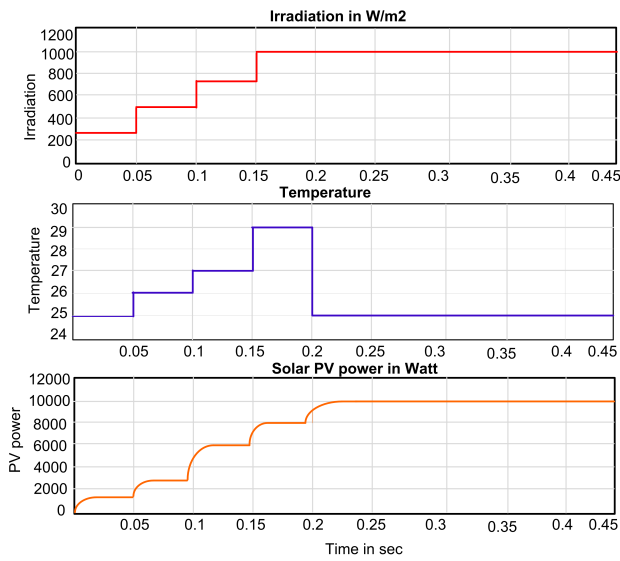


Fig. 10: Fuzzy based MPPT controller PV output power waveform under various irradiance and temperature

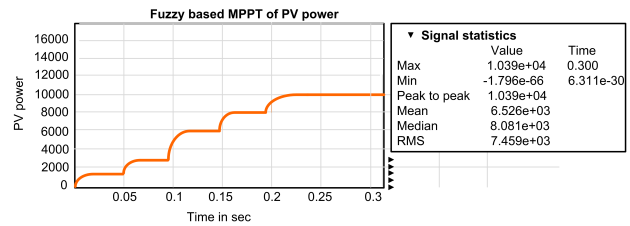


Fig. 12: Fuzzy based MPPT controller PV output power waveform under various weather conditions

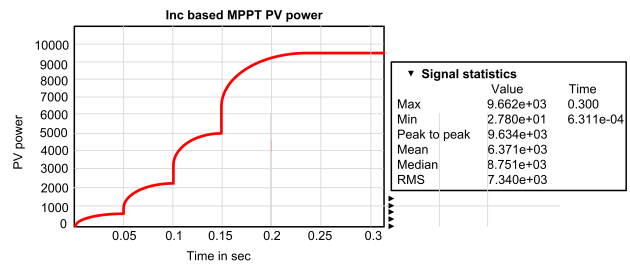


Fig. 13: INC based MPPT controller PV output power waveform under various weather conditions

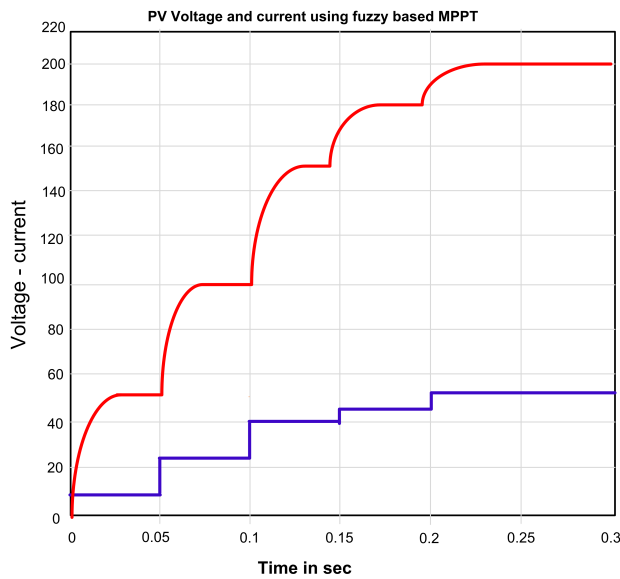


Fig. 11: Fuzzy based MPPT controller boost converter voltage and current waveform under various irradiance and temperature (Blue : Voltage) (Red: Current)

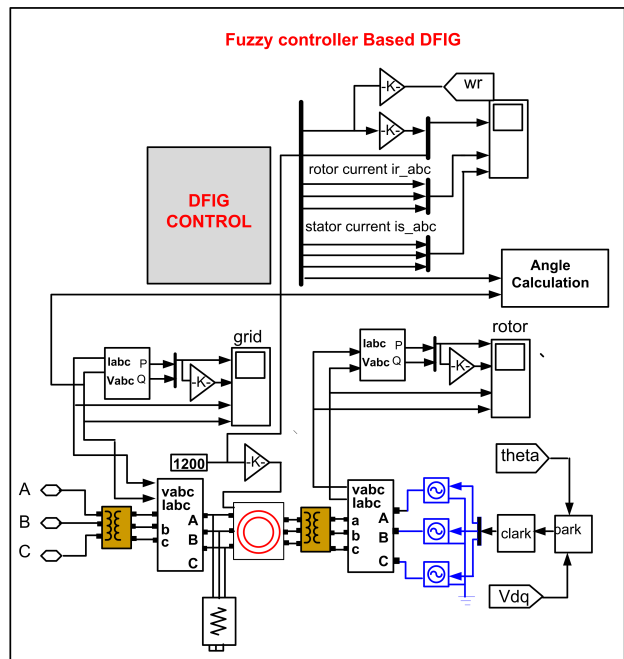


Fig. 14: A simulation model of fuzzy controller based DFIG based wind energy conversion system.

current waveform are presented in fig 11. The PV output power waveform has been presented in fig 12. The Conventional MPPT controller (Incremental Conduction) PV output waveform has been presented in fig 13. The comparative analysis has been presented in table 1.

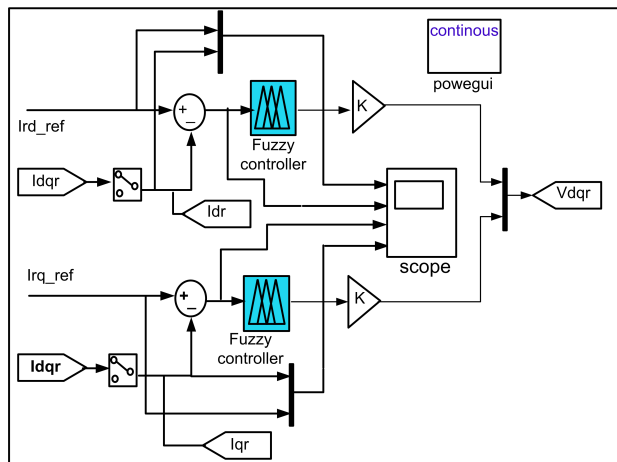


Fig. 15: Fuzzy based Rotor Current controller

3 Fuzzy Based Rotor Current Control for DFIG

The doubly-fed induction generator (DFIG) system is a widespread system in which the power electronic interface controls the rotor currents to achieve the variable speed necessary for maximum energy capture in variable winds [7][8][9]. Because the power electronic only processes the rotor power, typically less than 25% of the overall output power, the DFIG offers the advantages of speed control with reduced cost and power losses.

The fuzzy logic controller has been developed for DFIG rotor current controller for improving the system power quality as shown in fig 14 and fig 15 [9]. The DFIG rotor currents are classified into two types such as direct axis current (Id) and quadrature axis current (Iq). Therefore fuzzy logic controller has been developed separately for controlling currents Id and Iq as shown in fig 16 and fig (17 a) respectively. The fuzzy input and output membership function are developed by using trapezoidal function, then the centroid is used for defuzzification method.[9].

The fuzzy controller has been developed for direct axis current regulation and has direct axis current as an input membership function as shown in fig (17 b), regulated direct axis current as an output membership function as shown in fig (17 c). Also the fuzzy controller has been developed for quadrature axis current regulation and has one input and one output membership functions such as quadrature axis current as an input membership function as shown in fig (17 d), regulated quadrature axis current as an output membership function as shown in fig 18. The direct and quadrature axis fuzzy rules are formed based on input data and presented in fig 19 and fig 20.

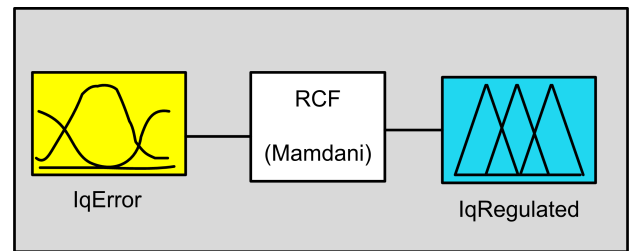
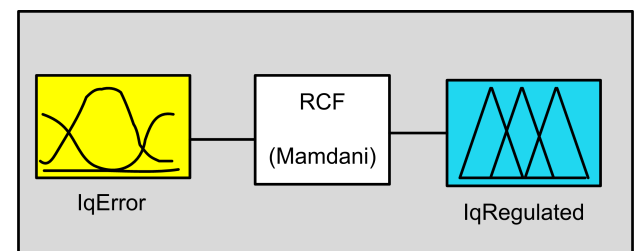
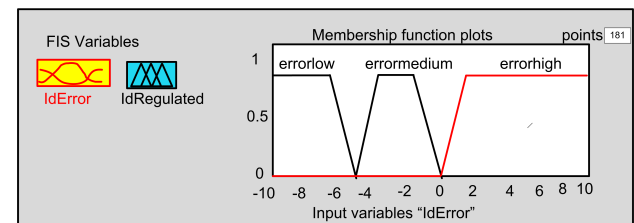


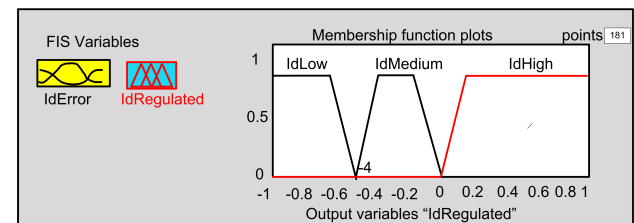
Fig. 16: Fuzzy based Rotor Current controller



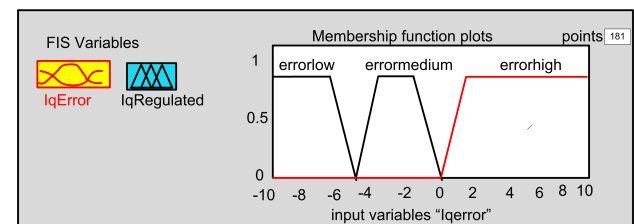
(a)



(b)



(c)



(d)

Fig. 17: (a) Design of Fuzzy Controller for Iq regulator (b) Input Membership function for Id regulator (c) Output Membership function for Id regulator (d) Input Membership function for Iq regulator

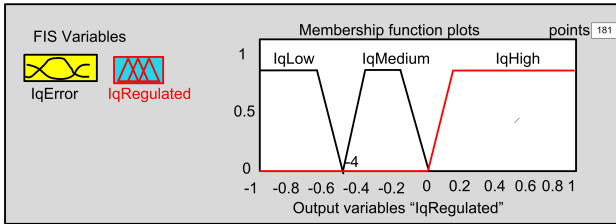


Fig. 18: Output Membership function for Iq regulator

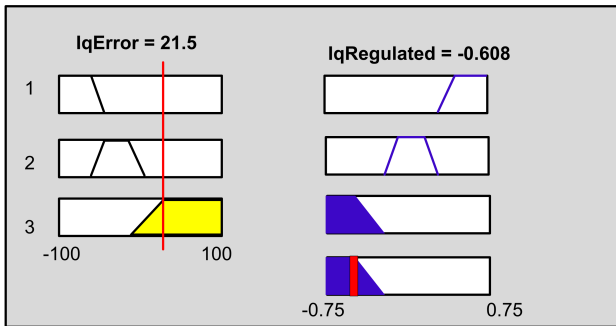


Fig. 19: Fuzzy rules for Id current regulator

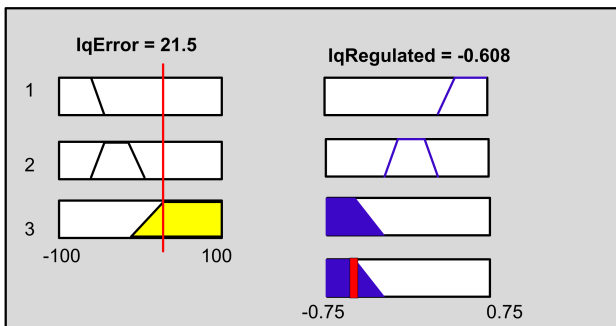


Fig. 20: Fuzzy rules for Iq current regulator.

3.1 Fuzzy membership function

The membership functions are formed using straight lines. There are various membership functions namely Triangular Membership Function, Trapezoidal Membership Function, Gaussian Membership Function, Generalized bell Membership Function, π - Shaped Membership Function, S- Shaped Membership Function. In this work triangular membership function and Trapezoidal membership functions are used for the

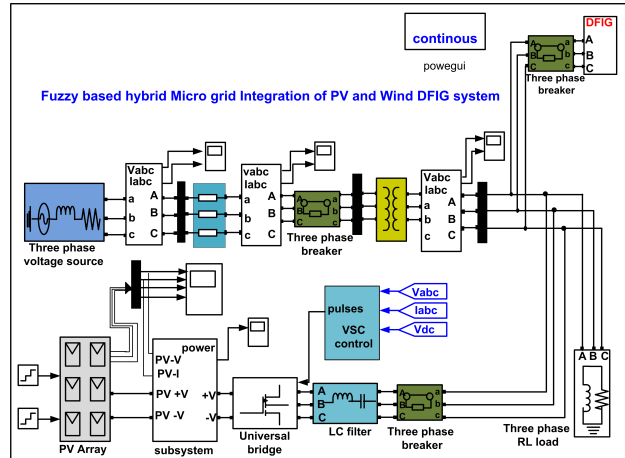


Fig. 21: A simulation model of hybrid PV / DFIG based grid integration system using fuzzy controller

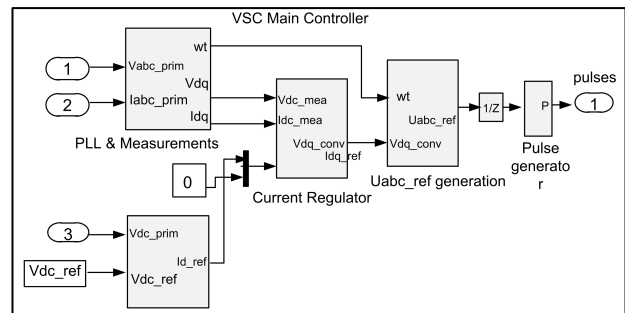


Fig. 22: Design of voltage source converters controller

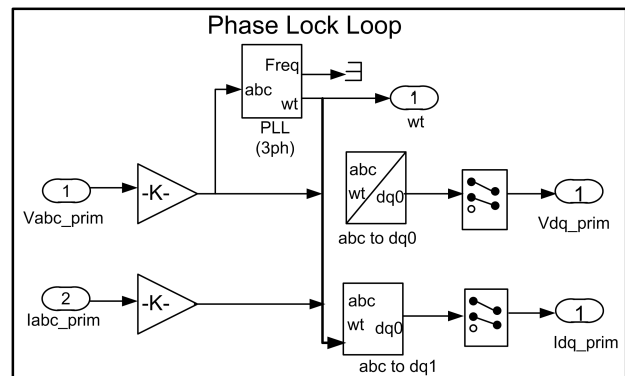


Fig. 23: Design of Phase lock loop

controller design. The various fuzzy controller membership functions are presented in fig 16 to fig 20.

4 Fuzzy Based Voltage Source Converter Controller

The complete simulation model of hybrid PV and DFIG based wind energy system for the grid integration using

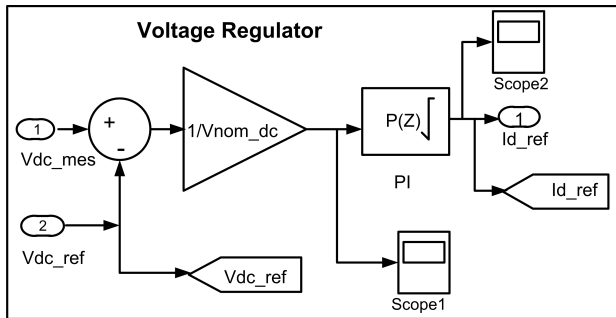
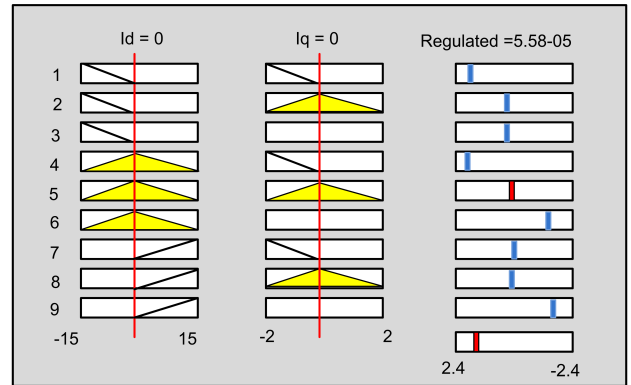
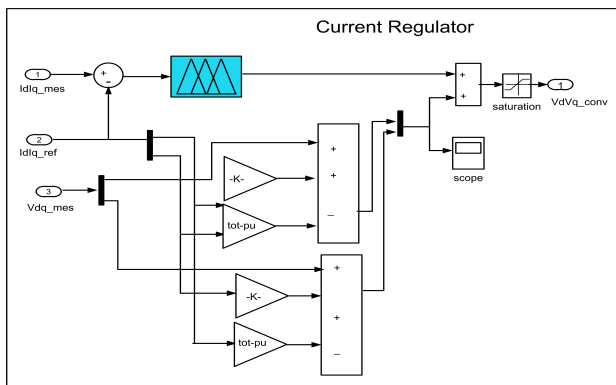


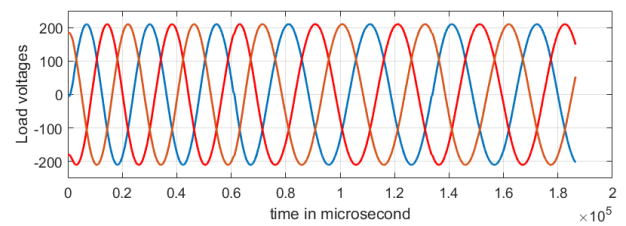
Fig. 24: Design of voltage regulator for grid integration of PV system



(c)

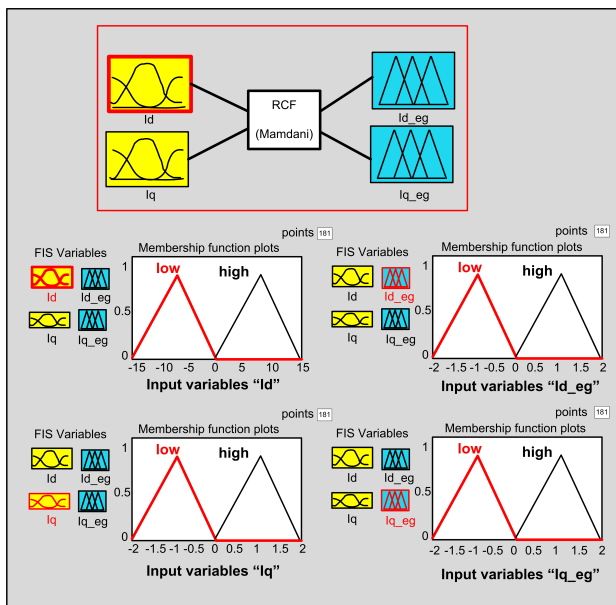


(a)

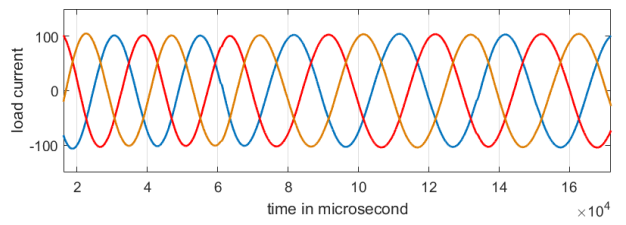


(d)

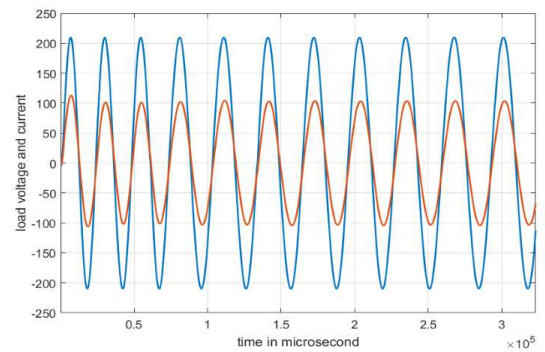
Fig. 25: (a) Design of current regulator for grid integration of PV system.; (b) Fuzzy controller membership function and its rules for current regulator of VSC.; (c) Fuzzy rules for current regulator.; (d) Voltage waveform of grid integrated hybrid PV / DFIG power system.



(b)



(a)



(b)

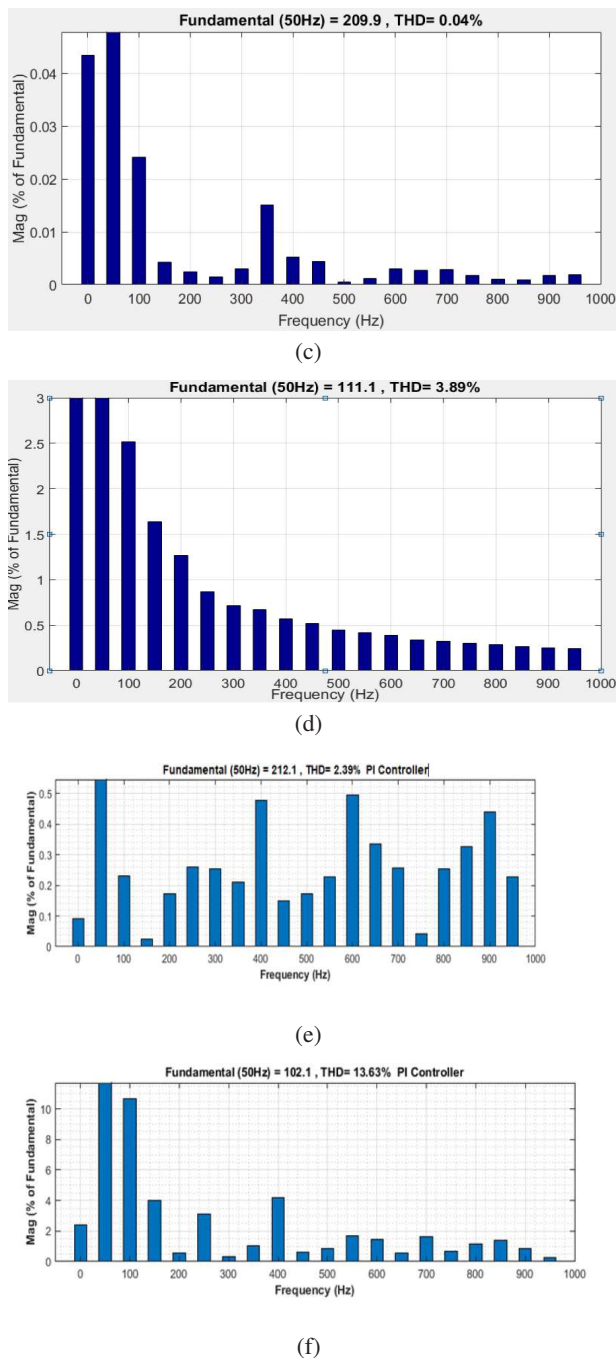


Fig. 26: (a) Current waveform of grid integrated hybrid PV / DFIG power system (b) Current in phase with voltage waveform (c) Voltage THD of hybrid system with fuzzy controller (d) Current THD of hybrid system with fuzzy controller (e) Current THD of hybrid system with PI controller (f) Voltage THD of hybrid system with PI controller

fuzzy controller is presented in the figure 21. The synchronizing of renewable energy source into the power grid has many challenges such as to match two AC source voltage profile, frequency profile and phase angle [12][13]. The voltage source converter controller performs a major role in solving the above said problems and is presented as shown in fig 22. The voltage source converter controller has three major parts such as a Phase lock loop, Voltage regulator and current regulator [14][15]. A phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal as shown in fig 23. Voltage regulation is to provide real-time control of voltage fluctuation, sag, surge and also to control other power quality issues such as spikes and EMI/RFI electrical noises [16]. It uses a MOSFET regulator generating pulse width modulated (PWM) AC voltage at high switching frequency as shown fig 24. The current regulator will control the inverter operation of power flow. When the Ids current is positive the inverter generate the active power and when Iq positive the inverter absorb the reactive power. In this paper the fuzzy controller has been developed for current regulator as shown in fig (25 a). The fuzzy logic controller has been designed for a current regulator for VSC [1]. The fuzzy controller has two input signals and two output signals such as input (direct axis and quadrature axis current) output (regulated direct axis and quadrature axis current) shown in fig (25 b). The fuzzy membership function are designed based on the triangle method for fuzzification process and used centroid method for defuzzification process The fuzzy rules are represented in fig (25 c). The direct axis current value is positive converter deliver the active power to Microgrid and quadrature axis current value is positive converter that absorb the reactive power from Microgrid. The proposed fuzzy control has been applied hybrid PV /Wind with Microgrid and its voltage source converter.

The fuzzy output signal is fed into the feed forward current regulator of converter based on the input signal of PWM controller generates triggering pulses of inverter for synchronize into microgrid. Figure (25 d) and figure (26 a) presents Voltage and Current Waveform of fuzzy controller-based grid integration of Hybrid PV- DFIG Power system respectively. The resultant load current is in phase with load voltage as presented in figure (26 b). Finally, the total harmonic distortion values are measured and presented in figures (26 c) and (26 d) respectively. The THD values for the proposed system for load voltage is 0.04% and the load current is 3.89%. Also the performance of the hybrid system is also analysed using conventional PI controller. The total harmonic distortion values in this case are measured and presented as shown in figures (26 e) and (26 f) respectively. The THD values for the load voltage is 2.39% and the load current is 13.63% using PI controller. The above observed THD values are compared with IEEE 1547 standard. Based on the standard value of grid integration of renewable energy source THD values less than 5% is acceptable. The

Table 2: Comparison between PI Controller and Fuzzy Controller for hybrid solar wind system

Parameter value	THD of PI controller in percentage	THD of Fuzzy controller in percentage
Voltage	2.39	0.04
Current	13.63	3.89

proposed system THD values are very less than IEEE 1547 standard.

5 Perspectives

This paper, discussed the modelling of hybrid solar PV system and DFIG based wind energy system. The fuzzy controller has been developed for maximum power point tracking for 10 KW photovoltaic power systems and analysed its performance under various weather conditions. The DFIG wind energy system has been developed in MATLAB environment and the designed fuzzy logic controller for rotor current controller. The proposed grid integration of hybrid PV and DFIG system has been simulated in MATLAB environment and hence developed a fuzzy controller for grid synchronizing of hybrid system into the power grid. The obtained results are compared with conventional controller and tabulated as shown in table 2. Also the proposed model simulation results are analysed with different operating conditions and evaluated with IEEE 1547 standard for proving the effectiveness on the system.

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References

- [1] Hemanand, T., Subramaniam, N.P. & Venkateshkumar, M., "Comparative analysis of intelligent controller based microgrid integration of hybrid PV/wind power system", *Journal of Ambient Intelligence and Humanized Computing* <https://doi.org/10.1007/s12652-018-0961-6>.
- [2] Yan Wang, Li Ding and Nan Li, "The application of fuzzy parameters self-tuning PID controller in MPPT of photovoltaic power system", *Proceedings 2011 International Conference on Transportation, Mechanical, and Electrical Engineering (TMEE)*, Changchun, 2011, pp. 1129-1132.
- [3] R. Cakmak, I. H. Altas and A. M. Sharaf, "Modeling of FLC-Incremental based MPPT using DC-DC boost converter for standalone PV system", 2012 International Symposium on Innovations in Intelligent Systems and Applications, Trabzon, 2012, pp. 1-5.
- [4] G. Anandhakumar, M. Venkateshkumar and P. Shankar, "Intelligent controller based MPPT method for the Photovoltaic power system", 2013 International Conference on Human Computer Interactions (ICHCI), Chennai, 2013, pp. 1-6.
- [5] K. Latha Shenoy, C Gurudas Nayak and Rajashekar P Mandi, "Design and Simulation of Incremental Conductance MPPT algorithm for PV applications", *National Conference on Recent advances in control strategies for integration of Distributed Generation sources to grid and control of their power quality issues*, Bangalore, 2016, pp.45-49.
- [6] R. Indumathi, M. Venkateshkumar and R. Raghavan, "Integration of D-Statcom based photovoltaic cell power in low voltage power distribution grid", *IEEE-International Conference On Advances In Engineering, Science And Management (ICAESM -2012)*, Nagapattinam, Tamil Nadu, 2012, pp. 460-465.
- [7] S. Elkhadiri, P. L. Elmenzhi and P. A. Lyhyaoui, "Fuzzy logic control of DFIG-based wind turbine", 2018 International Conference on Intelligent Systems and Computer Vision (ISCV), Feb, 2018, pp. 1-5.
- [8] J. Gambhir and T. Thakur, "Modeling and control of large wind farm based on DFIG using classical PI and fuzzy logic controller (FLC)", 2017 International Conference On Smart Technologies For Smart Nation (SmartTechCon), Bangalore, 2017, pp. 454-459.
- [9] F. Amrane and A. Chaiba, "A hybrid intelligent control based on DPC for grid-connected DFIG with a fixed switching frequency using MPPT strategy", 2015 4th International Conference on Electrical Engineering (ICEE), Boumerdes, 2015, pp. 1-4.
- [10] K. Latha Shenoy, C Gurudas Nayak and Rajashekar P Mandi, "Modeling and Performance study of DFIG for Wind Application", *IEEE 2017 International Conference On Smart Technology for Smart Nation Bangalore* pp 1616-1620
- [11] Qichang Duan, Fengxia Hao and Shicheng Feng, "Adaptive fuzzy control used in DFIG VSCF wind power generator system", 2008 7th World Congress on Intelligent Control and Automation, Chongqing, 2008, pp. 29-32.
- [12] M. El Azzaoui, H. Mahmoudi and K. Boudaraia, "Analysis and control of grid connected DFIG and solar PV based hybrid energy system", 2016 International Renewable and Sustainable Energy Conference (IRSEC), Marrakech, 2016, pp. 1104-1109.
- [13] A. Muhtadi and A. M. Saleque, "Modeling and simulation of a microgrid consisting solar PV & DFIG based wind energy conversion system for St. Martin's island", 2017 IEEE 3rd International Conference on Engineering Technologies and Social Sciences (ICETSS), Bangkok, 2017, pp. 1-6.
- [14] H. Boumaaraf, A. Talha, B. Boumaaraf and O. Bouhali, "Grid-connected hybrid renewable energy system using DFIG and multilevel inverter", 2016 8th International Conference on Modelling, Identification and Control (ICMIC), Algiers, 2016, pp. 826-830.

- [15] K. V. Vidyandandan and N. Senroy, "Improved frequency regulation in wind-PV-DG hybrid microgrid using wind turbines", 2016 IEEE 6th International Conference on Power Systems (ICPS), New Delhi, 2016, pp.1-6.
- [16] A. Hamadi, S. Rahmani, K. Addoweesh and K. Al-Haddad, "A modeling and control of DFIG wind and PV solar energy source generation feeding four wire isolated load", IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society, Vienna, 2013, pp. 7778-7783.
- [17] K. Latha Shenoy, C Gurudas Nayak and Rajashekar P Mandi, "Performance Analysis of SPWM and SVPWM Based Three Phase Voltage source Inverter", International Journal of Control Theory & Application, 9(21), 2016, pp. 307-314
- [18] J Sreedevi, Ashwiun N and M Naini Raju, "A study on Grid Connected PB system", IEEE Xplore, 978-1-4799-5141-3/14 2106 pp 1-6
- [19] D M Tobnagi, "A Review on Impacts of Grid Connected PV system on Distribution network", International Journal of Electrical, Computer, Energetic, Electronic & Communication ENgg, Vol.10, No.1, 2016



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