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Comparison Between Fuzzy and P&O Control for MPPT for Photovoltaic System Using Boost Converter

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Abstract
This paper presents fuzzy control method for maximum power point tracking (MPPT) of photovoltaic (PV) system under varying irradiation and temperature conditions. The fuzzy control method has been compared with perturb and observe (P&O) method as one of the most widely conventional method used in this area. Both techniques have been analyzed and simulated. Fuzzy technique gives better and more reliable control for this application.
Keywords: Photovoltaic, MPPT, P&O, FUZZY.

1. Introduction

Renewable energy sources play an important role in electricity generation. Various renewable energy sources like wind, solar, geothermal and biomass can be used for generation of electricity and for meeting our daily energy needs. Photovoltaic generation is becoming increasingly important as a renewable source since it offers many advantages such as incurring no fuel costs, not being polluting, required little maintenance, and emitting no noise, among others.

The photovoltaic voltage-current (V-I) characteristic is nonlinear and changes with irradiation and temperature. In general, there is a point on the V-I or voltage-power (V-P) curves, called the Maximum power point (MPP), at which PV operates with maximum efficiency and produces its maximum output power. The state of the art techniques to track the maximum available output power of PV systems are called the maximum-power point tracking (MPPT). Controlling MPPT for the solar array is essential in a PV system. There are many techniques have been developed to implement MPPT, these techniques are different in there efficiency, speed, hardware implementation, cost, popularity [1, 2].

One of the most widely used techniques in MPPT is P&O due to its simple and easily implementation. In this paper, intelligent control technique using fuzzy logic control is associated to an MPPT controller in order to improve energy conversion efficiency and compared with P&O method. Simulation and analysis of P&O and fuzzy logic control are presented.

2. Modeling and Characteristic of solar panel

2.1 Modeling of solar panel

The model of solar cell can be categorized as p-n semiconductor junction, when exposed to light, the DC current is generated. The PV cell equivalent circuit can be represented as an ideal current source, diode, parallel resistance and series resistance as shown in Fig.1, where the current source is the light generated current which is directly proportional to the solar irradiation. The series and the shunt resistances represent a voltage loss on the way to the external contacts and the leakage current in the shunt path respectively [3, 4].

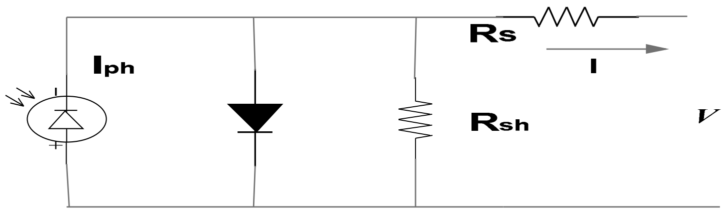


Fig.1. PV modeling

The mathematical model which relates the output current to the output voltage is given by the equation (1) [5, 6].

$$I = I_{ph} - I_o \left[\exp\left(\frac{q}{kTA} (v + IR_S) - 1 \right) - \frac{(v + IR_s)}{R_{sh}} \right] (1)$$

where I_{ph} is the current generated by the incident light (it is directly proportional to the Sun irradiation),I& v are the PV array output current and voltage respectively, I_o is the reverse saturation or leakage current of the diode, q is the electron charge (1.60217646 e-19 C), k is the Boltzmann constant (1.3806503 e−23 J/K), A is the diode ideality constant, R_s & R_{sh} are series and shunt resistance of PV respectively, and T (in Kelvin) is the cell's working temperature.

The photocurrent (I_{ph}) mainly depends on the solar insolation level and cell's working temperature, which is described by equation (2)

$$I_{ph} = \left(I_{sc} + K_1(T - T_{ref})\right)\lambda \qquad (2)$$

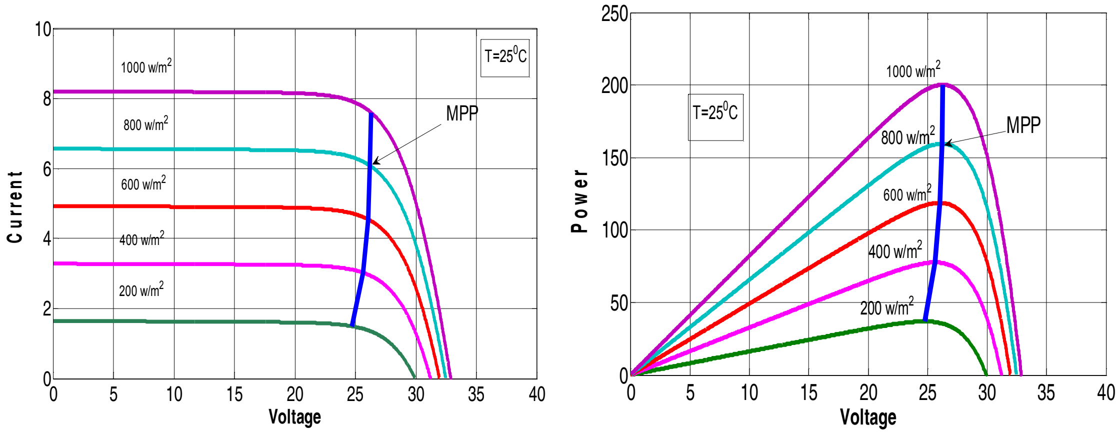
Where I_{sc} is the cells short-circuit current at a 25°C and1kW/m^2, K_1 is the cells short-circuit current temperature coefficient,), T_{ref} is the cell's reference temperature which equals to 25°C, and λ is the solar insolation level in kW/m^2.

2.2 Solar panel Characteristic

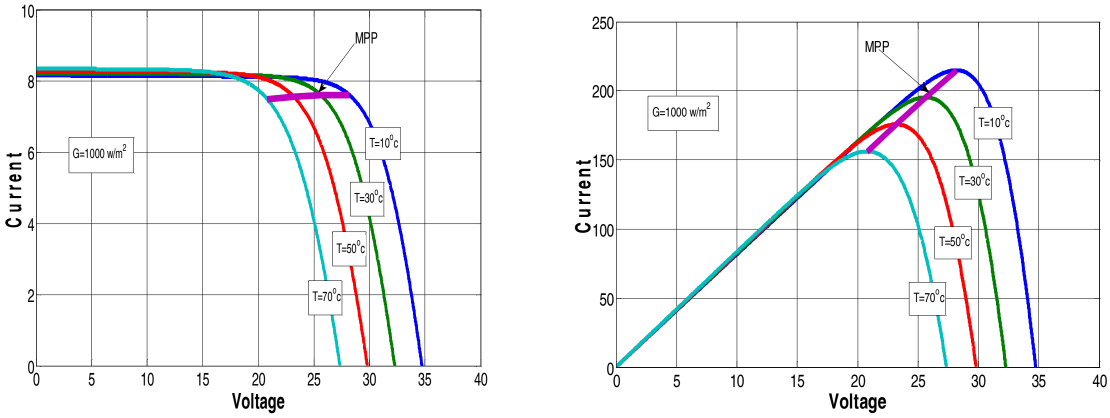
There are two main parameters that are used to draw I-V curve which are short circuit current (I_{sc}) and open circuit voltage (V_{oc}).

- Short circuit current (I_{sc}) is the maximum current that the cell can provide and it occurs when the cell is short circuited.
- Open circuit voltage (V_{oc}) is the maximum voltage that exists between the cell terminals.

The name plate data of the PV array used in our simulation has been taken from [7] as a simulation for KC200GT array. The module I-V, P-V characteristics at different insolation and temperature levels are illustrated in Fig .2, also the locus of MPP at each level is shown. It can be observed that the irradiation changes mainly affect the PV output current and the temperature changes affect PV output voltage. For direct coupling between the load and PV, the operating point is determined by the intersection between the load I-V curves and the PV I-V curves whatever the insolation level. For example in Fig.3, for any resistive load R, it has straight line I-V characteristic with slope 1/R, it gives one operating point for a certain insolation level, by varying the load value R, it's I-V curve slope varies also and so the operating point varies depending on these variation. Also for a specified value of the resistive load R_{opt}, it gives the MPP of the PV as an operating point, but that could be happened only for one insolation level.



(a)



(b)

Fig.2. (a) V-I ,P-V Characteristics of PV module at constant temperature and varyinginsolations,(b) V-I ,P-V Characteristics of PV module at constant insolationsand varying temperature.

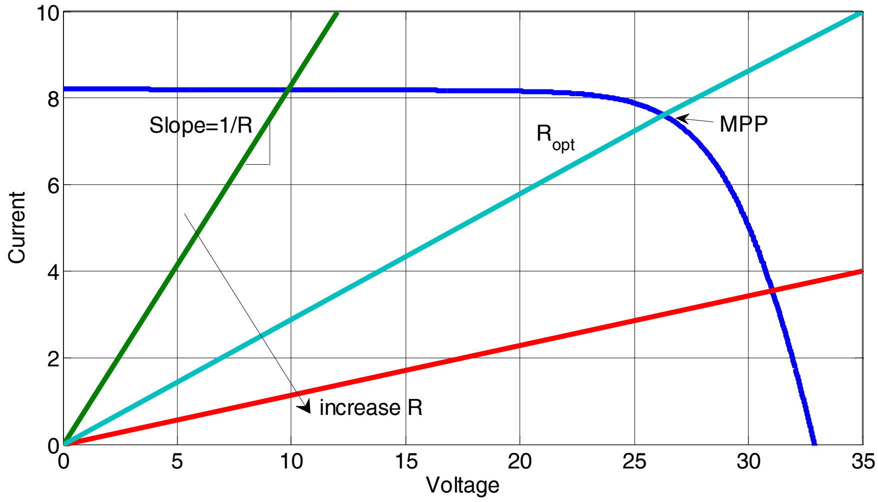


Fig.3. I-V curves of PV array and various resistive loads

3. Mppt Model

The circuit diagram of the energy conversion system is shown in Fig.4. The system consists of photovoltaic panel, a DC-DC boost converter, a fuzzy-based MPP tracker and a resistive load.

The PV array consists of 50 series PV cells. The I-V characteristic of array depends on the temperature and solar insolation level. The photovoltaic array operation depends on the load characteristics at which it is connected to. So when connected to load directly, the output of the PV array rarely works at MPP. However, to adapt the load and extract maximum power from a PV module, a DC-DC boost converter is used by adjusting its duty cycle under control of selected controller (in our case fuzzy and P&O algorithms) based MPPT controller such that the maximum solar panel output power is extracted under all operating conditions [8].

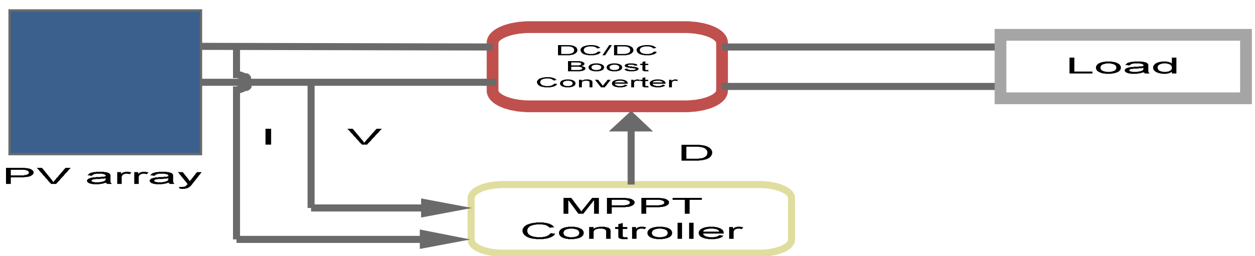


Fig.4. MPPT system

3.1 DC-DC converter

A boost converter is a step-up DC-DC power converter. Fig.5 shows the boost converter circuit using MOSFET switch. The converter operation can be divided into two modes. Mode 1 begins when the transistor is switched ON, the current in the boost inductor increases linearly, and the diode is OFF state, mode 2 begins when the transistor is switched OFF, the energy stored in the inductor is released through the diode to the load. The power flow is controlled by varying the on/off time of the MOSFET. The relationship between input and output voltages is given by equation (3) [9].

$$\frac{V_o}{V_i} = \frac{1}{(1 - D)} \quad (3)$$

Where V_i is the PV output voltage, V_o voltage of boost converter, D is duty cycle, that can be expressed by equation (4).

$$D = \frac{T_{on}}{T} \quad (4)$$

Where T_{on} is time when MOSFET is switched on, T is cycle period time. The transistor operates as a switch; it is turned on and off depending on pulse width modulated (PWM) control signal. PWM operates at constant frequency i.e T is constant and T_{on} is varying, so D can be varied from 0 to 1.

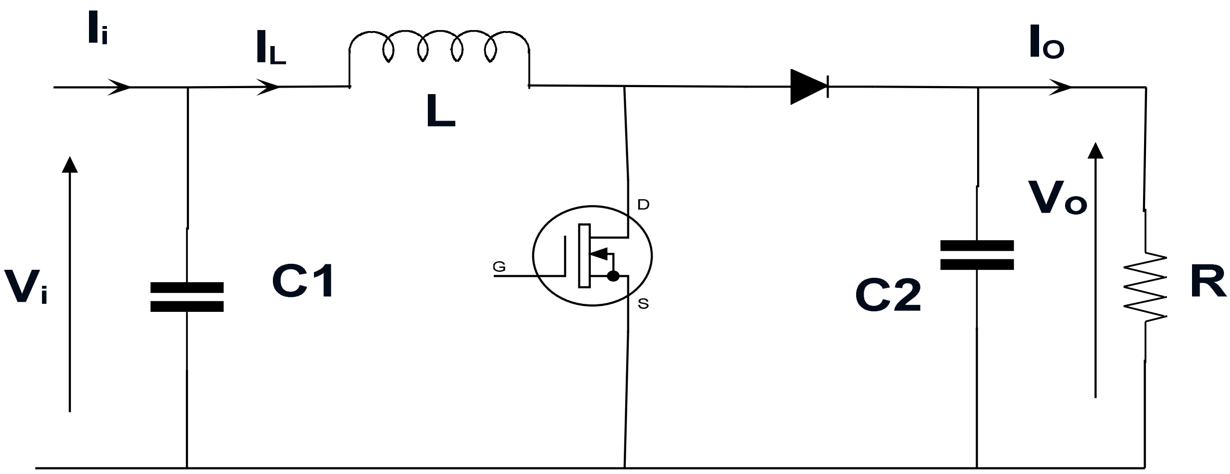


Fig.5. Boost converter Circuit diagram

4. MPPT controller

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.

4.1 perturb & observe

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 [10, 11]. The flow chart of algorithm has 4 cases as shown in Fig.6 and can be detailed as following

- When $\Delta P < 0$ & $V(j) > V(j-1)$, this yields to $D(j+1) = D(j) - \Delta D$
- When $\Delta P < 0$ & $V(j) < V(j-1)$, this yields to $D(j+1) = D(j) + \Delta D$
- When $\Delta P > 0$ & $V(j) < V(j-1)$, this yields to $D(j+1) = D(j) - \Delta D$
- When $\Delta P > 0$ & $V(j) < V(j-1)$, this yields to $D(j+1) = D(j) + \Delta D$

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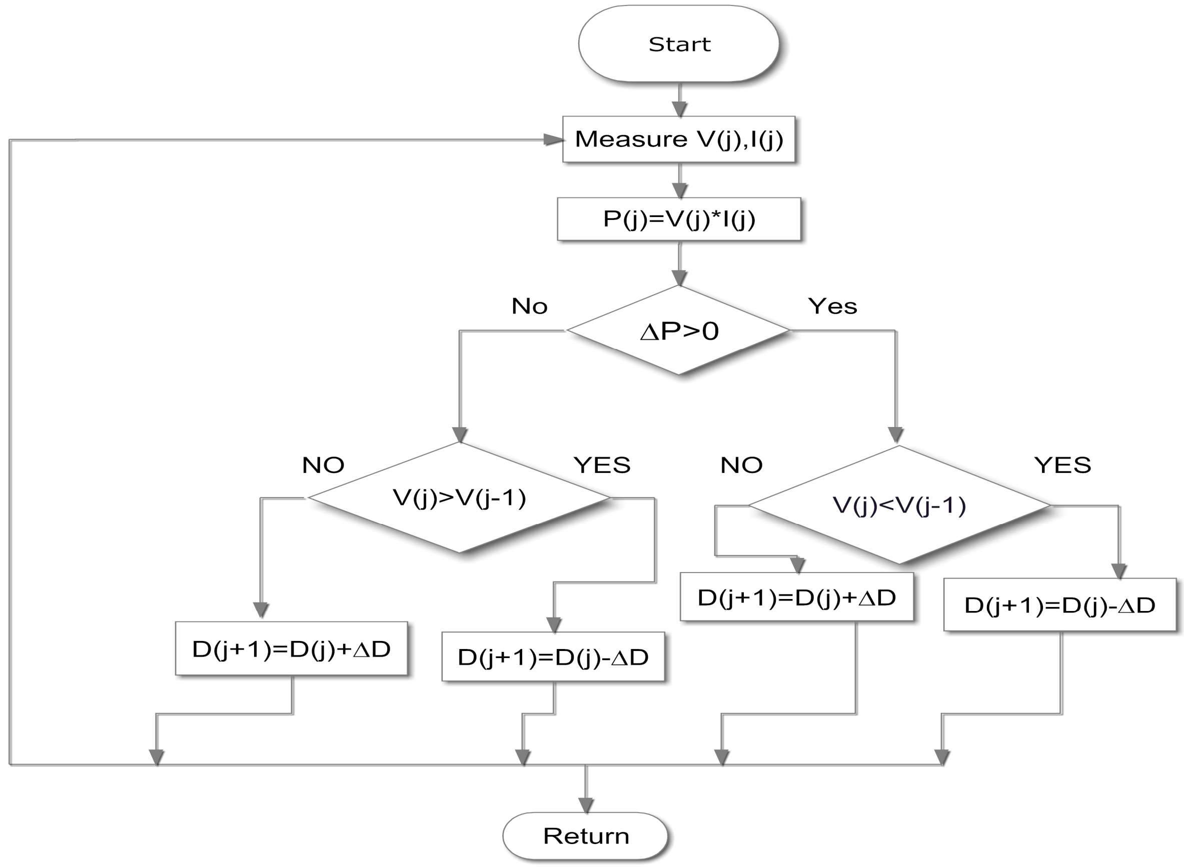


Fig.6. P&O flowchart

Where ΔD is chosen value by trial and error in simulation. A simulation of the P&O algorithm has been implemented by using MATLAB; Fig.7 shows the simulation results for different values of ΔD.

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.

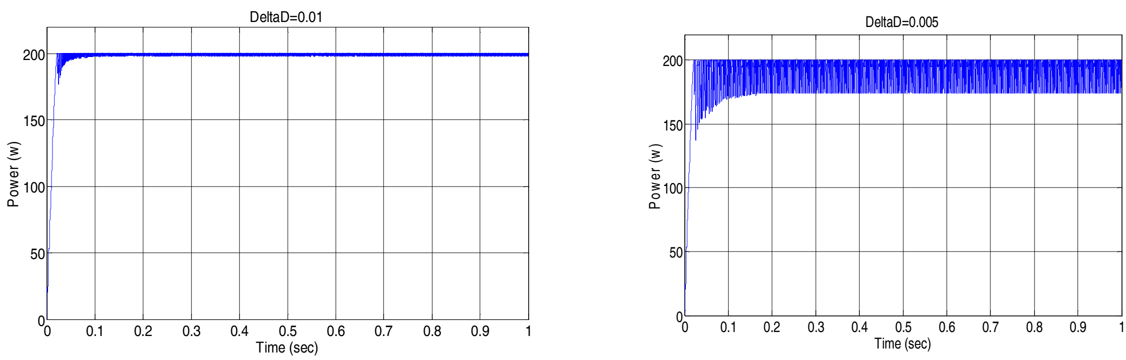


Fig.7. P&O MPPT for different ΔD

4.2. MPPT using 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 [12]. The proposed FLC is shown in Fig.8; 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 (5), (6).

$$E(j) = \frac{P_{pv}(j) - P_{pv}(j-1)}{V_{pv}(j) - V_{pv}(j-1)} \quad (5)$$

$$CE(j) = E(j) - E(j-1) \quad (6)$$

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 as shown in Fig.9 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.

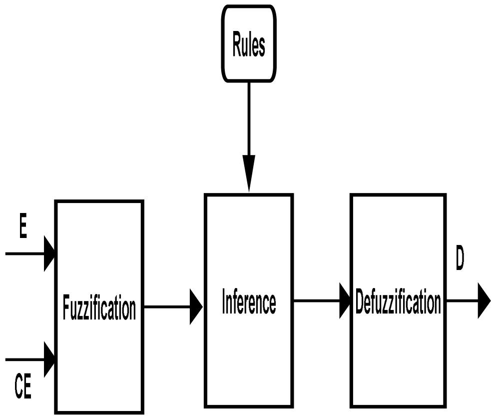


Fig.8. Fuzzy controller diagram

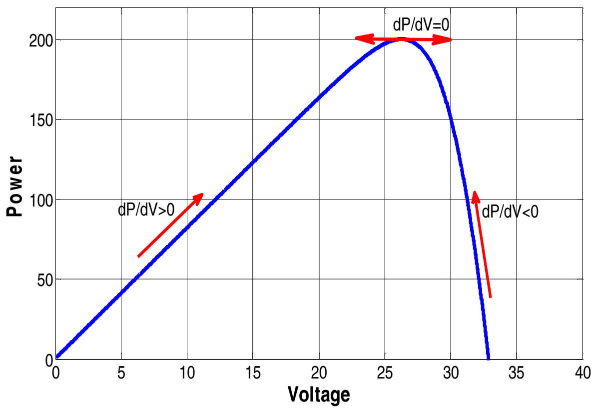


Fig.9.p-v curve at 1000 w/m2

The fuzzy controller design contains the three following steps:

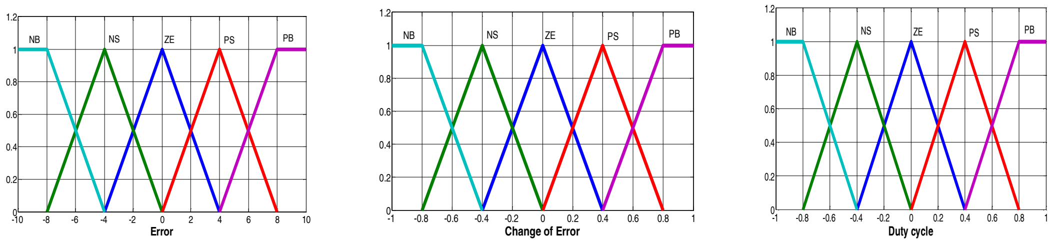
- Fuzzification

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 five linguistic variables (such as ZE (zero), PB (positive big), PS (positive small), NB (negative big), NS (negative small)) using basic fuzzy subsets as shown in Fig.10.

- 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 25 fuzzy control rules listed in table I.

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.



(a) (b) (c)

Fig.10. Membership function of E, CE and D

Table I. FLC Rules base

E \ CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

- 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.

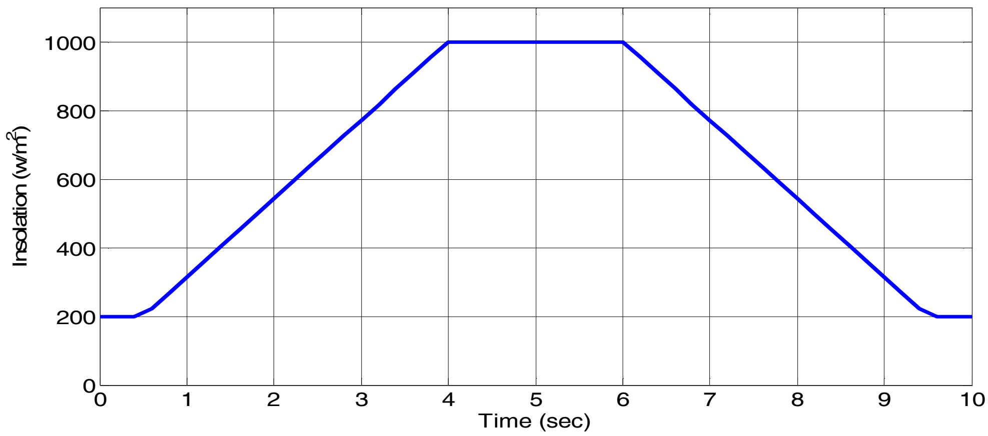
5. Simulation results

An extensive simulation for both techniques has been done using MATLAB. Some selected results are presented with a comparison between fuzzy and P&O MPPT controllers. The following simulation were presented for different insolation levels from 200 to 1000 W/m^2 at fixed temperature of 25°C as shown in Fig.11, and at different temperature levels from 10^{o}c to 70^{o}c at fixed insolation of 1000 W/m^2 shown in Fig.12.

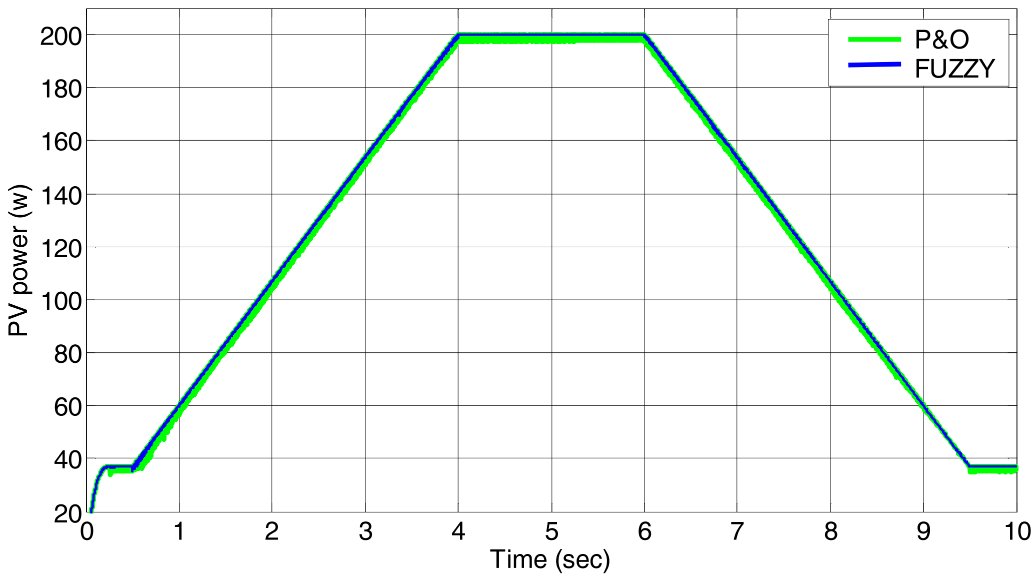
Fig.11 (a), (b), (c) and (d) show the simulation results of PV operating point and load curves for simulation time 10 sec (varying insolation level from 20% to 100%). The figure shows the result when using fuzzy and P&O as MPPT controller.

Fig 12(a), (b),(c)and (d)show the simulation results of PV operating power at maximum power point and load curves at varying temperature and constant irradiation at 1000 W/m^{2}which is being tracked by fuzzy and P&O controllers.

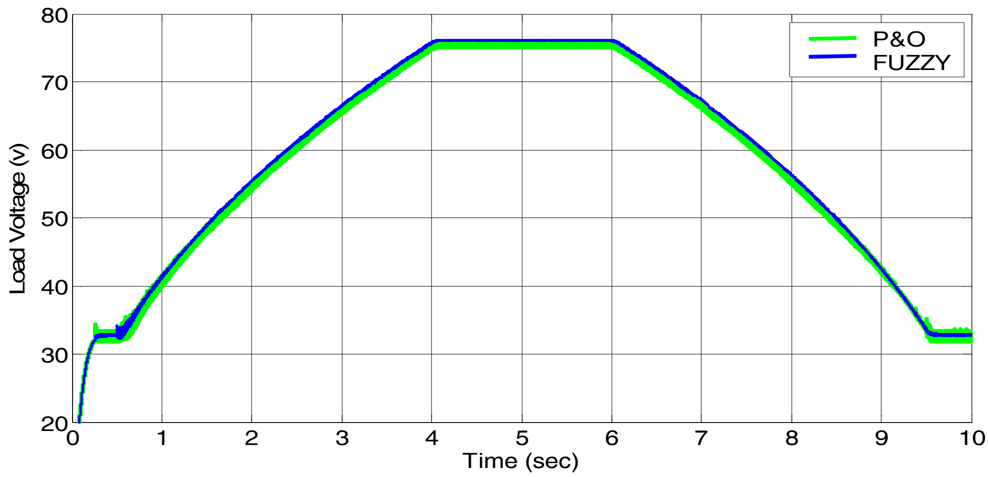
Fig.13 shows the output power of PV at fixed insolation level and temperature for both controllers. As shown fuzzy controller shows smother power signal line, less oscillating and better stable operating point than P&O. From the simulation results, it can be deduced that the fuzzy controller has better performance than P&O, and it has more accuracy for operating at MPP.


Insolation (w/m2)
Time (sec)
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
8
9
10

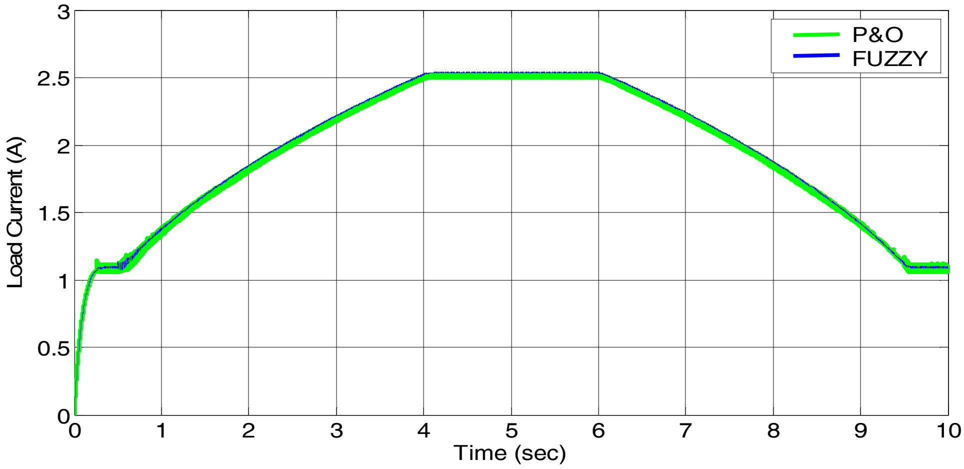
(a)


P&O
FUZZY
PV power (w)
Time (sec)
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10

(b)

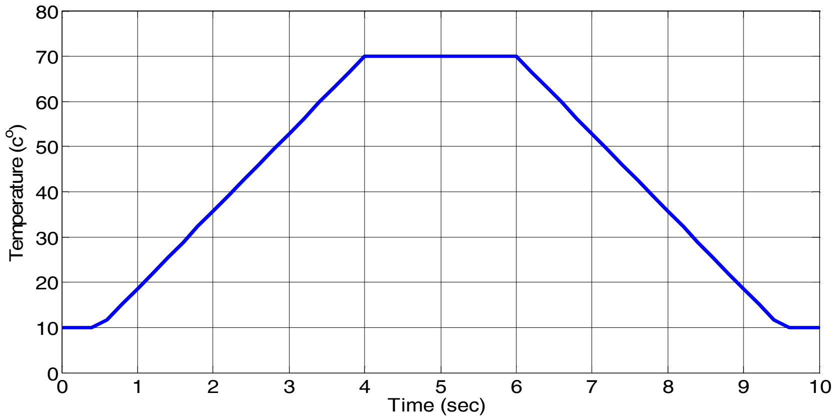

P&O
FUZZY
Load Voltage (v)
Time (sec)
80
70
60
50
40
30
20
0
1
2
3
4
5
6
7
8
9
10

(c)

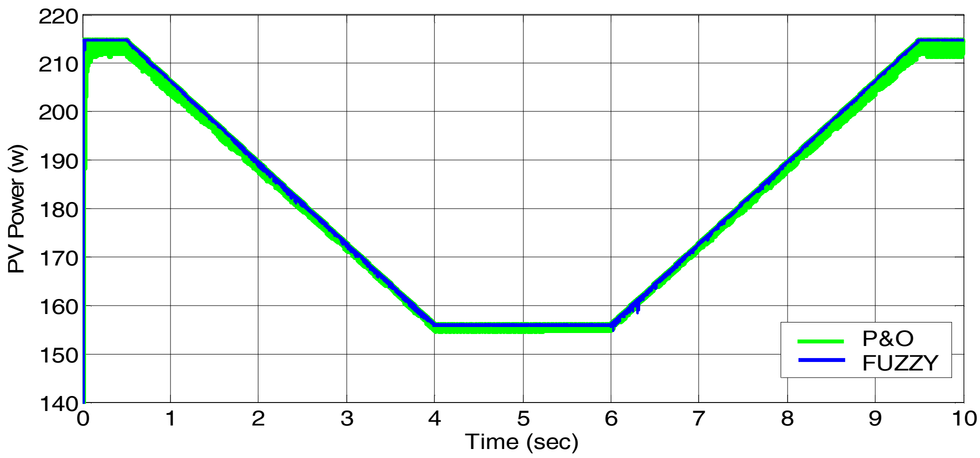


(d)

Fig11.Simulation result at varying insolation



(a)



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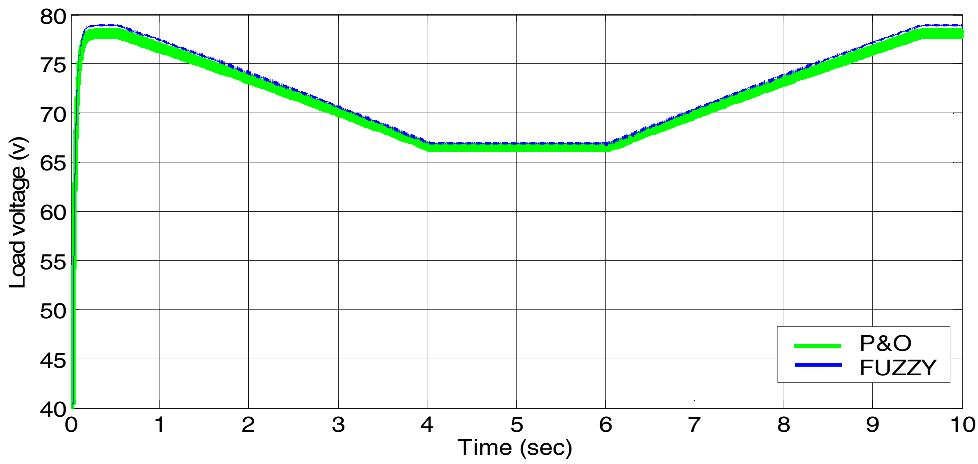
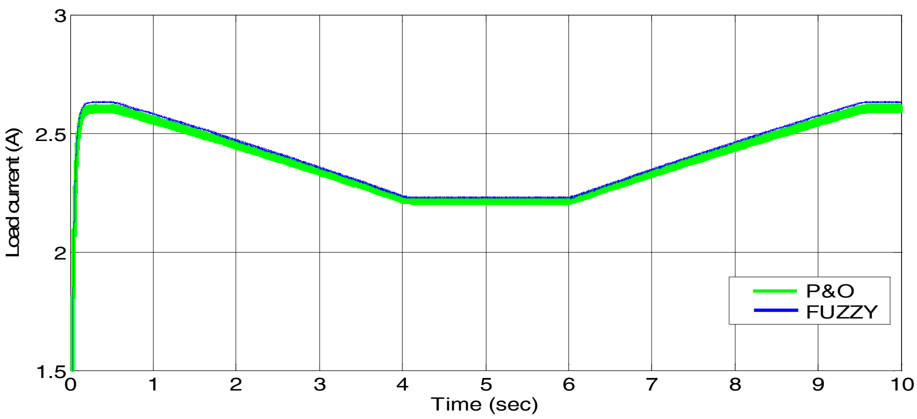


(c)



(d)

Fig12.Simulation result at varying temperature

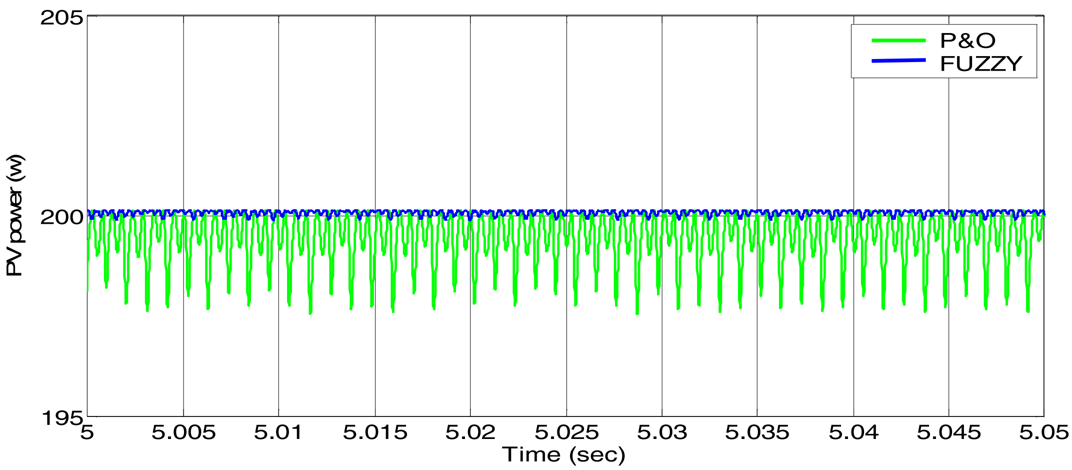


Fig13.Simulation result at constant temperature and insolation

6. Conclusion

This paper presented a mathematical model for PV. It also included MPPT at varying irradiation and temperature conditions. P&O and fuzzy logic controller have been designed and simulated for the proposed PV system, comparison for simulation results have been presented for different irradiation condition. Fuzzy controller showed better performance with lower oscillation.

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