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Comparison of MPPT Systems in Error Optimization using PID, Fuzzy and Hybrid Fuzzy in Multivariable Environment

Chandani Sharma[1*] and Anamika Jain[2]

1: Assistant Professor, Department of Electronics and Communication Engg., Graphic Era University, Dehradun, India
2: Professor, Department of Electronics and Communication Engg., Graphic Era University, Dehradun, India

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Recent surveys conducted in the field of Power Control and Engineering show that photovoltaic (PV) systems are currently being discussed worldwide and research on the same is being carried globally. It is necessary to optimize the expanding use of photovoltaic systems through error detection in Maximum Power Point Tracking (MPPT) systems. Through this paper, an attempt is made to develop an efficient photovoltaic MPPT system using hybrid fuzzy technique to extract maximum power under a multivariable environment (changing temperature and irradiance). The MPPT system using Hybrid Controller (combining PID & FLC) has an increased efficiency and optimized output in comparison to the MPPT system using PID and Fuzzy individually. The system has explored a concept of computing academic performance indices with three MPPT models for future research based on global MPP calculation.

Keywords: *PV; MPPT; Hybrid fuzzy; PID and Fuzzy; Global MPP; Academic performance indices*

Introduction

The power output from photovoltaic (PV) systems is the largest when it is operated at the Maximum Power Point (MPP). Practically, under Standard Test Conditions (STC) it is obtained at temperature 25°C and irradiance 1000 W/m^2. A MPP Tracker is used to maintain this set point under a multivariable environment i.e. varying temperature and varying irradiance. Two different types of tracking systems are known: Passive and Active. Whereas a number of MPPT strategies are available based on single or multivariable approach designed using conventional or intelligent controllers [1-5].

Various types of MPPT systems are designed to meet voltage regulation, frequency regulation, power and harmonics control with quick response time, reduced error and increased gain. However, due to difference in real time system and results of digital simulated system it is sometimes not adaptable to obtain MPP in multivariable environment. Thus, there arises the need of error detection and optimization. The SPC (Statistical Process Control) management tool compiles an overall mathematical measure for multiple sets of simulation and determines performance index. The performance index

**Corresponding author:* chandani19nov@gmail.com

estimates errors in the output. The appropriate response is calculated by detecting and reducing errors between measured and required set point.

The performance index approximates the process performance. It delivers an index for a process which measures how close a process is running to its desired specification limits, relative to the variability of the process. The larger the index, the lesser is the functional capability of system, *i.e.*, system does not operate at its full potential and the output is not within specified limits. Performance indices are classified as (a) Academic and (b) Practical indices. Academic indices are straight forward and computed along with simulation of the process or system being run at different instants of time. On the other hand, Practical indices are calculated for the final response obtained after the system has been simulated. It is found that academic performance indices are generally preferred over practical ones as the quantitative characterization is directly and quickly obtained when simulating with academic indices. Moreover, they are adaptive to changing environmental conditions. The other advantages include fast computation and reduced complexity of physical set up that raises the cost of the system when used with practical indices [6-22].

The approach used in the present work is to determine academic performance indices and thereby optimize MPPT system through attainment of suitable tuning and scaling gain constants. The tuning and scaling gain constants are evaluated on integral of error. The error is computed by difference of voltage obtained from PV and converter subsystem and desired set point at STC (21.07 V). The academic performance indices are computed and direct comparison between different MPPT systems using different sets of tuning parameters is obtained.

Design and Simulation of Three MPPT Systems

Three MPPT systems [1-3] are designed using conventional controller (PID), intelligent controller (FLC) and fusion of both, *i.e.*, hybrid controller (PD+I FLC) [4-6]. The commercially available Solarex MSX-60W panel is designed using mathematical Simulink modeling in MATLAB. Thereafter, Buck converter (Step Down) is connected across the output of panel to achieve STC [4-6]. The output of the converter is adjusted to the set point (21.07 V), and the controller is used to monitor set point under multivariable environment. The controller delivers a control function that acts as an input to make the converter output approach the set point. Different gain constants of controllers are tested and tuned to achieve optimized results for the converter output by minimizing error. Error is generated by difference in output obtained from converter to the desired *i.e.*, 21.07 V.

For PID, the tuning gains are three gain control parameters K_P (Proportional gain), K_I (Integral gain) and K_D (Derivative gain). For FLC, it is the fuzzy sets *i.e.*, the number and type of membership functions with crossover points and its respective range (*i.e.*, Universe of Discourse formulated with set of rules). For Hybrid PD+I FLC, in addition to FLC, four scaling gains *i.e.*, GU (normalization gain), GE (proportional gain), GCE (derivative gain) and GIE (integral gain) are added and the system is tuned to achieve appropriate results.

The academic performance metrics include: IAE (Integral of Absolute Error), ISE (Integral of Square Error), ITAE (Integral of Time multiplied by Absolute Error) and ITSE (Integral of Time multiplied by Square Error). The computed errors are minimized for integral of error *e(t)*. These are described below:

ISE (Integral of Squared Error): It is an analytical approach that uses linear quadratic weights for tracking set point based on cumulative sum of error. It is calculated using Parseval's theorem. The expression for ISE is:

$$ISE = \int_0^\infty \{e(t)\}^2 \, .dt \qquad (1)$$

IAE (Integral of Absolute Error): It is a non-analytical form of error based on computing integral for a sum of areas below and above set point without adding any weights to track set point. The expression for IAE is:

$$IAE = \int_0^\infty |e(t)| \, . \, dt \qquad (2)$$

ITSE (Integral of time multiplied by Squared Error): This criterion is used to check long duration errors, where an additional factor of time is multiplied with fast settling time. The expression for ITSE is:

$$ITSE = \int_0^\infty t . \{e(t)\}^2 \, .dt \qquad (3)$$

ITAE (Integral of time multiplied by Absolute Error): This measure tunes system rapidly when compared to all other indices. It possesses various other features like easy applicability, optimal selectivity, and reliability. The least value of ITAE provides appropriate selectivity of the system performance. The expression for ITSE is:

$$ITAE = \int_0^\infty t . |e(t)| \, . \, dt \qquad (4)$$

The three MPPT systems *i.e.*, conventional (PID), intelligent (FLC) and hybrid controller (PD+I FLC) are developed and simulated for obtaining ISE, IAE, ITSE and ITAE for multivariable conditions. Different temperatures in the range of 0°C to 45°C with varying Gaussian irradiance function are considered for same. The MPPT system performance is analyzed by using the converter voltage output and academic indices obtained. The system with least errors and the converter output close to set point yields optimized results, and thus are preferred for utility-based applications.

Firstly, the calculation of academic errors is done in MPPT system using Proportional Integral and Derivative controller. PID evaluates past error using proportional tuning factor K_P, present error using integral factor K_I and future predictive error using derivative of obtained error K_D due to difference in output obtained from converter to the desired *i.e.*, 21.07 V.

The tuning gains of the conventional controller were experimented for different values of three gain control parameters (K_P, K_I and K_D). However, the most appropriate results were obtained for K_P (Proportional gain) = 0.1, K_I (Integral gain) = 0.05 and K_D

(Derivative gain) = 0.1 and the same values are used in MPPT set up as shown in Figure 1.

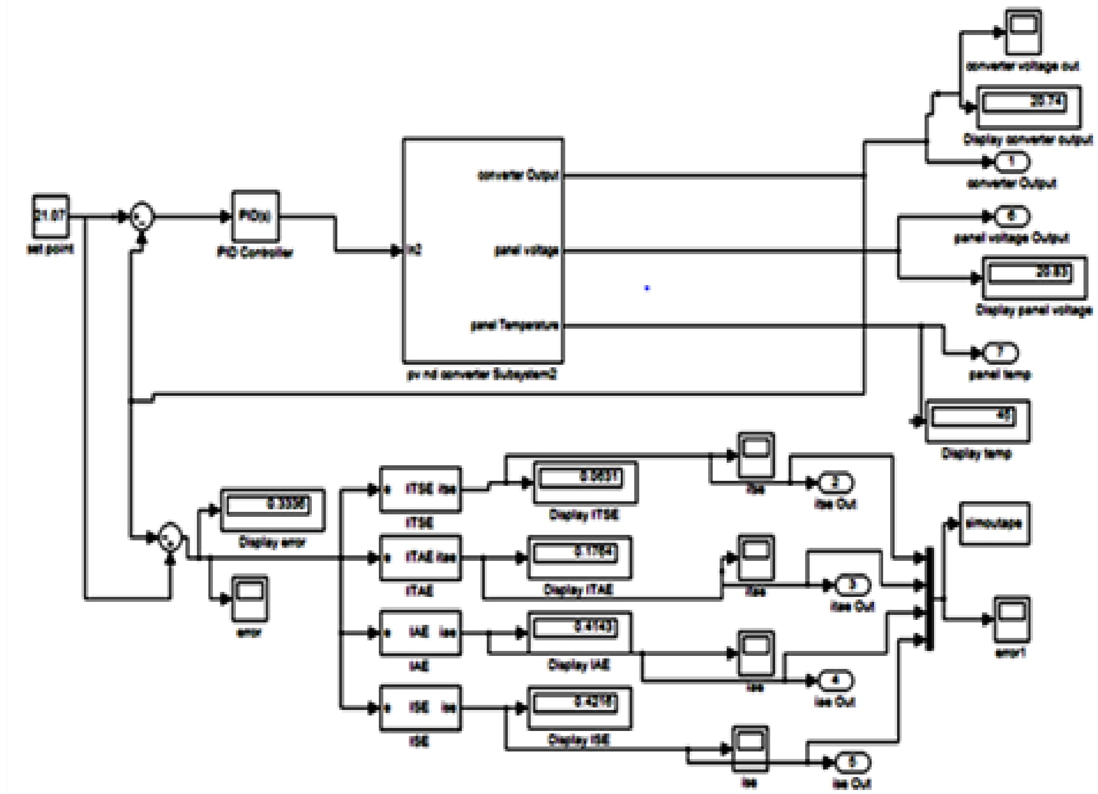

Figure 1. Block diagram of Implemented PID for error check

The output of PV and converter subsystem using PID appears 20.70 V. The developed MPPT on simulation for ISE, IAE, ITSE and ITAE delivers output responses as shown in Figure 2.

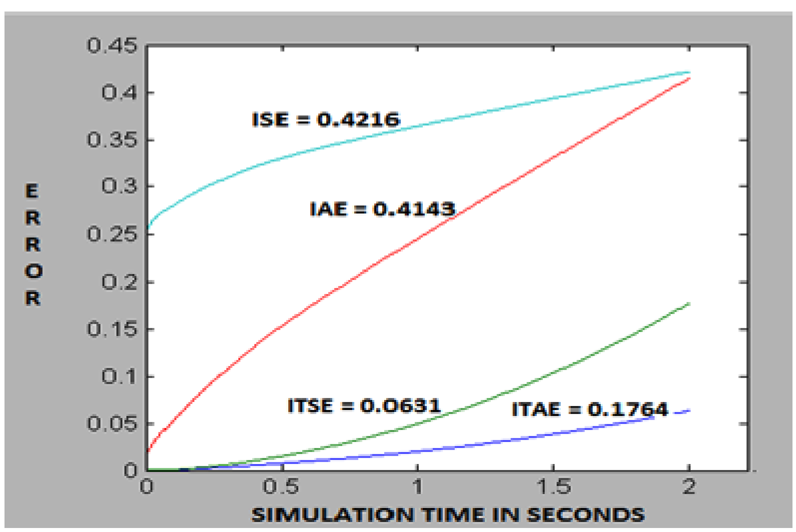

Figure 2. Simulated outputs using PID

Since the outputs and error indices are not appreciably good, simulation is then carried out using Fuzzy Logic controller. Fuzzy logic offers a promising solution to this conceptual design of MPPT through fuzzy modeling by removing the dependence of tuning using a set of rules that automatically monitors system closer to set point.

In this context, Mamdani type FLC using two inputs (error E (n) and change in error ΔE (n)) with one output (duty cycle of converter) is designed. The effect of interaction between the two input parameters (E (n) and ΔE (n)) with output parameter duty cycle (DC) is tested for various types of membership functions using three and five subsets. From observations, three Gaussian functions are chosen for which crossover point 0.5 is selected. The universe of discourse for the input variable E (n) is chosen to be [-0.01, +0.15] and ΔE (n) is taken as [-10, +10] while the output variable duty cycle is chosen to be as [-0.4, 0] to monitor MPP for developed MPPT model.

The nine rules corresponding to same are written in rule editor of the Fuzzy Inference System and are fired when the input is given to the controller. Based on these rules, the system works, and the implication method is applied. The generalization or outputs obtained after the implication method are aggregated and the defuzzification is done to find the crisp output.

The MPPT system designed using a Fuzzy Logic Controller is given in Figure 3.

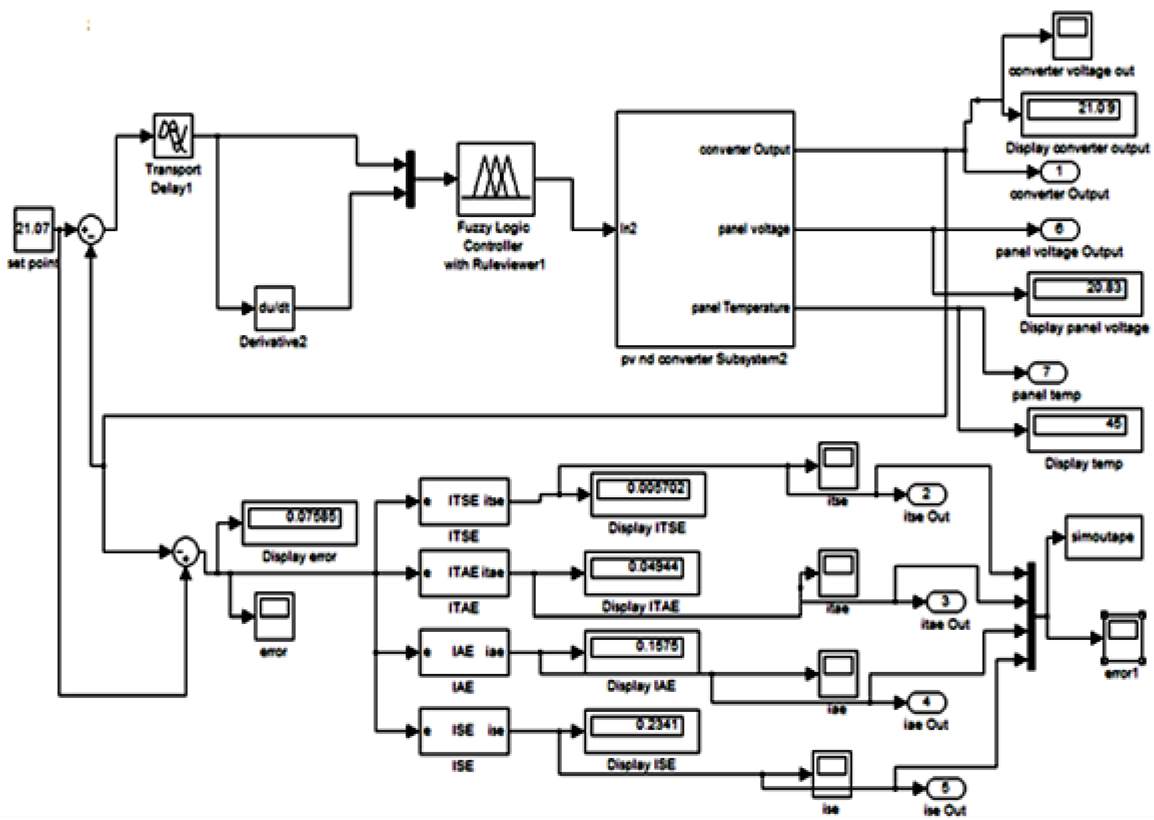

Figure 3. Block diagram of Implemented FLC for error check

The converter output obtained is improved and found to be 21.03 V at STC. The system results for academic indices simulation are shown in Figure 4.

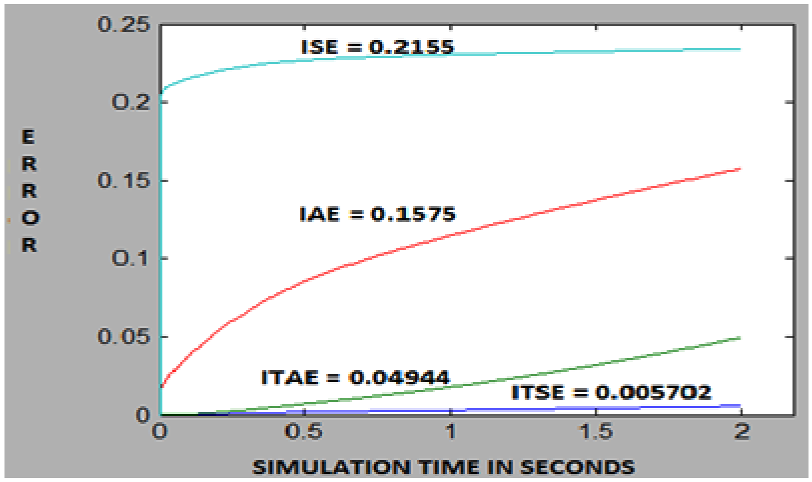

Figure 4. Simulated outputs using FLC

Despite the advantages and improved converter output with optimized indices of FLC over PID, there remain a number of drawbacks in its implementation. Fuzzy Controllers are characterized by a number of parameters such as input/output scales, center and width of membership function, selection of appropriate fuzzy control rules etc. The complexity of these parameters can be varied by simply developing a hybrid controller. The PID and FLC controllers are combined together and PD+I FLC MPPT system.

The MPPT system developed using hybrid fuzzy technique uses a Fuzzy logic controller with a rule viewer, two summing elements, two multiplexers, a differentiator, an input block, four gain elements representing the scaling gains (GU demoralization factor, GE proportional gain, GCE the derivative gain and GIE integral gain). The system developed is shown in Figure 5.

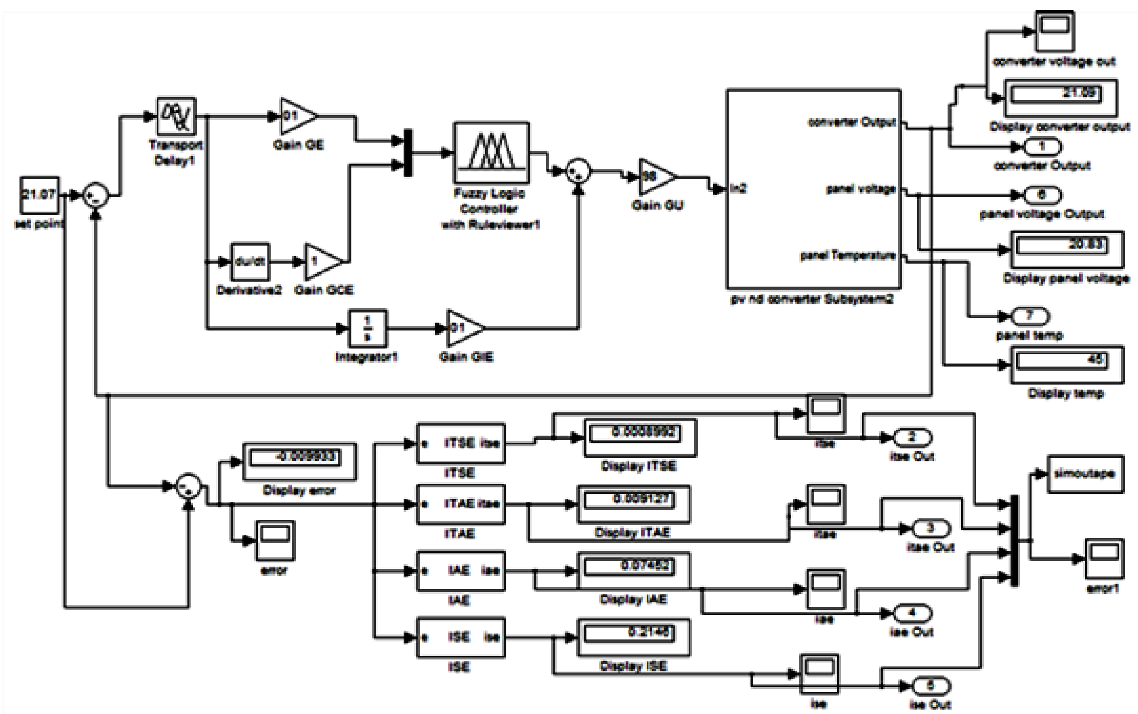

Figure 5. Block diagram of Implemented PD+I FLC for error check

The system is tuned for the optimum output with four scaling gains, which are achieved with GE = 0.1, GCE = 1, GIE = 0.01, GU = 1.5. The converter output obtained from hybrid controller is 21.04 V that was the closest to set point (21.07 V) as compared to PID (20.70V) and FLC (21.03V). The academic performance indices obtained by simulating the system is shown in Figure 6.

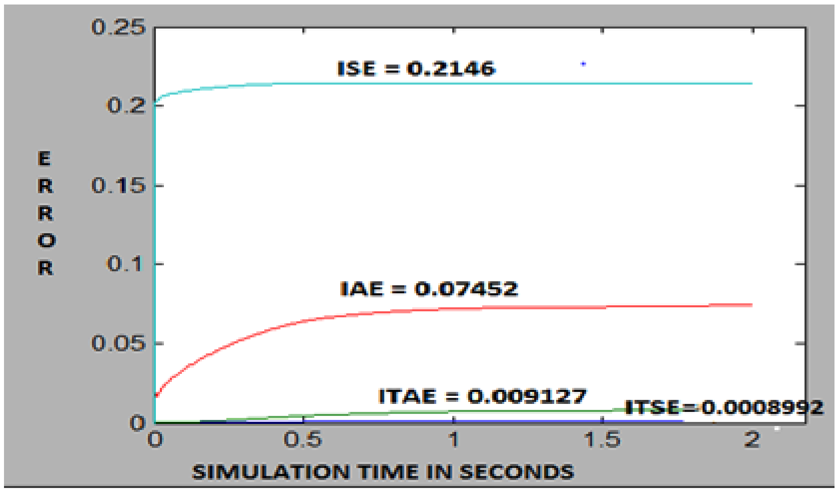

Figure 6. Simulated outputs using PD+I FLC

Comparison of Three MPPT Systems

A comparison is framed for academic performance indices calculated for three MPPT designed and simulated models. This is shown below in Tables 1 to 4 with graph outputs Figures 7 to 10. Firstly, the comparison is made for Integral of time multiplied by square error (ITSE). Table 1 shows observations for same followed by graphs in Figure 7.

Table 1. Observation for ITSE

T °C	PID	FLC	PD+I FLC
5	0.0003	0.000006	0.0000132
10	0.0007	0.000142	0.0000525
15	0.0015	0.000328	0.0001056
20	0.0032	0.000724	0.0002569
25	**0.0133**	**0.001610**	**0.0004247**
30	0.0163	0.002259	0.0005944
35	0.0254	0.003257	0.0006172
40	0.0356	0.004897	0.0007985
45	0.0631	0.005702	0.0008992

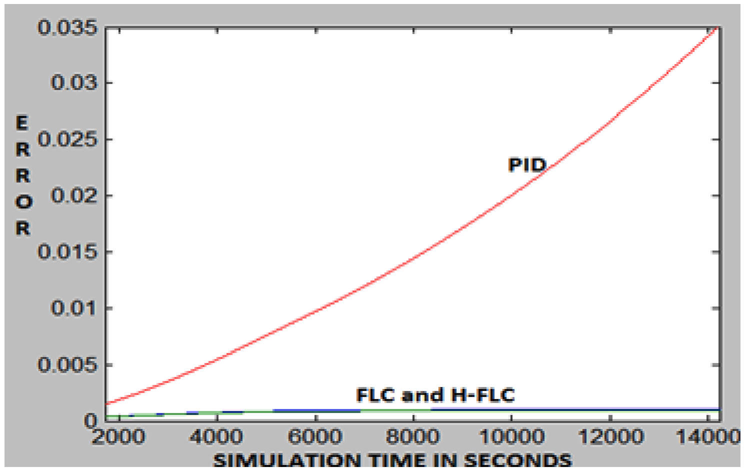

Figure 7. Graphical comparison of MPPT Systems for ITSE

It is observed that ITSE appears the minimum for the hybrid system when compared to intelligent and conventional systems. At the STC temperature of 25 °C, the respective values of errors appear 0.0133 (PID), 0.001610 (FLC) and 0.0004247(PD+I FLC) and on process completion appear 0.0631(PID), 0.005702(FLC) and 0.0008992(PD+I FLC). This proves the least error in PD+I FLC based MPPT system. Next, the comparison is made for Integral of time multiplied by absolute error (ITAE). Table 2 and Figure 8 show the same.

Table 2. Observation for ITAE

T °C	PID	FLC	PD+I FLC
5	0.0001	0.00000	0.000000
10	0.0009	0.00004	0.000047
15	0.0018	0.00009	0.000098
20	0.0042	0.00024	0.000135
25	**0.0168**	**0.00097**	**0.000478**
30	0.0345	0.00465	0.000956
35	0.0987	0.00947	0.001180
40	0.1452	0.02535	0.004765
45	0.1764	0.04944	0.009127

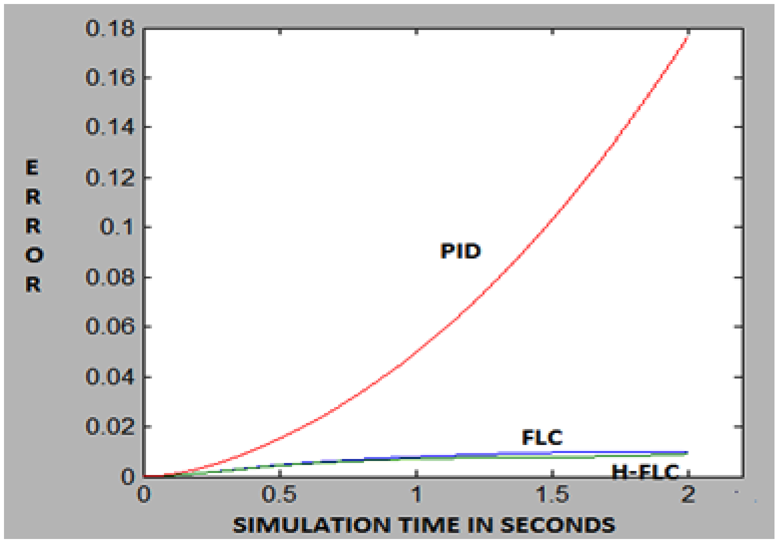

Figure 8. Graphical comparison of MPPT Systems for ITAE

From the results, it can be seen that ITAE appears the minimum for the hybrid system when compared to an intelligent and conventional system. At the STC temperature-25°C, the respective values of errors appear 0.0168 (PID), 0.00097(FLC) and 0.000478 (PD+I FLC) and on process completion appear 0.176 (PID), 0.04944 (FLC) and 0.009127 (PD+I FLC). This proves the least error in PD+I FLC-based MPPT system. Next, observations for Integral of absolute error (IAE) are carried out. This is shown in Table 3 followed by graphical outputs in Figure 9.

Table 3. Observation for IAE

T °C	PID	FLC	PD+I FLC
5	0.0041	0.0015	0.00030
10	0.0097	0.0021	0.00051
15	0.0214	0.0047	0.00097
20	0.0643	0.0078	0.00174
25	**0.0987**	**0.0089**	**0.00389**
30	0.1146	0.0587	0.00887
35	0.2156	0.0877	0.01421
40	0.3289	0.1214	0.04778
45	0.4143	0.1575	0.07452

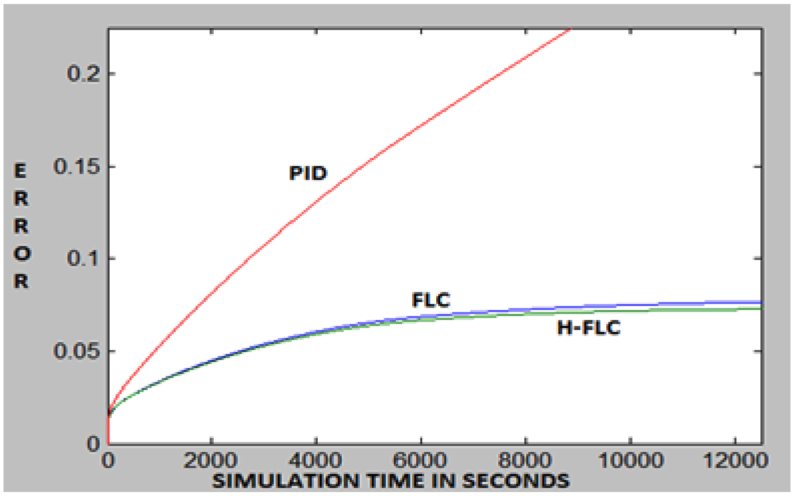

Figure 9. Graphical comparison of MPPT Systems for IAE

It is clear from above that, IAE appears to be the least for the hybrid system when compared to an intelligent and conventional system. At STC temperature 25 °C, the respective values of errors appear 0.0987 (PID), 0.0089 (FLC) and 0.00389 (PD+I FLC) and on process completion appear 0.4143 (PID), 0.1575(FLC) and 0.07452 (PD+I FLC). This proves the least error is obtained in PD+I FLC-based MPPT system. Now, test results are compared for Integral of Squared Error (ISE), observation for same is shown in Table 4 followed by Figure 10.

Table 4. Observations for ISE

T °C	PID	FLC	PD+I FLC
5	0.2092	0.2007	0.2000
10	0.2131	0.2011	0.2009
15	0.3255	0.2017	0.2012
20	0.3487	0.2048	0.2037
25	0.3941	0.2098	0.2089
30	0.4003	0.2106	0.2101
35	0.4161	0.2115	0.2108
40	0.4198	0.2138	0.2125
45	0.4216	0.2155	0.2146

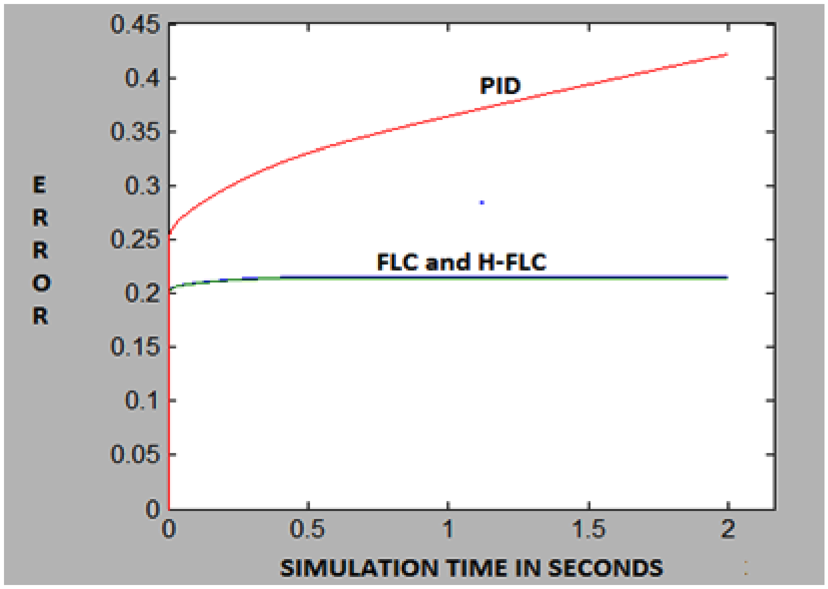

Figure 10. Graphical comparison of MPPT Systems for ISE

For ISE also, it is found that value appears the minimum for the hybrid system when compared to an intelligent and conventional system. At the STC temperature of 25 °C, the respective values of errors appear 0.3941 (PID), 0.2098 (FLC) and 0.2089 (PD+I FLC) and on process completion appear 0.4216 (PID), 0.2155 (FLC) and 0.2146 (PD+I FLC). This proves the least error in PD+I FLC based MPPT system.

Thus, it is clear from observations (Tables 1 to 4) and graphical displays (Fig. 7 to 10) that the PID controlled system gives very large errors in comparison to FLC and hybrid FLC controlled system. The academic indices are optimized appropriately in hybrid MPPT system when compared to intelligent MPPT system. Also, the converter output is the closest to set point and achieved throughout simulation in comparison to other two systems. This is shown in Figure 11.

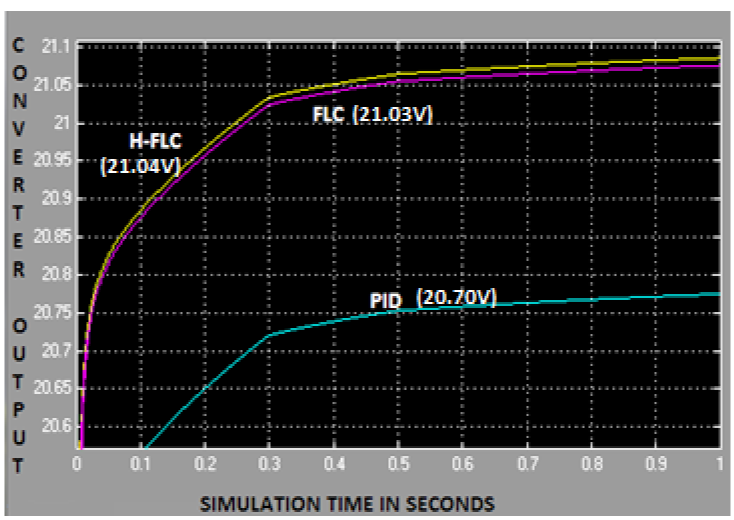

Figure 11. Converter outputs for PID, FLC, and Hybrid FLC designed MPPT Systems

CONCLUSIONS

The three MPPT systems developed are tested for Academic Performance Indices and its optimization. The converter outputs corresponding to three different controllers are obtained and optimized with the most appropriate results in the hybrid MPPT. It is found that by using suitable values of scaling gains the PD+I FLC system generates the most convenient outputs. It is clear from observations that the academic indices were least calculated for PD+I FLC system and the MPPT output obtained is very close to desired set point. The developed MPPT system can be further used for different application-based systems. The results obtained can serve as an advantage for future scholars and researchers working on MPPT systems.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

REFERENCES

[1] Chandani Sharma, Anamika Jain, "Solar Panel Mathematical Modelling using Simulink" International Journal of Engineering Research and Applications, vol. 4, no. 5, pp 67-72, May 2014.
[2] Chandani Sharma, Anamika Jain, "Simulink based Multivariable Solar Panel Modelling" Telkominika Indonesian Journal of Electrical Engineering, vol. 12, no. 8, pp 5784-5792, August 2014.
[3] Chandani Sharma, Anamika Jain, "Maximum Power Point Tracking Techniques-A Review" International Journal of Recent Research in Electrical and Electronics Engineering, vol. 1, no. 1, pp. 25-33, June 2014.
[4] Chandani Sharma, Anamika Jain, "Performance Comparison of PID and Fuzzy Controllers in Distributed MPPT" International Journal of Power Electronics and Drive Systems, vol. 6, no. 3, pp. 625-635, September 2015.
[5] Chandani Sharma, Anamika Jain, "Modeling of Buck Converter Models in MPPT using PID and FLC", TELKOMNIKA (Telecommunication Computing Electronics and Control), vol. 13, no. 4, pp. 1270-1280, December 2015.
[6] Chandani Sharma, Anamika Jain, "Academic Performance Indices: Error Calculation in Distributed MPP Tracking using PID and FLC" Journal of Graphic Era University, vol. 4, no. 1, pp. 1-16, August 2016.
[7] B. Subudhi, R. Pradhan, "Characteristics evaluation and parameter extraction of a solar array based on experimental analysis," in Proceedings of 9th IEEE Power

Electronics and Drives Systems, Singapore, December 5–8, 2011. DOI: 10.1109/PEDS.2011.6147269

[8] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi, “MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell”, International Journal of Renewable Energy Research, vol. 2, no. 2, pp. 213-218, 2012.

[9] J. Jantzen, “Tuning of Fuzzy PID Controllers”, Tech. report no 98-H 871 (fpid), Technical University of Denmark, Department of Automation, 30 Sep 1998. https://pdfs.semanticscholar.org/7d0e/da80a8b206d4d29fe6df65597c8078a110b2.pdf (accessed on 4/26/2018)

[10] S. Z. He, S. Tan and F. L. Xu, “Fuzzy self-tuning of PID controllers”, Fuzzy Sets and Systems, vol. 56, pp. 37-46, 1993.

[11] J. Surya Kumari, C. Saibabu, “Maximum Power Point Tracking Algorithms for Grid Connected Photovoltaic Energy Conversion System”, International Journal of Power Electronics and Drive System, vol. 3, no. 4, pp. 424-437, December 2014.

[12] B. Subudhi, R. Pradhana, “A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems” IEEE Transactions on Sustainable Energy, vol. 4, no. 1, pp. 89 – 98, January 2013.

[13] M. S. Ait Cheikh, C. Larbes, G. F. Tchoketch Kebir, A. Zerguerras “Maximum power point tracking using a fuzzy logic control scheme”, Revue des Energies Renouvelables, vol. 10 no. 3, pp. 387 – 395, 2007.

[14] C. A. R. Paja, G. Spagnuolo, G. Petrone, M. Vitelli, J. D. Bastidas, “A multivariable MPPT algorithm for granular control of PV systems,” in Proc. IEEE Int. Symp. Ind. Electron., pp. 3433–3437, 2010.

[15] Rosa A. Mastromauro, Marco Liserre, Antonio Dell Aquila, “Control Issues in Single-Stage Photovoltaic Systems MPPT, Current and Voltage Control” IEEE Transactions on Industrial Informatics, vol. 8, no. 2, pp. 241-254, May 2012.

[16] Huiying Zheng, Shuhui Li, Timothy A. Haskew, Yang Xiao, “Impact of uneven shading and bypass diodes on energy extraction characteristics of solar photovoltaic modules and arrays”, International Journal of Sustainable Energy, vol. 32, no. 5, pp. 351-365, October 2013.

[17] Tow Leong Tiang, Dahaman Ishak, “Modeling and simulation of deadbeat-based PI controller in a single-phase H-bridge inverter for stand-alone applications”, Turkish Journal of Electrical Engineering & Computer Sciences, vol. 22, pp. 43-56, January 2014.

[18] International Energy Agency, Technology Roadmap: Solar Photovoltaic Energy, 2014. https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf (accessed on 4/26/2018)

[19] D. Sera, L. Mathe, T. Kerekes, S.V. Spataru, R. Teodorescu, “On the Perturb-and-Observe and Incremental Conductance MPPT Methods for PV Systems” IEEE Journal of Photovoltaics, vol 3, no. 3, pp. 1070 – 1078, July 2013.

[20] Essam Natsheh, A. Khalid Buragga, “Comparison between Conventional and Fuzzy Logic PID Controllers for Controlling DC Motors”, International Journal of Computer Science Issues, vol. 7, no. 5, pp. 128-134, September 2010.

[21] P. Venugopal, A. Ganguly, P. Singh, “Design of Tuning Methods of PID Controller using Fuzzy Logic”, International Journal of Emerging trends in Engineering and Development, vol. 5, no. 3, pp. 239-248, September 2013.

[22] Reseeds, "Control System Optimisation: Criteria and Analytical Methods", 2003. http://www.reseeds.com/control%20system%20optimisation.pdf (accessed on 4/26/2018)