Design and Analysis of P&O and FLC MPPT Techniques for Photovoltaic System

G. Sudhakar and J. Surya Kumari

Abstract: **The studies on the photovoltaic system are extensively increasing because of a large, secure, essentially exhaustible and broadly available resource as a future energy supply. However, the output power induced in the photovoltaic modules is influenced by an intensity of solar cell radiation, temperature of the solar cells and *so* on. Therefore, to maximize the efficiency of the photovoltaic system, it is necessary to track the maximum power point of the PV array, for this Maximum Power Point Tracking (MPPT) technique is used. Some MPPT techniques are available in that perturbation and observation (P&O) and Fuzzy logic controller (FLC). A P&O method is the most simple, which moves the operating point towards the maximum power point periodically increasing or decreasing the Duty cycle ratio of the Boost converter. It was proved that the P&O method control system sometimes deviating from the maximum power point. When the MPP is reached, the P&O method will oscillate around it in case of constant or slowly varying atmospheric conditions and it takes the more convergence time. To enhance the performance of the P&O algorithm, this paper presents the application of the Fuzzy Logic Control (FLC) to the MPPT.**

Keywords: **Boost converter, *Fuzzy logic controller, modeling of PV arrays, perturb and observe, Photovoltaic system, and Simulation Results.***

I. Introduction:

A photovoltaic system converts sunlight into electricity. The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays. The term array is usually employed to describe a photovoltaic panel (with several cells connected in series and/or parallel) or a group of panels. The term array used henceforth means any photovoltaic device composed of several basic cells. The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an alternative measure of renewable green power, energy conservation and demand-side management. The performance of a PV array system depends on the operating conditions as well as the solar cell and array design quality. The output voltage, current and power of PV array vary as functions of solar irradiation level, temperature and load current. Therefore the effects of these three quantities must be considered in the design of PV arrays so that any change in temperature and solar irradiation levels should not adversely affect the PV array output to the load/utility, which is either a power company utility grid or any stand alone electrical type load.

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Perturbation and Observation (P&O) can track the Maximum Power Point (MPP) all the time, irrespective of the atmospheric conditions, type of PV panel, and even aging, by processing actual values of PV voltage and current. Since the cost of the required circuitry for implementing on-line MPPTs is higher, they are usually employed for larger PV arrays. P&O method is widely used in PV systems because of its simplicity and easy of implementation. However, it presents drawbacks such as slow response speed, oscillation around the MPP in steady state, and even tracking in wrong way under rapidly changing atmospheric conditions. In order to overcome these drawbacks and improve the P&O response, this paper proposes a fuzzy based MPPT technique.

Organization of the paper is photovoltaic cell modeling, Boost converter, Maximum power point tracking (MPPT) Techniques are Perturbation and Observation (P&O) and fuzzy logic and Simulation results.

II. Photovoltaic cell modeling

Equivalent Circuit of Photovoltaic Cell:

A mathematical description of current voltage terminal characteristics for PV cells is available in literature. The single exponential equation which models a PV cell is derived from the physics of the PN junction and is generally accepted as reflecting the characteristic behavior of the cell. A double exponential equation may be used for the polycrystalline silicon cells.

$$I = I_{ph} - I_s\left(\frac{\exp(q.(V+IR_S))}{N.K.T} - I\right) - \frac{(V+IR_S)}{R_{sh}} \quad (1)$$

A solar cell, which is basically a *p-n* semiconductor junction directly, converts light energy into electricity. PV cells are grouped in larger units called PV modules, which are further interconnected in a parallel-series configuration to form PV arrays or generators. The photovoltaic cell considered can be modeled mathematically using the following procedure.

Voltage output of a PV cell

$$V_{pv} = \left[\frac{N_S AKT}{q}\right] \ln\left[\frac{N_P \times I_{ph} - I_{pv} + N_P \times I_O}{I_O}\right] - I_{PI} R_S \quad (2)$$

Current output of a PV cell

$$I_{pv}=N_p\times I_{ph}-N_p\times I_o\left[\exp\left\{\frac{q\times(V_{pv}+I_{pv}R_s)}{N_s AKT}\right\}-1\right] \quad (3)$$

$$I_{ph}=[I_{scr}+K_t(T-298)]\times \lambda/100 \quad (4)$$

$$I_o=I_{or}\left[\frac{T}{T_r}\right]^3\exp\left[\frac{q\times E_{go}}{BK}\left\{\frac{1}{T_r}-\frac{1}{T}\right\}\right] \quad (5)$$

The PV array power ***P*** can be calculated using the following equation

$$P_{pv}=I_{PV}\times V_{PV} \quad (6)$$

$$P_{pv}=V_{pv}\times N_p\times I_{ph}-V_{pv}\times N_p\times I_o\left[\exp\left\{\frac{q\times(V_{pv}+I_{pv}R_s)}{N_s AKT}\right\}-1\right] \quad (7)$$

Where,

V_{pv} is output voltage of a PV cell(V)

I_{pv} is output current of a PV cell(A)

N_s is the number of modules connected in series

N_p is the number of modules connected in parallel

I_{ph} is the light generated current in a PV cell (A)

I_o is the PV cell saturation current (A)

R_s is the series resistance of a PV cell

A=B is an ideality factor=1.6

K is Boltzmann constant=1.3805e-23Nm/K

T is the cell temperature in Kelvin=298K

Q is electron charge=1.6e-19Coulombs

$T_{r=}$The reference temperature=301.18k

$I_{scr=}$ PV cell short-circuit current at 25°c and 100Mw/cm^2=3.27A

K_i =The short-circuit current temperature co-efficient at I_{scr}=0.0017A/°C

λ=is the PV cell illumination (MW/cm^2)=100Mw/cm^2

I_{or} =Saturation current at $T_{r=}$2.0793e^{-6A}

E_{go}= is the band gap for silicon=1.1eV

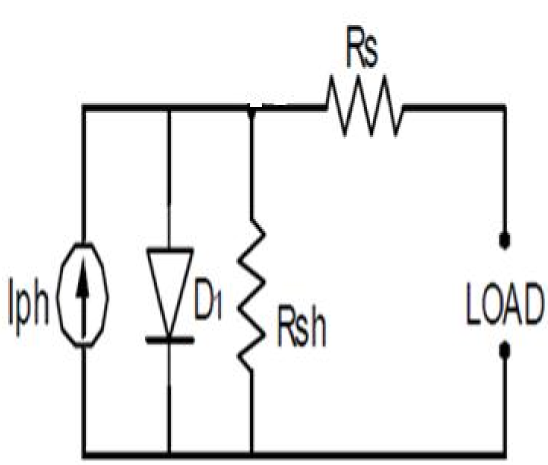


Fig.1 PV Cell Circuit Model

The complete behavior of PV cells are described by five model parameters (I_{ph}, N, Is, Rs, R_{sh}) which is representative of the physical behavior of PV cell/module. These five parameters of PV cell/module are in fact related to two environmental conditions of solar isolation & temperature. The determination of these model parameters is not straightforward owing to non-linear nature of equation.

Characteristic I–V curve of a practical PV device and the three remarkable points: short circuit (0, I_{sc}), MPP (V_{mp}, I_{mp}), and open circuit (Voc, 0).

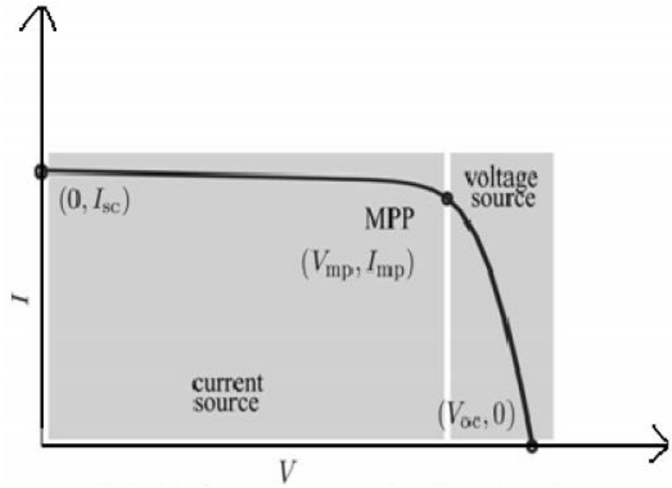


Fig.2 Maximum Power Point (Vmp, Imp).

III. Boost Converter

The boost converter which has boosting the voltage to maintain the maximum output voltage constant for all the conditions of temperature and solar irradiance variations. A simple boost converter is as shown in fig.3

For steady state operation, the average voltage across the inductor over a full period is zero and the boost converter input and output relation is equation 8 represents

$$\frac{V_o}{V_{in}}=\frac{T}{T_{off}}=\frac{1}{1-D} \quad (8)$$

By designing this circuit we can also investigate performance of converters which have input from solar energy. A boost regulator can step up the voltage without a transformer. Due to a single switch, it has a high efficiency.

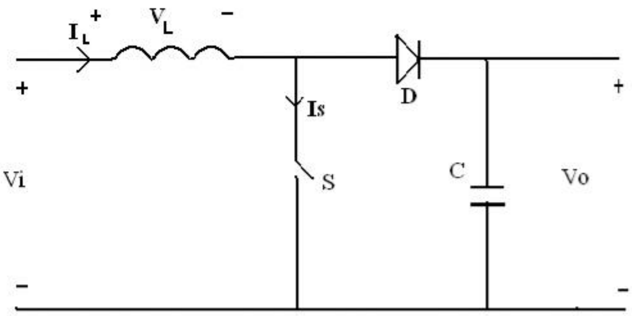


Fig.3 Boost converter

IV. MPPT Techniques

MPPT is essentially a real time process to search for the operating point which gives the maximum available power that can be extracted from the PV array at any insolation level. Two MPPT techniques will be presented and simulated.

A. Perturb & Observe (P&O)

The principle of P&O is to perturbation by acting decrease or increase on the PWM duty cycle of boost converter and then observing the direction of change of PV output power, If at any instant j the output PV power P (j) & voltage V (j) is greater than the previous computed power P (j−1) & V (j-1), then the direction of perturbation is maintained otherwise it is reversed. The flow chart of algorithm has 4 cases as shown in Fig.5 and can be detailed as following

- When ΔP <0 & V (j)>V (j-1), this yields to D (j+1) = D (j) -ΔD
- When ΔP <0 & V (j) <V (j-1), this yields to D (j+1) = D (j) + ΔD
- When ΔP >0 & V (j) <V (j-1), this yields to D (j+1) = D (j) - ΔD
- When ΔP >0 & V (j) <V (j-1), this yields to D (j+1) = D (j) + ΔD

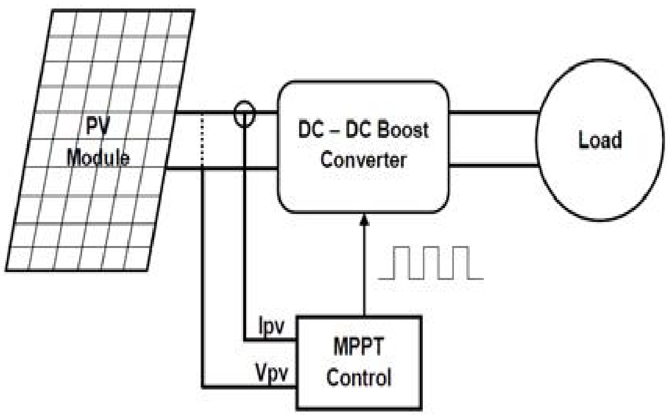


Fig.4 Block diagram of P&O MPPT technique

Where ΔD is chosen value by trial and error in simulation. A simulation of the P&O algorithm has been implemented by using MATLAB.

Despite the P&O algorithm is easy to implement it has mainly the following drawbacks:

- Cannot always operate at the maximum power point due to the slow trial and error process, and thus the Maximum available solar energy from the PV arrays cannot be extracted all the time.
- The PV system always operates in an oscillating mode which leads to the need of complicated input and Output filters to absorb the harmonics generated.

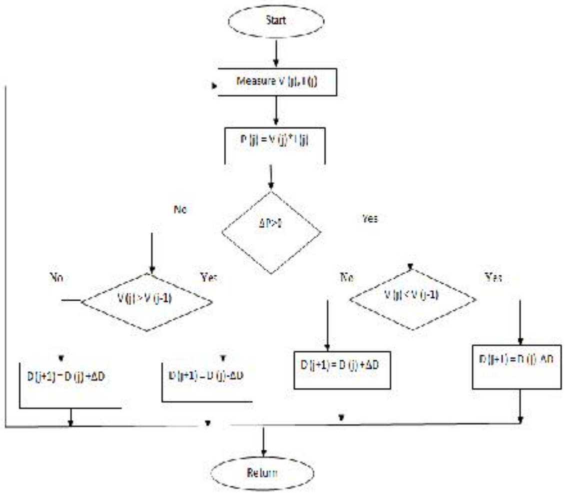


Fig.5 P&O flowchart

B. Fuzzy Logic Control

Fuzzy logic is one of the most powerful control methods. It is known by multi-rules-based resolution and Multivariable consideration. Fuzzy MPPT is popular for over last decade. Fuzzy logic controllers (FLC) have the advantages of working with imprecise inputs, no need to have accurate mathematical model, and it can handle the nonlinearity. The proposed FLC is shown in Fig.7; it consists of two inputs and one output. The two FLC input variables are the error (E) and change of error (CE) that expressed by equation (9), (10).

$$E(J) = \frac{Ppv(j) - Ppv(j-1)}{Vpv(j) - Vpv(j-1)} \quad (9)$$

$$CE(J) = E(j) - E(j-1) \quad (10)$$

Where P_{pv}, V_{pv} are the PV power and voltage respectively at instant j. E (j) shows if the load operating point at the instant j 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 (j) expresses the moving direction of this point. Where the control action duty cycle D used for the tracking of the maximum power point by comparing with the saw tooth waveform to generate a PWM signal for the boost converter.

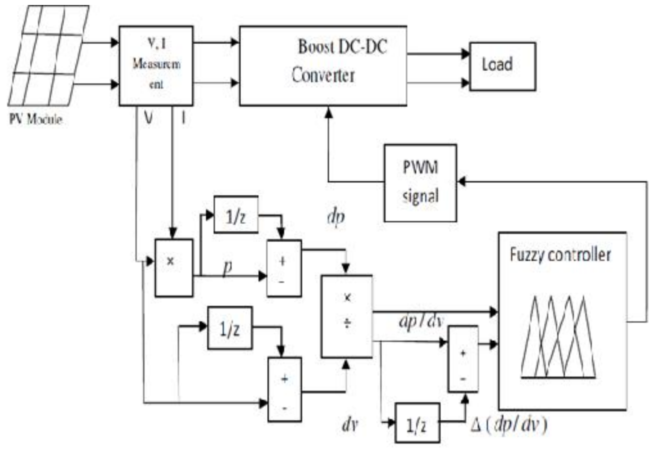


Fig.6 Block diagram of FLC based MPPT control

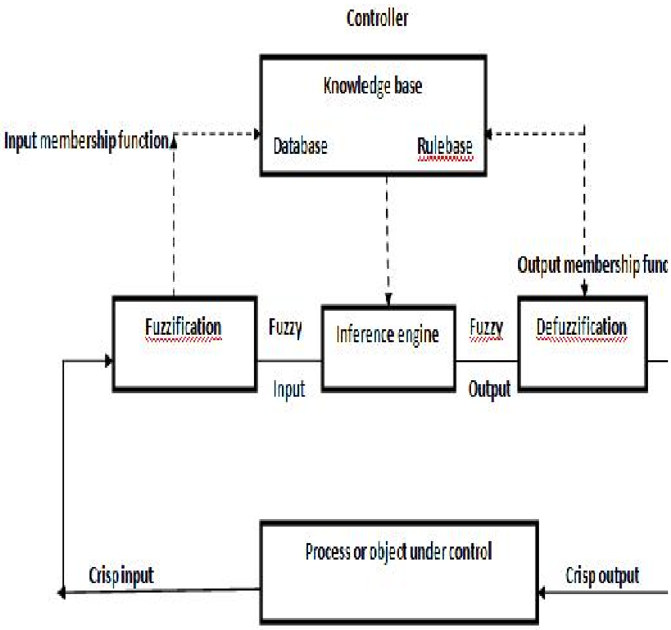
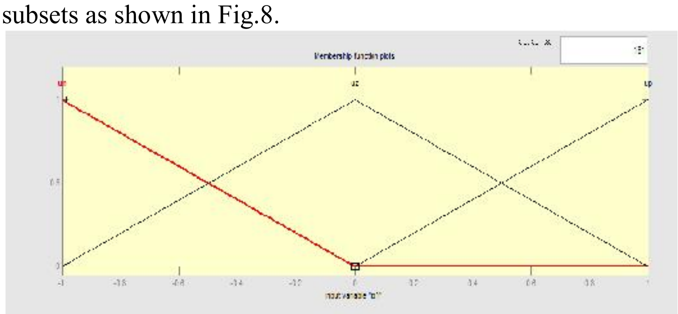


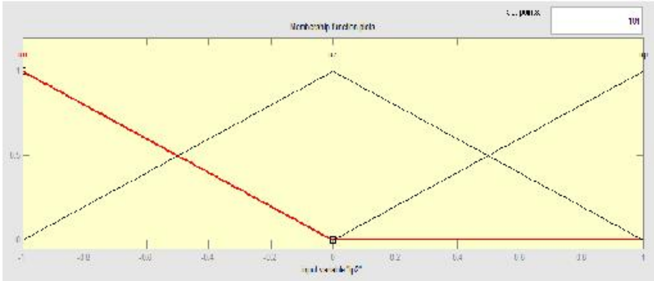
Fig.7 Internal structure of Fuzzy Logic Controller

- **Fuzzification**

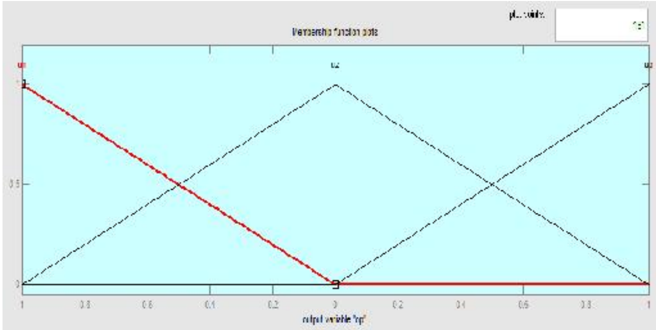
The fuzzification is the process of converting the system actual inputs values E and CE into linguistic fuzzy sets using fuzzy membership function. These variables are expressed in terms of three linguistic variables such as UZ (zero), UN (negative), and UP (positive)) using basic fuzzy subsets as shown in Fig.8.



(a)



(b)



(c)

Fig.8 Membership functions of E, CE and D

- **Rule base & inference engine**

Fuzzy rule base is a collection of if-then rules that contain all the information for the controlled parameters. It is set according to professional experience and the operation of the system control. The fuzzy rule algorithm includes 9 fuzzy control rules listed in table 1.

Fuzzy inference engine is an operating method that formulates a logical decision based on the fuzzy rule setting and transforms the fuzzy rule base into fuzzy linguistic output. In this paper Mamdani's fuzzy inference method, with Max-Min operation fuzzy combination has been used.

Table 1: FLC Rule base

CE / E	UN	UZ	UP
UN	p	p	n
UZ	p	z	n
UP	p	p	n

- **Defuzzification**

Defuzzification of the inference engine, which evaluates the rules based on a set of control actions for a given fuzzy inputs set. This operation converts the inferred fuzzy control action into a numerical value at the output by forming the union of the outputs resulting from each rule. The center of area (COA) algorithm is used for defuzzification of output duty control parameter. i.e If E is NB and CE is ZO then crisp D is PB, it means that if the operating point is far away from the MPP by the right side, and the variation of the slope of the curve is almost Zero; then increase the duty cycle.

V.Simulation Results

A. PV array curves:

For constant temperature 25◦c and different intensity. The PV array current constant up to some voltage level and then it will be decreased. The PV array current always increases with

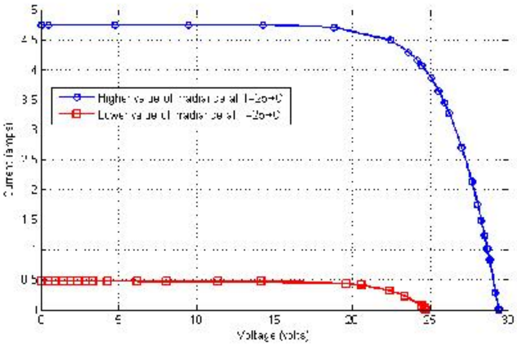


Fig.9 I-V charecteristics of PV array with different

the irradiance and at constant temperature.

For constant temperature 25◦c and different intensity. The PV array power increases up to some voltage level and then it will be decreased. The PV array power always increases with intensity.

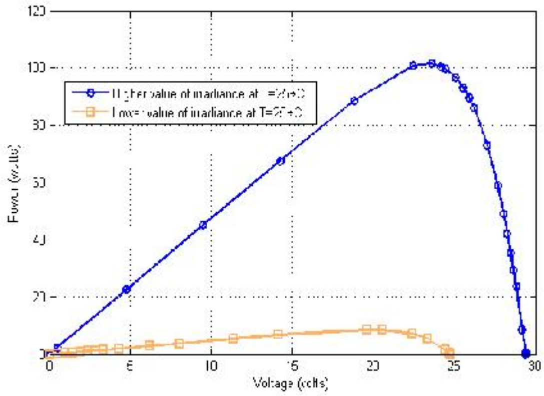


Fig.10 P-V charecteristics of PV array with different irradiance and at constant temperature

The effect of temperature on the I-V charecteristics of the PV array is shown in fig.11. The current is constant up to some voltage level and then it will gradually decrease.

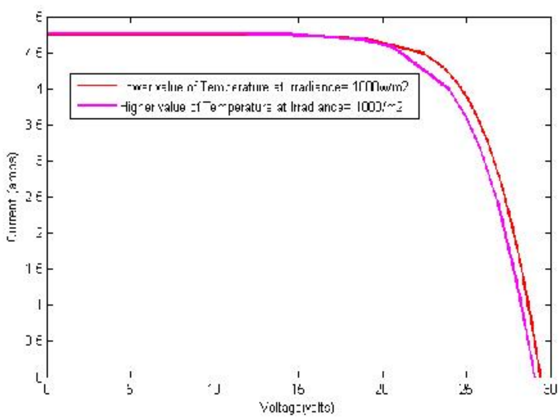


Fig.11 I-V charecteristics of PV array with different temperature and at constant irradiance

The effect of temperature on the P-V charecteristics of the PV array is shown in fig.12. The generated power is gradually decreased with increase in temperature and maximum power available more at low temperature.

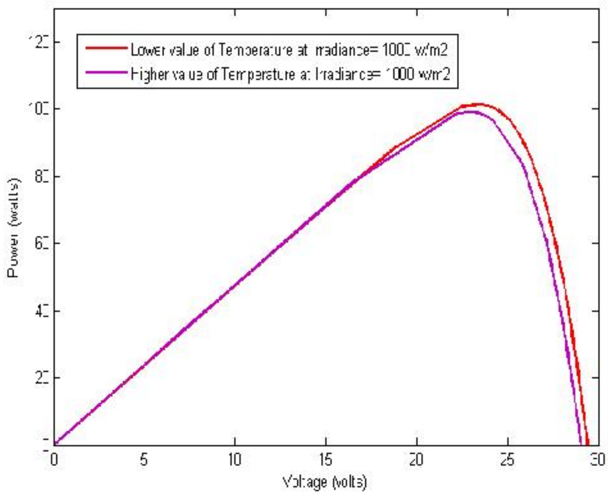


Fig.12 P-V charecteristics of PV array with different temperature and at constant irradiance

B.Perturb and Observe:

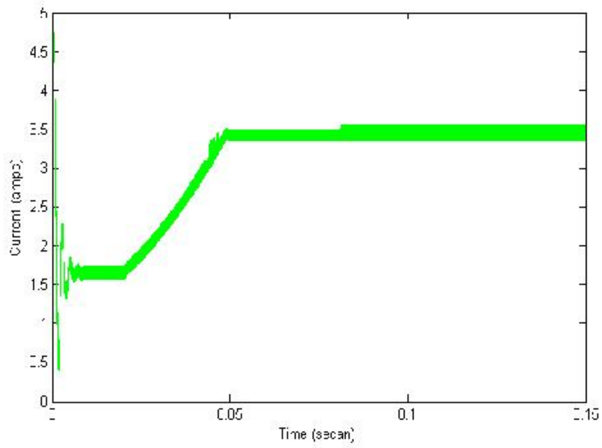


Fig.13(a) PV array output current for P&O MPPT technique

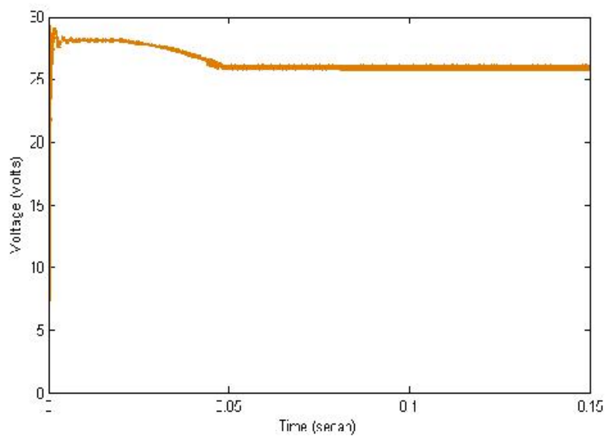


Fig.13(b) PV array output voltage for P&O MPPT technique

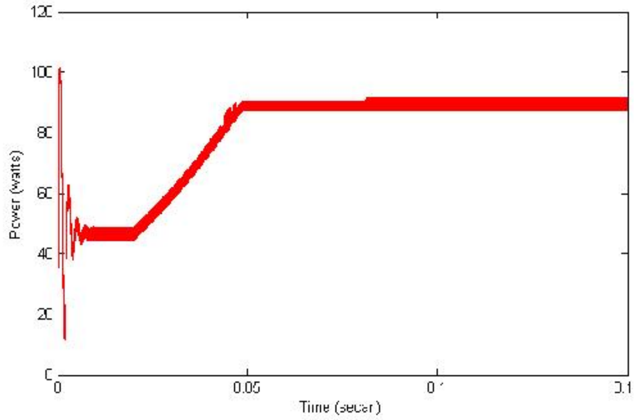


Fig.13(c) PV array output power for P&O MPPT technique

From fig.13 The response with perturbe and observe MPPT technique waveform are (a) PV array output current (b) PV array output voltage (c) PV array output power at temperature= 25◦c and Irradiance= 1000 w/m^2

C. Fuzzy Logic Controller:

From fig.14 The response with Fuzzy Logic Controller Technique waveforms are (a) PV array output current (b) PV array output voltage (c) PV array output power at Temperature= 25◦c and Irradiance= 1000w/m^2.

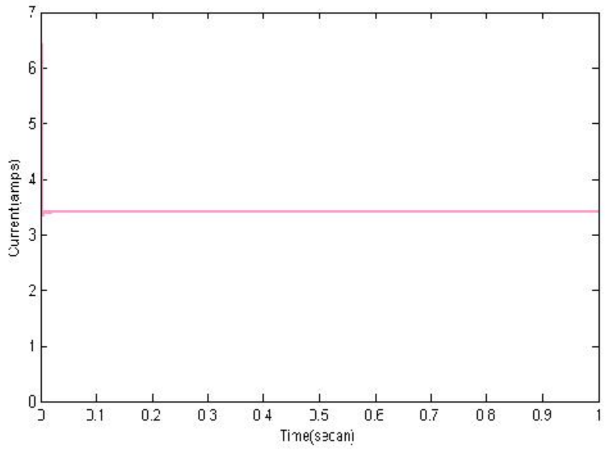


Fig.14 (a) PV array output current for FLC MPPT control

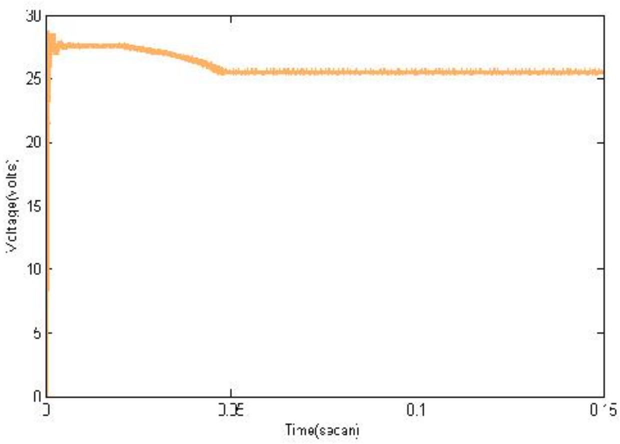


Fig.14 (b) PV array output Voltage for FLC MPPT control

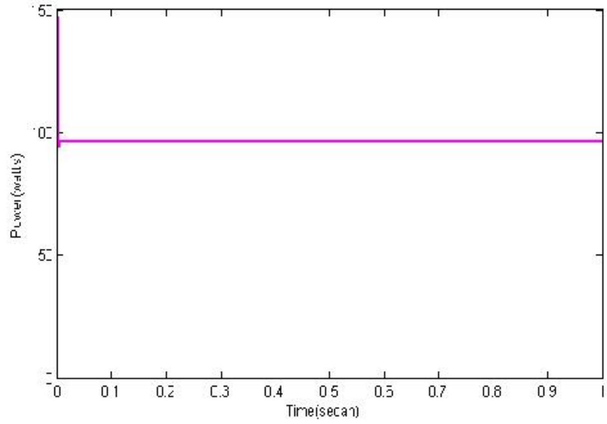


Fig.14 (c) PV array output power for FLC MPPT control

D. Comparison of With MPPT and Without MPPT:

The output power waveforms without MPPT (open loop) and with MPPT P&O and FLC as shown in fig.15. From figure we can observe that the settling time of power waveform in fuzzy logic controller is less than that of open loop and perturb and observe.

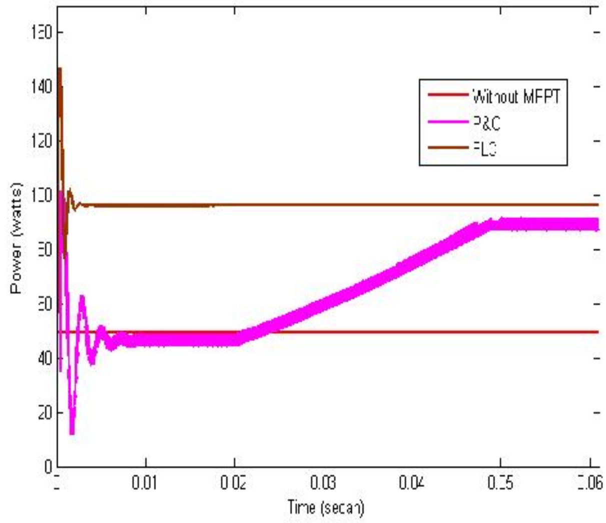


Fig.15 PV array output power waveform with and without MPPT

VI. Results comparison of Open loop, P&O and FLC based MPPT:

Table 2: comparison of open loop, P&O and FLC.

MPPT controller	Total Harmonic Distortion (THD)	Settling time t_{ss}(secan)
Without MPPT	≈ 9.0	≈ 0.01
Perturb and observe	≈ 5.0	≈ 0.005
Fuzzy Logic Controller	≈ 1.5	≈ 0.002

From above table we can say that thetotal harmonic distortion in fuzzy logic controller based MPPT is less than that of open loop and P&O MPPT techniques. The settling time of power wave form in FLC based MPPT is less than that of open loop and P&O MPPT techniques.

VI. Conclusion

This paper presents mathematical model of PV array and comparison of conventional P&O MPPT controller with an intelligent control strategy of MPPT for PV system using the Fuzzy logic controller. The proposed MPPT can track the MPP faster when compared to the conventional P&O method. In conclusion, the proposed MPPT using fuzzy logic can improve the transient performance of the system. The results of simulation show that fuzzy logic based MPPT controller has provided more power than conventional P&O MPPT and open loop systems.

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References:

[1] Ahmed K. Abdelsalam, *Member, IEEE*, Ahmed M. Massoud, *Member, IEEE*, Shehab Ahmed, *Member, IEEE*, and Prasad N. Enjeti, *Fellow, IEEE* "High-Performance Adaptive Perturb and Observe MPPT Technique for Photovoltaic-Based Micro grids", IEEE transactions on power electronics, vol. 26, no. 4, april 2011.

[2] T. Esram and P. L.Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," *IEEE Trans. Energy Conv.*, vol. 22, no. 2, pp. 439–449, Jun. 2007.

[3] Chokri Ben Salah, Mohamed Ouali, "Comparison of Fuzzy Logic and Neural Network in Maximum Power Point Tracker for PV Systems", Elsevier, Electric Power Systems Research, vol.81, pp.43-50, July 2011.

[4] Mohamed Salhi1 ,Rachid El-Bachtri2, "Maximum Power Point Tracker Using Fuzzy Control for Photovoltaic System", International Journal of Research and Reviews in Electrical and Computer Engineering, vol.1, no.2, pp.69-75, June 2011.

[5] I. H.Altas, and A.M. Sharaf "A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment" 1-4244-0632-3/07/$20.00 ©2007 IEEE.

[6] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho " Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays" IEEE transactions on power electronics, vol. 24, no. 5, may 2009.

[7] Balakrishna S, Thansoe, Nabil A, Rajamohan G, Kenneth A.S., Ling C. J. " The Study and Evaluation of Maximum Power Point Tracking Systems", organized by universiti tenaga nasional, bangi, selangor, malaysia; 28-30 august 2006.

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[9] J. Surya Kumari, Dr. Ch. Sai Babu, A. Kamalakar Babu " Design and Analysis of P&O and IP&O MPPT Techniques for Photovoltaic System" International Journal of Modern Engineering Research (IJMER) Vol.2, Issue.4, July-Aug. 2012 pp-2174-2180 ISSN: 2249-6645.

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