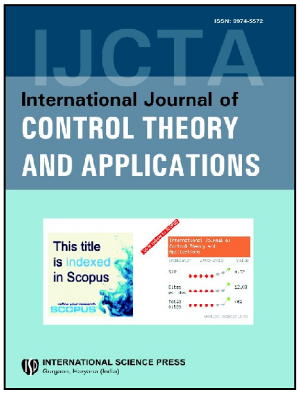


International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 9 • Number 49 • 2016

An Improvement of Static and Dynamic Performance Based on Adaptive Fuzzy Logic MPPT Control in PV Systems

J Surya Kumari*, Ch Sai Babu, D Lenine* and M Suresh Babu***

** Department of Electrical and Electronics Engineering, RGM College of Engg. & Tech., Nandyal, India*
*** Department of Electrical and Electronics Engineering, JNT University, Kakinada, India*

Abstract: In the photovoltaic (PV) system, the solar cell due to the non-linear characteristics and the effect of atmospheric conditions produces only 30-40% of energy from the available. Thus, PV systems require maximum power point tracking (MPPT) techniques to extract the maximum power from the available. In this paper, an adaptive fuzzy logic (AFL) MPPT algorithm is proposed to improve the static and dynamic performance of the PV system. The conventional perturb and observation (P&O) MPPT algorithm is replaced by the adaptive perturb and observe (AP&O) and fuzzy logic MPPT algorithm to produce the duty cycle to the boost converter used in PV system for tracking of maximum power. The AFL MPPT algorithm gives better performance of the PV system and proves its accuracy under variation of load and environmental conditions. These techniques are simulated and the results are verified and compared through MATLAB/Simulink.

Key Words: Model of Photovoltaic, DC-DC Boost converter, MPPT Controller, Adaptive perturbs and observe Fuzzy logic controller.

1. INTRODUCTION

The increasing prices and the limited stock of non-renewable sources like coal and other fossil fuels made the renewable energy sources as the alternative for the generation of electricity. Due to the growing demand on electricity the photovoltaic energy, as it is freely available, reduced size, less operational and maintenance costs became the promising alternative for the generation of electrical energy for both standalone and grid connected modes of PV system. In the PV system, the solar cell with its non-linear characteristics and due to the effect of atmospheric conditions like irradiance and temperature has the poor tracking efficiency. The I-V curve and P-V curve of PV system give the unique MPP at particular operating voltage and current. To obtain the maximum tracking efficiency, the PV system must be operated at maximum power point (MPP) which can be achieved by maximum power point tracking (MPPT) techniques. There are various MPPT techniques [1], which are used for tracking the maximum power from the PV system such as curve fitting, perturb and observation (P&O), incremental conductance, fractional open circuit voltage, fractional short circuit current etc,. The adaptive P&O MPPT technique [6-10] is widely used to track the maximum power point in the PV system because of its simplicity and ease of implementation. But this technique has the drawbacks such as the operating point oscillates around the

MPP and more ripples are present in the output power. Hence, to improve the static and dynamic characteristics of the PV system and to overcome the drawback of AP&O MPPT algorithm, the adaptive fuzzy logic MPPT algorithm [16-22] is proposed in the PV system.

II. MATHEMATICALMODEL OF PVCELL

A solar cell is basically a p-n junction fabricated in a thin layer of semiconductor. The PV cell converts electromagnetic radiation of solar energy into electricity by using photovoltaic effect. The single diode equivalent circuit of the PV cell is most commonly used for MPPT technologies.

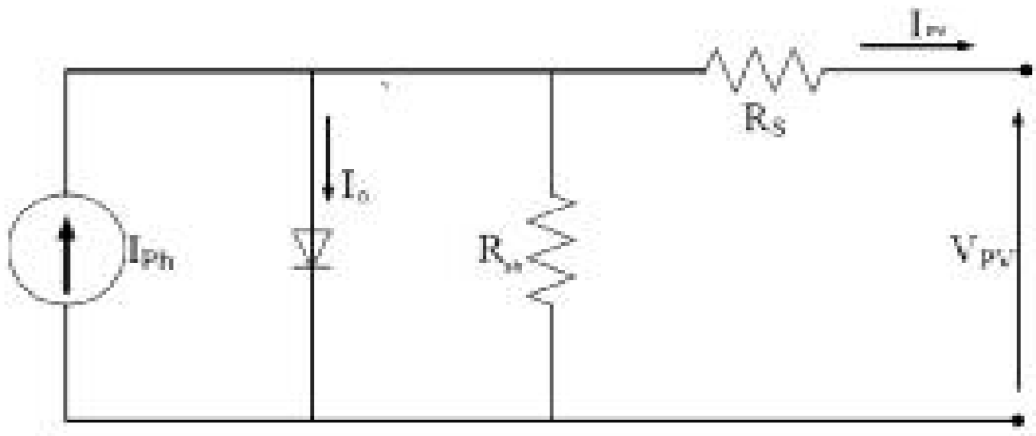


Figure 1: PV cell modeled as single-diode circuit

Here the current source I_{ph} represents the cell photocurrent. R_{sh} and Rs are the intrinsic shunt and series resistances of the cell, respectively. To simplify the analysis R_{sh} and Rs may be neglected as the value of R_{sh} is very large and that of Rs is very small. PV cells are connected in larger units called PV module which are further interconnected in a parallel-series configuration to form PV arrays. The specification of PV cell module is shown in table 1. The mathematical model of the photovoltaic cell [2-5], is given by equations (1)-(4). Photo-current of module is given by in (1),

$$I_{ph} = (I_{SCr} + K_i\,(T - 298)) \times \lambda / 1000 \tag{1}$$

Reverse saturation current of module;

$$I_{rs} = I_{SCr} /[\exp(qV_{oc} / N_s kAT) - 1] \tag{2}$$

Saturation current of module:

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q * E_{go}}{Bk}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{3}$$

The output current of PV module,

$$I_{PV} = N_P * I_{ph} - N_p * I_o\left[\exp\left(\frac{q * (V_{pv} + I_{pv}R_s)}{N_s AkT}\right) - 1\right] \tag{4}$$

Where,

$$V_{pv} = V_{oc}; N_p = 1 \text{ and } N_s = 36$$

Table 1
Parameters of PV Module at Standard Conditions

Specification Parameters	*Rating*	*Units*
Rated Power	100	Watts
Voltage at Maximum Power (V_{MP})	18.6	Volts
Current at Maximum Power (I_{MP})	5.4	Amps
Open Circuit Voltage (V_{oc})	21.6	Volts
Short Circuit Current (I_{sc})	6.43	Amps

III. MPPT TECHNIQUES

(A) Adaptive P&O MPPT Technique

Maximum power point tracker (MPPT), despite its drawback of low efficiency, is a technique to achieve delivery of power from array to the load. It is needed to improve the tracking efficiency. All the MPPT techniques [9-14], heather to discuss till now may not work well due to environmental condition, sudden change of reference voltage/ current threshold and load. The proposed AP&O MPPT method surpasses these drawbacks by quick reaction to this operating point. The effectiveness of proposed algorithm in terms of steady-state performance and improved tracking efficiency are discussed in this section. The flowchart for the proposed algorithm is shown in Fig. 3.

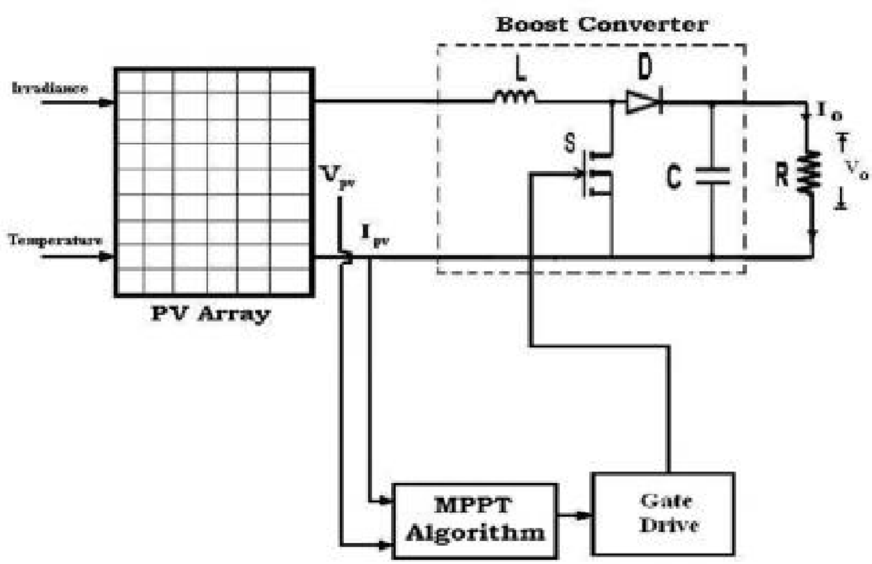


Figure 2: Block diagram of PV system with MPPT

The output power of the PV array depends upon the solar irradiance and cell temperature. The output power of PV module is given to the load through the DC-DC boost converter. The PV output voltage and current is given to AP&O MPPT controller as an input. The AP&O MPPT controller generates duty cycle based on the fixed step-size perturb. In this method, the duty cycle is varied accordingly to perturbation voltage and operating point oscillates around the MPPs. By changing duty cycle, it can match the characteristic impedance of the PV array to the load impedance. Therefore, it quickly transfers the maximum power to the load. The block diagram of the PV system with MPPT technique is shown in the Fig. 2. In this technique observing the effectiveness of PV system with a small perturbation is considered in the PV current and duty cycle given in Eq. (5) & (6),

$$\Delta I = I(K) - I\,(K - 1) \tag{5}$$

$$\Delta D = D(K) - D(K - 1) \tag{6}$$

$$I(K) = I(K - 1) + \Delta I \tag{7}$$

$$D(K) = D\,(K - 1) + \Delta D \tag{8}$$

If the instant current *I(k)* is greater than previous computed current *I(k-1),* then the direction of the perturbation is maintained otherwise it is reversed. The modified equations from Eq. (5) & (6), are written in Eq. (7) & (8). The maximum power is obtained when the ratio of power and duty cycle is equal to zero given in Eq. (9).

$$\Delta P / \Delta D = 0$$

The output of the boost converter is $V_o = \dfrac{V_{mp}}{(1 - D)}$, therefore

$$V_{mp}\,(k) = V_0\,(1 - D(k)) \tag{9}$$

The PV voltage is varied with the variations in duty cycle, and then the power of PV system is calculated from the Eq. (7) and (10). Therefore, the PV output power is given by Eq. (11).

$$P(k) = V(k) * I(k) \tag{10}$$

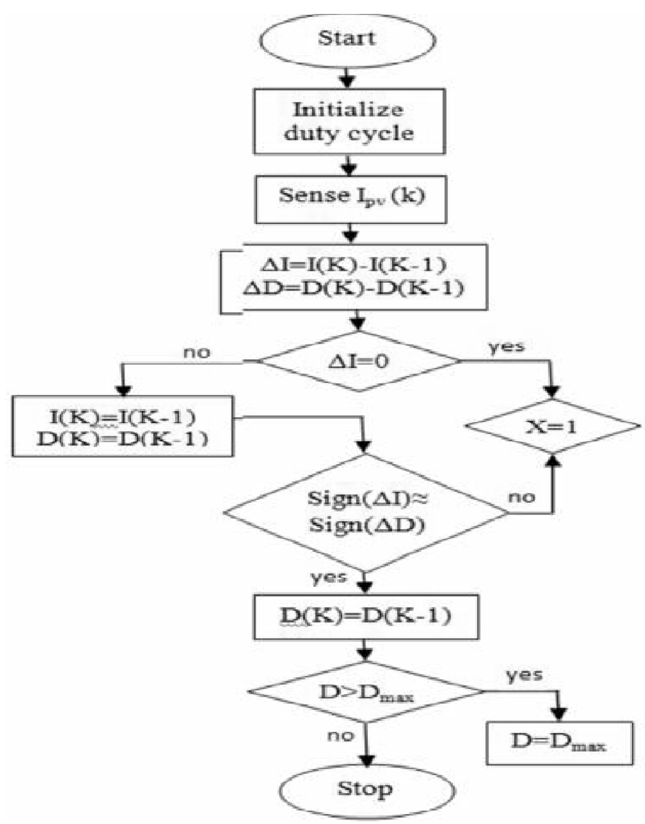


Figure 3: Flowchart for AP&O MPPT

(B) Adaptive Fuzzy Logic MPPT Technique

In the recent years the fuzzy logic controllers plays the promising role in tracking of the MPP in PV systems. Fuzzy logic controllers do not require the knowledge of the exact model and have the advantage to be robust and relatively simple to design. On the other hand, they require the complete knowledge of the operation of the PV system by the designer. The general block diagram of the fuzzy logic controller is shown in Fig. 4.

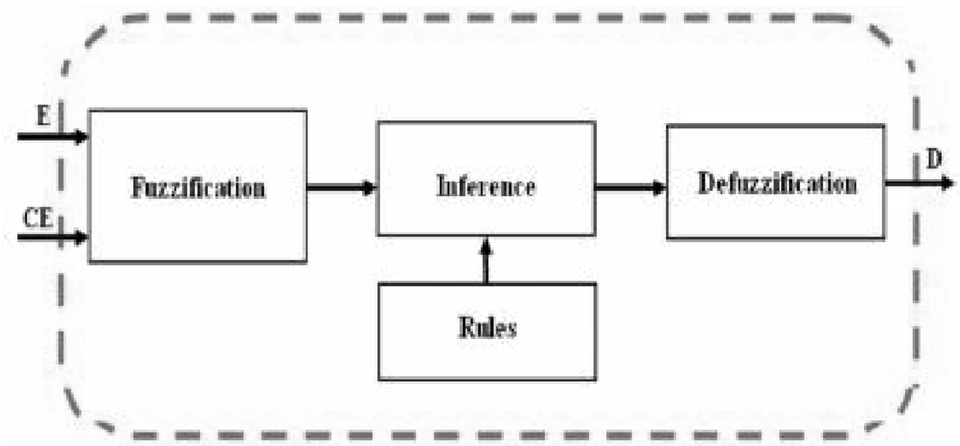


Figure 4: General Block diagram of fuzzy logic controller

In the fuzzification process, the crisp inputs are converted into the linguistic variables or fuzzy inputs. The proposed MPPT algorithm has two inputs and single output. The two fuzzy inputs are the error (E) and change of error (CE) at sampled times k, given in Eq (12) and (13). Where Pph*(k)* and *Vph(k)* are the power and voltage of the PV array, respectively. E (k) shows if the load operating point at the instant k is located on the left or on the right of the maximum power point on the P-V characteristic where it is equals to zero at MPP, while the change of error CE (k) expresses the moving direction of this point. The simulation block of fuzzy logic controller is shown in Fig. 5. The fuzzy input variables are expressed in terms of linguistic variables such as PB (positive big), PS (positive small), Z (zero), NS (negative small), NB (negative big) using basic fuzzy subset for input and output variable shown in Fig. 6.

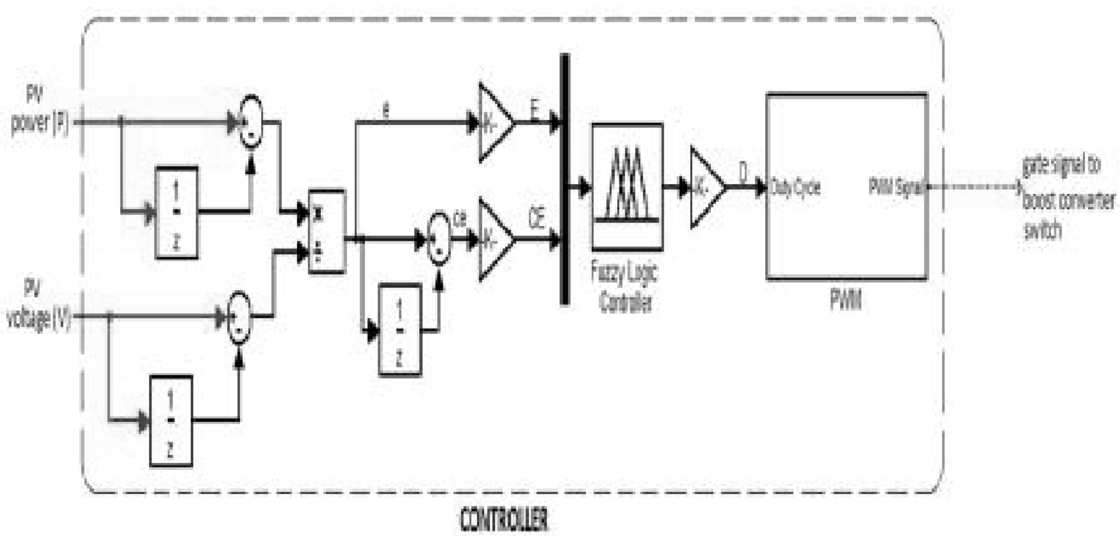


Figure 5: Simulation Block of Fuzzy logic Controller

Table 2
Fuzzy Rule Table

E \ *CE*	*NB*	*NS*	*Z*	*PS*	*PB*
NB	Z	Z	PB	PB	PB
NS	Z	Z	PS	PS	PS
Z	PS	Z	Z	Z	NS
PS	NS	NS	NS	Z	Z
PB	NB	NB	NB	Z	Z

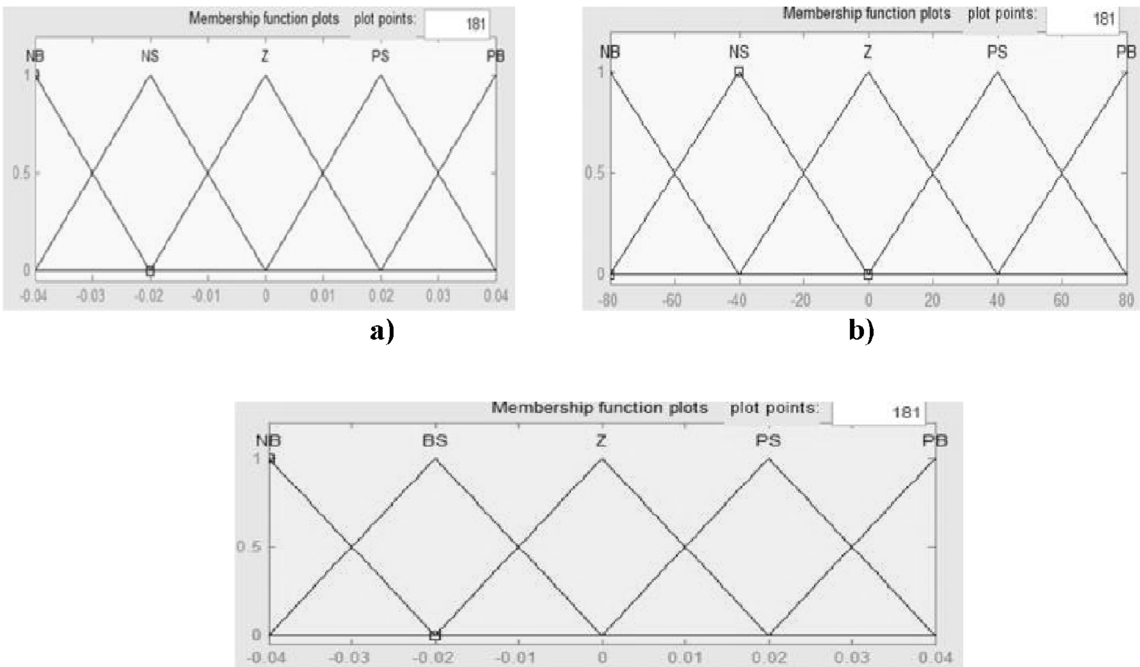
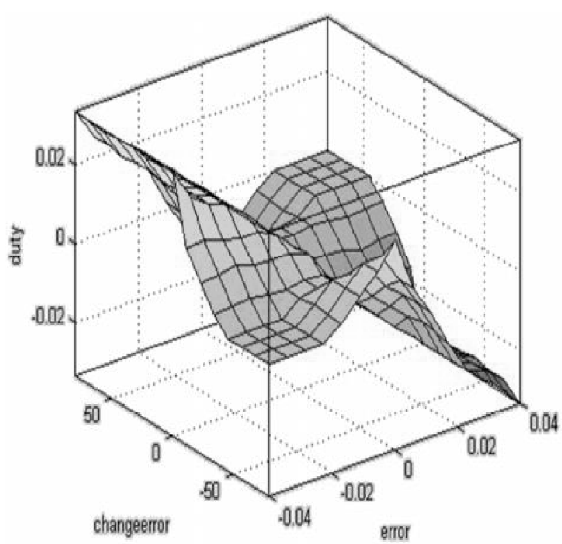


Figure 6: Membership functions of (a) Error (b) Changing Error (c) Duty Cycle



In inference process, the control rules must be designed in order that input variable (E) has to always be zero. This process is carried out by using Mamdani's method with maxmin composition. The fuzzy rule table is shown in Table 2. The fuzzy surface viewer for the designed rules is shown in Fig.7. In the defuzzification process, the fuzzy output or linguistic variable is converted into the crisp output duty cycle (D) which used for the tracking of the maximum power point by comparing with the sawtooth waveform to generate a PWM signal for the boost converter. The flowchart of AFL MPPT algorithm is shown in Fig. 8.

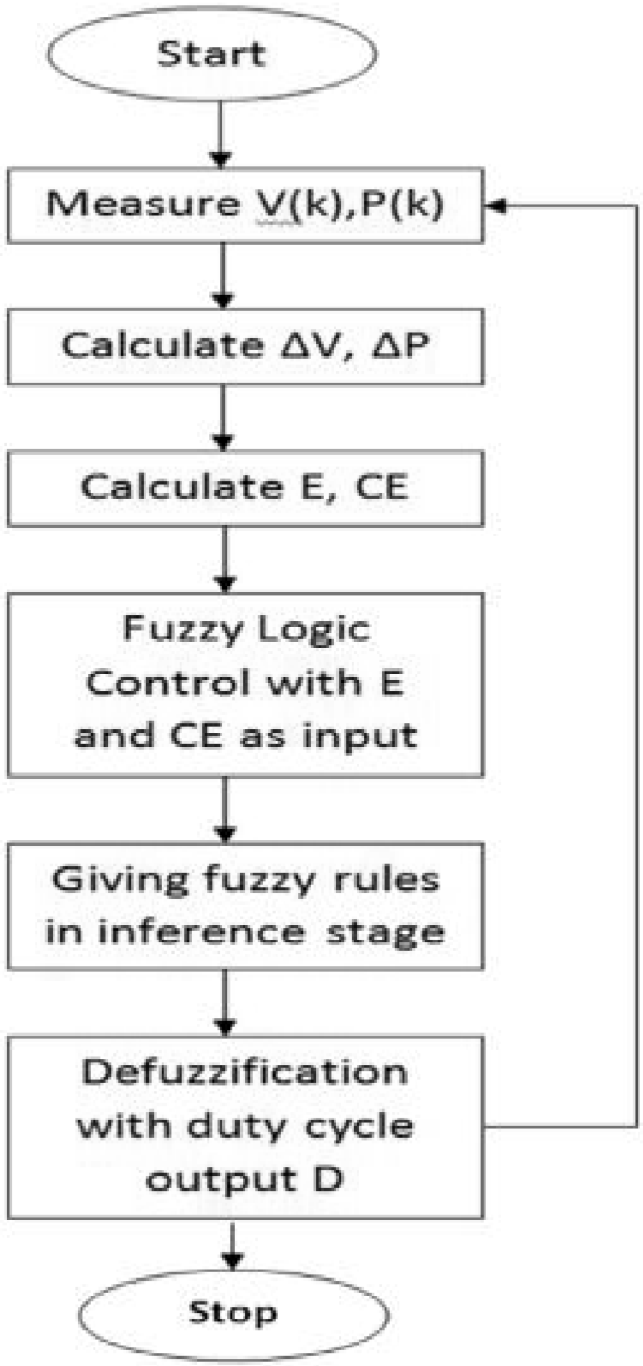


Figure 8: Flow chart for AFLC

IV. RESULTS ANDANALYSIS

The simulation of the photovoltaic module with the both adaptive P&O and adaptive fuzzy logic based-MPPT algorithms are carried out by using MATLAB/Simulink and the results for different irradiance and loads with both MPPT techniques are observed and the comparisons are given in this section. The characteristics of I-V and P-V curves of a PV module with different irradiance levels at constant temperature (25^0C) are shown in Fig.9 and Fig.10. From fig 10, it is observed that when irradiance is increased the corresponding PV power is increased. From Fig.11-Fig13, the comparison of PV output power, voltage and current for both MPPT techniques at standard conditions i.e. at irradiance (1000W/m2) and temperature (250C) are given. In Fig 14, the output power

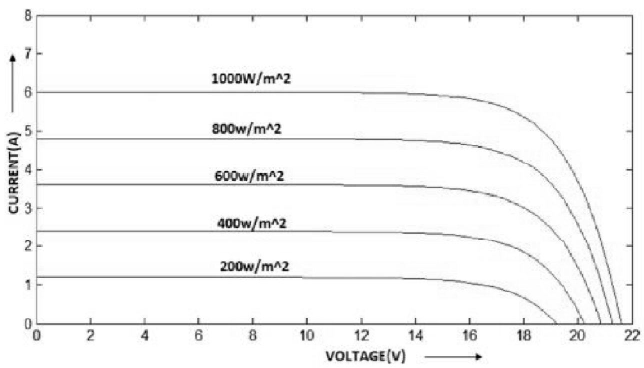


Figure 9: I-V curves for different irradiance

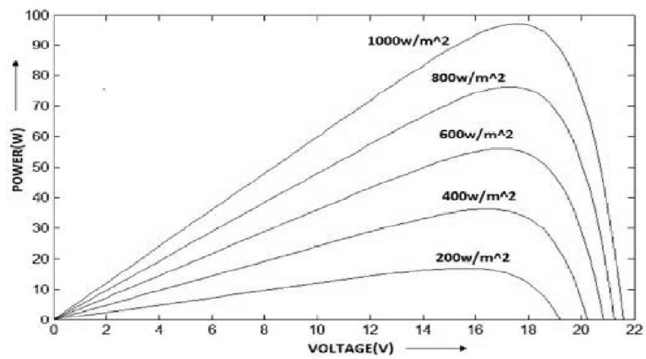


Figure 10: P-V curves for different irradiance

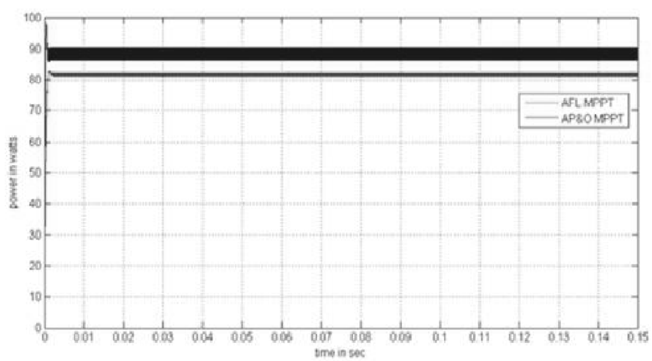


Figure 11: PV output power at standard conditions

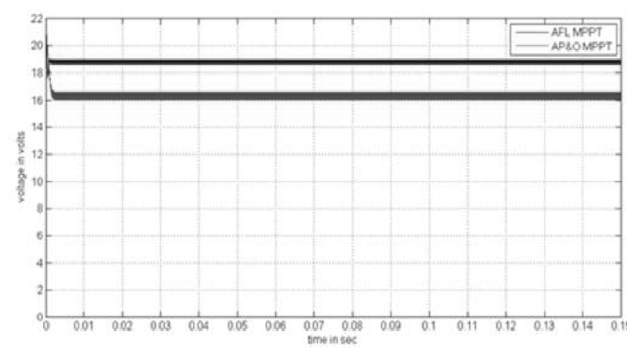


Figure 12: PV output voltage at standard conditions

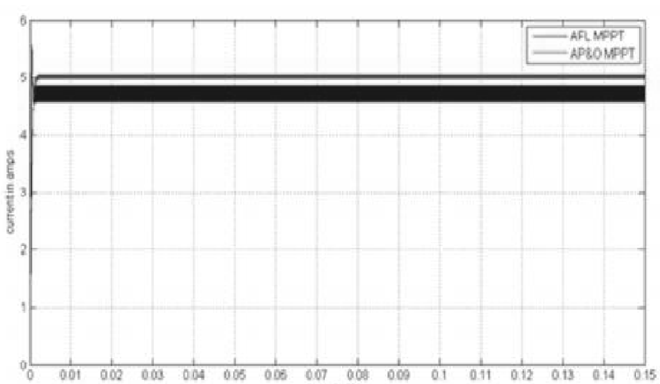


Figure 13: PV output current at standard conditions

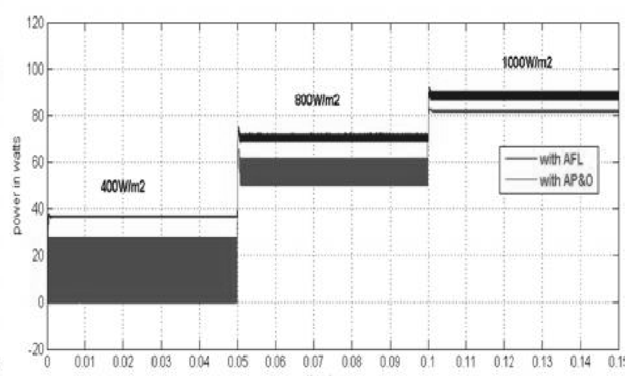


Figure 14: PV output power for sudden change of irradiance at constant temp (25 °C) and load

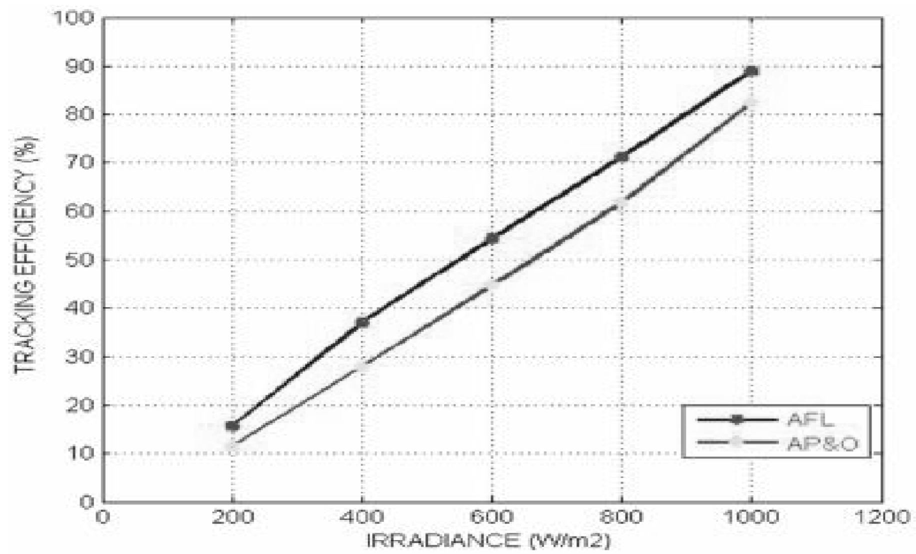


Figure 15: Analytical evaluation of Tracking Efficiency (%) at Different Irradiances

of PV array with sudden change of irradiance level is shown and it can be observed that at low irradiance, the oscillations in the PV output power of PV module with AFL based MPPT is reduced whereas, in AP&O MPPT technique the oscillations in the PV output power is increased.

Table 3
Evaluation PV Output Voltage, Current and Power with Different Irradiance at Constant Temperature is (25°C)

Irradiance (W/m^2)	PV Syatem with Different MPPT Control Technique					
	Adaptive Perturb and Observe			Adaptive Fuzzy Logic Controller		
	V_{mp}(volts)	I_{mp}(amps)	P_{mp}(watts)	V_{mp}(volts)	I_{mp}(amps)	P_{mp}(watts)
1000	16.63	5.08	82.4	18.64	4.84	89
800	14.89	4.23	61.69	18.5	3.8	71.2
600	14.26	3.17	44.6	18.13	3.01	54.4
400	13.35	2.15	27.9	17.4	2.15	37.01
200	11.2	1.08	11.5	12.32	1.27	15.63

It is verified that the proposed AFL MPPT algorithm of PV system strategy works well for low/medium/ high irradiance range. Fig.15 shows the analytical evaluation of tracking efficiency (%) at different irradiance ratings. Evaluation of PV output voltage, current and power with different irradiance at constant temperature (25oC) is shown in Table 3.

The PV module with AFL based MPPT gives significant improvement of tracking efficiency (%) for higher loads compared to AP&O MPPT technique due to the effective tuning of the error to almost zero. The analytical evaluation of tracking efficiency (%) at different load values is shown in Fig.16. Evaluation of PV output voltage, current and power with different loads at standard temperature conditions is shown in table 4.

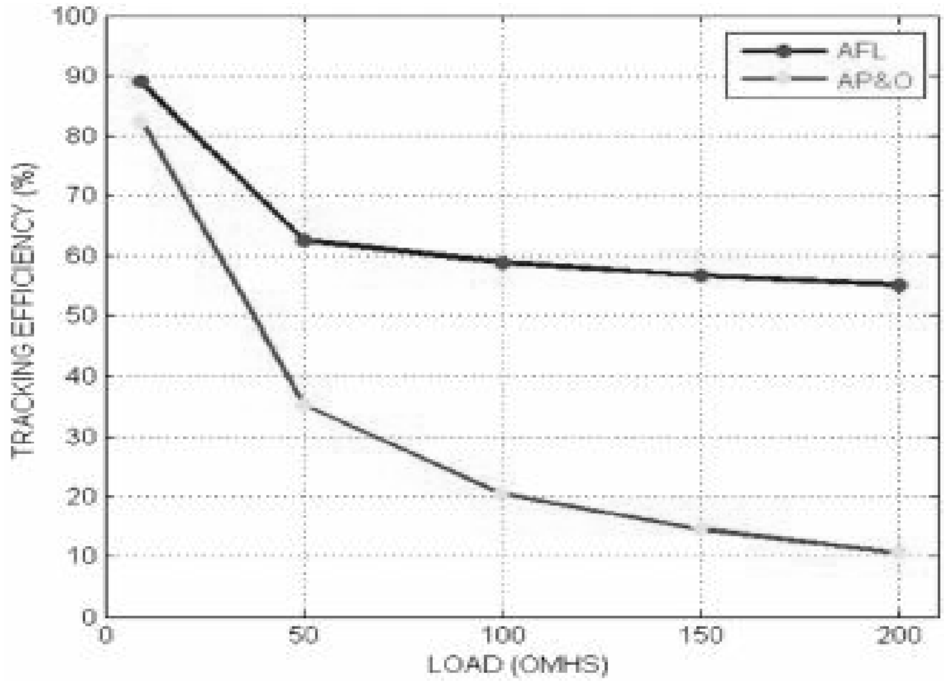


Figure 16. Analytical evaluation of Tracking Efficiency (%) at Different Load

Table 4
Evaluation PV Output Voltage, Current and Power with Different Loads at Standard Conditions

Load(Ω)	*PV System with Different MPPT Control Technique*					
	Adaptive Perturb and Observe			*Adaptive Fuzzy Logic Controller*		
	V_{MP}*(volts)*	I_{MP}*(amps)*	P_{MP}*(watts)*	V_{MP}*(volts)*	I_{MP}*(amps)*	P_{MP}*(watts)*
9	16.63	5.08	82.4	18.64	4.84	89
16	19.73	3.1	61.2	19.1	4.37	83.6
35	20.33	2.3	46.99	19.8	3.35	66.8
50	20.71	1.7	35.26	20.1	3.2	62.5
75	20.93	1.33	27.86	20.15	2.98	60.15
100	21.1	0.96	20.34	20.2	2.84	58.8
125	21.21	0.8	16.98	20.24	2.78	57.6
150	21.27	0.7	14.5	20.27	2.75	56.6
175	21.32	0.58	12.5	20.28	2.72	55.8
200	21.36	0.49	10.6	20.3	2.69	55.1

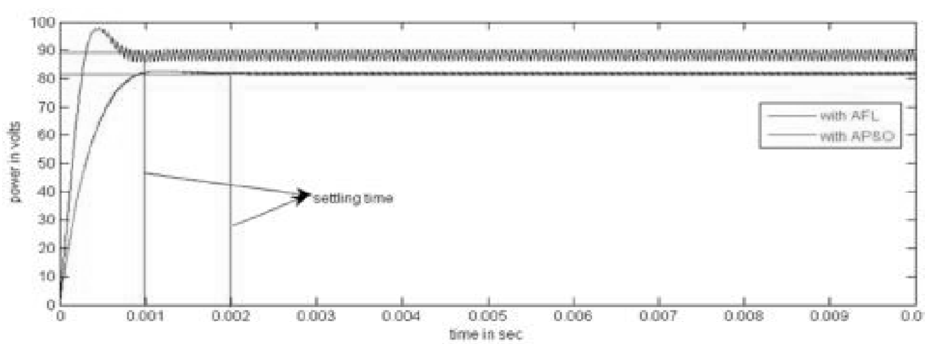


Figure 17: Dynamic response of PV output Power

Table 5
Evaluation of Dynamic response of PV system at Standard Conditions

MPPT Techniques	*Dynamic Response*	
	Settling Time (Sec)	*Power Peak Overshoot (watts)*
Adaptive Perturb and Observe	0.002	2.6
Adaptive Fuzzy Logic Controller	0.001	9

The dynamic response of the PV module with both MPPT techniques at standard conditions is shown in Fig. 17. It can be observed that the settling time for the PV module is reduced in AFL based MPPT than the AP&O MPPT technique shown in table 5. With the decrease in irradiance, the power peak overshoot is minimum in AFL based MPPT and maximum in AP&O MPPT technique.

V. CONCLUSION

In this paper, an adaptive fuzzy logic based MPPT algorithm for a solar PV system has been presented. The operation of AFL based MPPT algorithm is investigated for different irradiance and load conditions. The AFL based MPPT technique effectively extracts maximum available power from solar PV module and the response is extremely fast with good dynamics. The tracking efficiency, speed and accuracy of PV module with AFL based MPPT is significantly higher than that of the conventional AP&O MPPT under different irradiance and load conditions. Therefore, the simulation results shows, the effective operation of AFL based MPPT algorithm for real-time PV system applications at all irradiance and load conditions.

REFERENCES

[1] Bidyadhar Subudhi, *Senior Member, IEEE*, and Raseswari Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems" IEEE transactions on sustainable energy, vol. 4, no. 1, January 2013.

[2] J. Surya Kumari and Ch. Sai Babu, "Mathematical Modeling and Simulation of Photovoltaic Cell using Matlab- Simulink Environment" International Journal of Electrical and Computer Engineering (IJECE) Vol. 2, No. 1, February 2012.

[3] N. Pandiarajan and Ranganath Muthu "Mathematical Modeling of Photovoltaic Module with Simulink", International Conference on Electrical Energy Systems (ICEES 2011), 3-5 Jan 2011.

[4] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, *Member, IAENG* "Development of Generalized Photovoltaic Model Using Matlab/Simulink",Proceedings of the World Congress on Engineering and Computer Science 2008 WCECS 2008, October 22 - 24, 2008, San Francisco, USA.

[5] Habbati Bellia, Ramdani Youcef , Moulay Fatima "A detailed modeling of photovoltaic module using MATLAB", NRIAG Journal of Astronomy and Geophysics (2014) 3, 53– 61.

[6] F. Liu, Y. Kang, Y. Zhang, and S. Duan, "Comparison of P&O and hill climbing MPPT methods for grid-connected PV generator," in *Proc.3rd IEEE Conf. Industrial Electron. Applicat.*, Singapore, Jun. 3–5, 2008.

[7] W.Xiao andW. G. Dunford, "A modified adaptive hill climbing MPPT method for photovoltaic power systems," in *Proc. 35th Annu. IEEE Power Electron. Conf.*, Achan, Germany, Oct. 3–7, 2004.

[8] L. Piegari and R. Rizzo, "Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking," *IET Renew. Power Gener.*, vol. 4, no. 4, pp. 317–328, 2010.

[9] N. Femia, D. Granozia, G. Petrone, G. Spagnuolo, andM. Vitelli, "Predictive and adaptive MPPT perturb and observe method," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 43, no. 3, pp. 934–950, Jul. 2007.

[10] J. Suryakumari and G. Sahiti "Analysis and Simulation of Modified Adaptive Perturb and Observe MPPT Technique for PV Systems", International Journal of Emerging Trends in Electrical and Electronics (IJETEE – ISSN: 2320-9569) Vol. 9, Issue. 1, Nov-2013.

[11] Marcelo G. Villalva, Ernesto Ruppert F Analysis and Simulation of the P&O MPPT Algorithm Using a Linearized PV Array Model IEEE transaction, 2009.

[12] Trishan Esram and Patrick L. Chapman, Senior Member, IEEE "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 22, NO. 2, JUNE 2007.

[13] T. Noguchi and H. Matsumoto, "Maximum power point tracking method of photovoltaic using only single current sensor," in Proc. 10th Eur. Conf Power Electron. Applicat., Toulouse, France, Sep. 2–4, 2003.

[14] C. Liu, B.Wu, and R. Cheung, "Advanced algorithm for MPPT control of photovoltaic systems," in Proc. Canadian Solar Build. Conf., Montreal, QC, Canada, Aug. 20–24, 2004.

[15] Femia, N., Petrone, G., Spagnuolo, G. and Vitelli, M. (2005) Optimization of Perturb and Observe Maximum Power Point Tracking Method. *IEEE Transactions on Power Electronics*, 20, 963- 973.

[16] A. Mathew and A. I. Selvakumar, "New MPPT for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive network," *IEEE Trans. Energy Conv.*, vol. 21, no. 3, pp. 793–803, Sep. 2006.

[17] C.-S. Chiu, "T-S fuzzy maximum power point tracking control of solar power generation systems," *IEEE Trans. Energy Conv.*, vol. 25, no. 4, pp. 1123–1132, Dec. 2010.

[18] Ze Cheng, Hongzhi Yang, Yanli Liu "Self-adjusting Fuzzy MPPT PV System Control by FPGA Design" IEEE *Trans.* 978-1-4244-6255-1/11/$26.00 ©2011.

[19] G. Sudhakar and J. Surya Kumari, "Design and Analysis of P&O and FLC MPPT Techniques for Photovoltaic System", IRET Transaction on Power Electronics and Drives (ITPED) Vol. 1, Issue. 1, Oct. 2013.

[20] Maynara A. Aredes, Bruno W. França, Maurício Aredes "Fuzzy Adaptive P&O Control for MPPT of a Photovoltaic Module", Journal of Power and Energy Engineering, 2014.

[21] Chim, C., Neelakantan, P., Yoong, H. and Teo, K.T.K. (2011) Fuzzy Logic Based MPPT for Photovoltaic Modules Influenced by Solar Irradiation and Cell Temperature. 13*th* *International Conference on Computer Modelling and Simulation* (*UKSim*), Cambridge, 30 March-1 April 2011, 376-381.

[22] Chin, C.S., Chin, Y.K., Chua, B.L., Kiring, A. and Teo, K. (2012) Fuzzy Logic Based MPPT for PV Array under Partially Shaded Conditions. 2012 *International Conference on Advanced Computer Science Applications and Technologies* (*ACSAT*), Kuala Lumpur, 26-28 November 2012, 133-138.