

Comparison of P&O and Fuzzy Logic Controller in MPPT for Photo Voltaic (PV) Applications by Using MATLAB/Simulink

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Abstract : Energy is essential component for improving the living condition of the civilization. One of the major concerns in the power sector is that day to day increasing power demand has forced to use the fossil fuels in extreme causing the increasing serious environmental problems thus it is essential to use renewable energies which are characterized by their negligible pollution level and environmental friendly. Solar photovoltaic is a phenomenon where the solar irradiance is converted directly into electricity through solar cell. The photovoltaic energy as an alternative energy source has been widely used as it is pollution free, abundant and broadly available. An important consideration in the use of PV system is to operate the system near maximum power point so as to increase the output efficiency of PV panel. Maximum power point tracking (MPPT) techniques are used in PV applications to extract the maximum power that PV panel can produce, which depends upon different atmospheric conditions i.e solar insolation and temperature. DC-DC converter is inserted between PV array and load for obtaining the desired voltage level at load side. In this paper, a new maximum power point tracker using fuzzy set theory is proposed to improve energy conversion efficiency. Fuzzy algorithm based on linguistic rules describing the operator's control strategy is applied to control boost converter for maximum power point tracking linguistic variables implemented in the fuzzy logic controller have been selected appropriately to modulate the DC-DC converter. Fuzzy logic controller provides advanced features such as fast response, good performance in terms of oscillations. The fuzzy logic controller is designed and analyzed in MATLAB/SIMULINK

Keywords: Maximum Power Point Tracking (MPPT); fuzzy logic controller (FLC); Photovoltaic (PV);

I. Introduction

Electrical energy is the most innovative inventions of all times. It has become one of the most essential commodities of human life. Electrical energy can be generated from renewable and non-renewable energy resources. The existing nonrenewable fossil fuel which is the main energy source available now a day is not enough to supply the world's power demand as the population and the demand of the electrical energy is increasing day by day. The need of electricity is the major issue for any country to develop and to improve the living condition of its peoples; it will also result in reduction in poverty. The world primary energy demand is expected to increase by 1.7% per year from 2002 and expanding to more than 50% in 2030 [1]. In order to meet the vast energy demand it forced us to use non- renewable fossil fuels in extreme manner result in major environmental problems, now to have the optimum use the sources provided by the nature we should meet our energy demands from renewable, ecofriendly sources such as solar and wind. Photo voltaic energy source is the one of the most popular energy source on which many researchers are working since it is clean, pollution free and endless and can meet ours demand without disturbing the environment. To decrease the use of conventional energy, PV source is to be integrated to the grid by means of step-up converters. As the efficiency of the PV source is very less an important consideration in the use of PV system is to operate the system near maximum power point so as to increase the output efficiency of PV panel, since the maximum power point depends on the temperature and irradiance which are non-linear in nature, maximum power point tracking control system is employed which can maximize the output energy of the PV system and work effectively on the non-linear variations in the parameters such as temperature and radiations.

There are many MPPT algorithms as perturb and observe (P&O), incremental conductance, fractional short circuit current, fractional open circuit voltage, neural networks and fuzzy logic. Each has their own advantage and disadvantages.

This paper focuses on the comparison of Fuzzy Logic Controller and Perturbation & observes (P&O) for the tracking of the maximum power point which is influenced by the non-linear characteristics of the PV panel depends upon the continuous varying environmental conditions such as temperature and solar radiations. The major problem with the existing solar energy MPPT harvesting technologies is that, the efficiency of solar power system is still very low and the PV system does not operate on its best efficiency corresponds to the non-linear variations, thus Fuzzy Logic Controller is designed and compared with P&O technique for the operation of the MPPT controller for effective operation under non-linear parameters variations. One of the most difficult parts is the designing of the fuzzy logic rules to track the maximum power point and control the DC-DC

converter. The combined PV system with Fuzzy logic controller or P&O in MPPT with DC-DC converter control is shown in Fig.1.

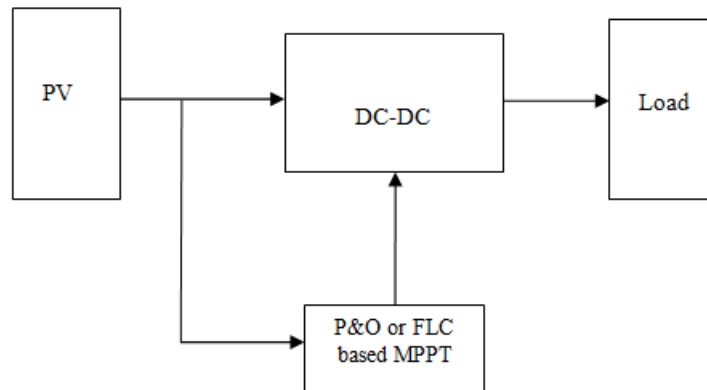


Fig.1 Block diagram of PV system with FLC and P&O based MPPT

II. PV Cell Model

Solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor. When light shines on a solar cell, photons with energy greater than the band gap energy of the semiconductor are absorbed and a large number of electron-hole pairs are created thus P-N junction makes it possible to convert light energy into electrical energy. Generated current from photons is proportional to the incident radiation. The simplest equivalent circuit of a solar cell is a current source in parallel with a diode. A PV module is formed by connecting the number of cells (generally 36, 72) in series and parallel to obtain the desired output voltage and current. The mathematical modeling of the PV cell uses the mono crystalline technology which has the best efficiency among all the commercially available technology [2]-[4].The equivalent circuit model of the solar cell is given in Fig.2.

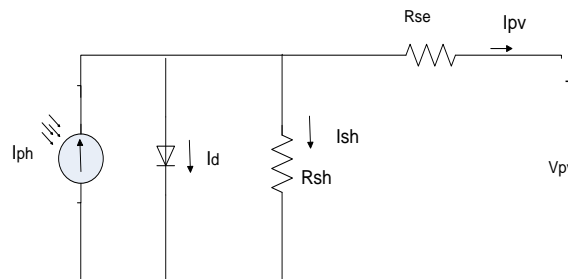


Fig.2 PV cell equivalent circuit

The mathematical expression for the above circuit is obtained from the knowledge of the physics of the PN junction diode and solar cell characteristics is generally expressed as the equations (1) given below.

$$I_{pv} = I_{ph} - I_o \left[e^{\frac{q(V_{pv} + I_{pv}R_{se})}{NKT}} - 1 \right] - \frac{(V_{pv} + I_{pv}R_{se})}{R_{sh}} \quad (1)$$

Where

I_{ph} is the photo current

I_o is the reverse saturation current of diode (A)

q is the electron charge (1.602×10^{-19} C)

V_{pv} is the voltage across the diode (V)

K is the Boltzmann's constant (1.381×10^{-23} J/K)

T is the junction temperature in Kelvin (K)

N is the ideality factor of diode

R_{se} is the series resistance of the diode

R_{sh} is the shunt resistance of the diode

A. Photo current:

The PV cell photocurrent depends on solar irradiance intensity and temperature which is described as equation (2)

$$I_L = \frac{\lambda}{\lambda_{ref}} [I_{sc,ref} + \mu_{Isc} (T - T_{ref})] \tag{2}$$

Where

$I_{sc,ref}$ is solar cell short-circuit current at reference condition.

μ_{Isc} is the solar cell short-circuit temperature coefficient.

On the other hand, the cell's reverse saturation current is described as:

$$I_R = I_{R,ref} \left(\frac{T}{T_{ref}} \right)^{\frac{3}{A}} \exp \left[qE_g \left(\frac{1}{T_{ref}} - \frac{1}{T} \right) / kA \right] \tag{3}$$

Where:

$V_{oc,ref}$ is solar cell open circuit voltage at reference condition;

E_g is band-gap energy in the solar cell, (1.12-1.15eV).

B. Matlab/Simulink model of PV Module:

The effect of shunt resistance (R_{sh}) is neglected as its value is very high and the simplified model equation is given in (4)

$$I_{pv} = N_p * I_{ph} - N_p * I_o \left[e^{\frac{q(V_{pv} + I_{pv}R_{se})}{NKT*N_s}} - 1 \right] \tag{4}$$

Where N_p is the number of parallel connection of cells (in this module $N_p=1$) and N_s is the number of cells connected in series (in this module $N_s=36$). The Matlab/Simulink model of the PV module is given in Fig.3.

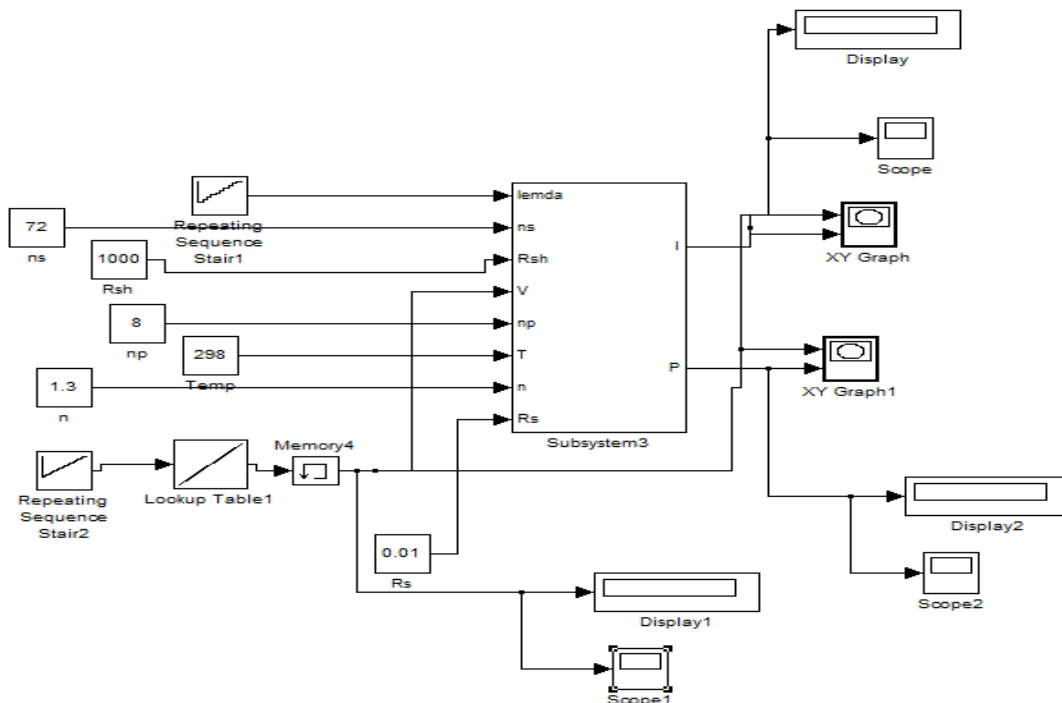


Fig.3 MATLAB/Simulink model of PV Module

Table.1 Electrical specifications of PV module

Parameter	Value
Maximum power (P_{MPP})	727.9 W
Voltage at P_{MPP} (V_{MPP})	76.27 V
Current at P_{MPP} (I_{MPP})	9.54 A
Open circuit Voltage (V_{OC})	89.64 V
Short circuit current (I_{SC})	10.17 A

C. Characteristics of PV module:

The V-I and P-V characteristics of above given module is obtained for a constant temperature of 25⁰C and at 400 W/m² irradiance are given in Fig.4 and Fig.5 respectively.

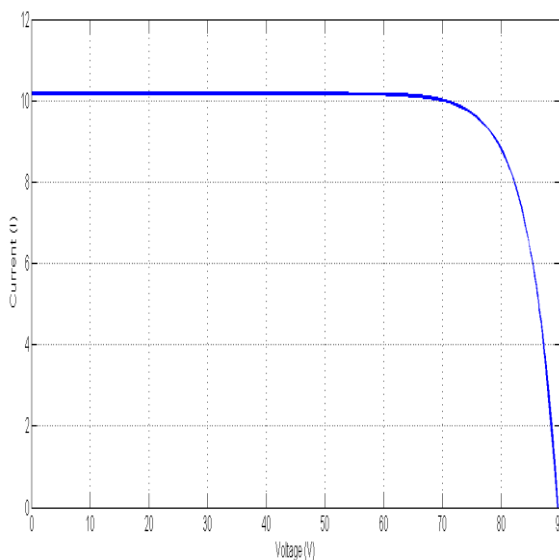


Fig.4 V-I Characteristics

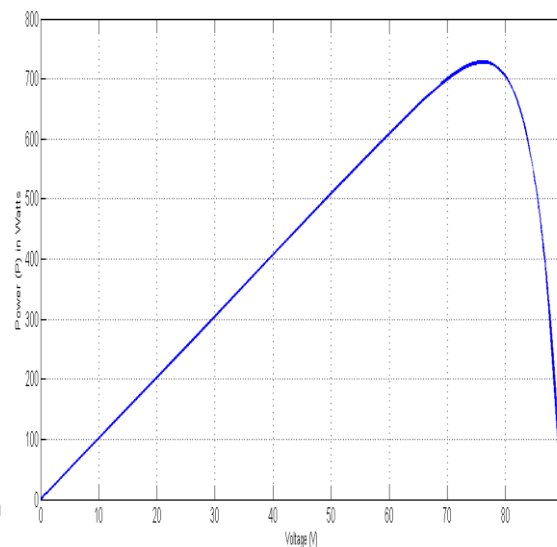


Fig.5 P-V Characteristics

III. Maximum Power Point Tracking

a. MPPT Controller:

MPPT Controller is an electronic DC/DC converter inserted between the PV array and load to achieve the maximum power that PV array can produce. It varies the electrical operating point of the module so that all the modules are able to deliver maximum available power at available temperature and irradiance.

b. MPPT Techniques:

MPPT Techniques are used in PV system to maximize the PV array output power by tracking the MPP continuously which depends on the panel temperature and irradiance.

There are different techniques are used to track the maximum power point [5]-[6]. Few of the most popular techniques are:

- 1) Perturb and observe method (P & O)
- 2) Incremental conductance method
- 3) Fractional short circuit current
- 4) Fractional open circuit voltage
- 5) Fuzzy logic
- 6) Neural networks

The choice of the algorithm depends on the complexity; the time takes to track the MPP and cost of implementation. In this paper P&O algorithm and Fuzzy logic controller are used to track the MPP.

IV. P&O Algorithm

In this algorithm a small error is introduced in the system due to this power of the module changes. If the change in power is positive then the perturbation is continued in that direction. After point MPP, the power at the next instant decreases, then perturbation is reversed. At steady state the algorithm oscillates around the peak point.

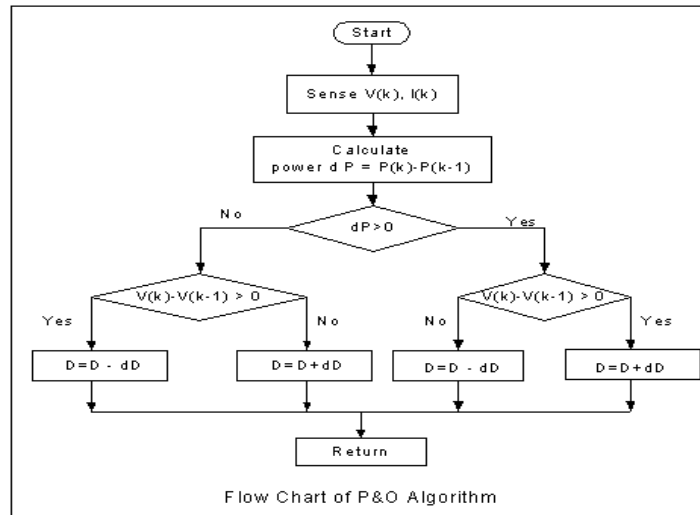


Fig.6 P&O algorithm

V. Dc-Dc Converter

DC–DC converters are generally used for controlling the output voltage and current of the PV module. There are many converters available in the literature which has their own advantages and disadvantages [7]. In this paper we use boost DC-DC converter.

The dc-dc converter is essential to match the load impedance with internal impedance of PV source to fulfill the maximum power transfer criteria.

The values of the capacitor and inductor is calculated as

$$L_{\min} = \frac{D(1-D)^2 R}{2f} \tag{5}$$

$$C = \frac{D}{R \left(\frac{\Delta V_o}{V_o} \right) f} \tag{6}$$

And the basic diagram of boost converter is shown in Fig.7

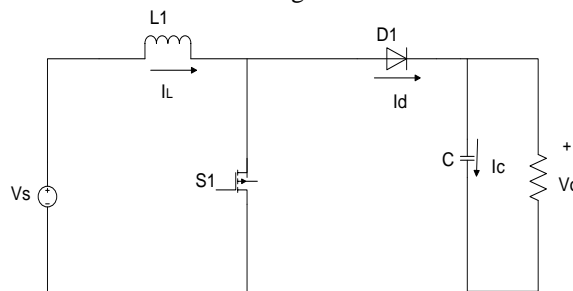


Fig.7 Boost converter

VI. Fuzzy Logic Controller

Fuzzy Logic controllers have been widely used in industrial process in the resented years due to their heuristic nature associated with simplicity, effectiveness and its multi-rule-based variable’s consideration for both linear and non-linear parameter variation of the system. Fuzzy system is composed of knowledge based rules system; the main part of FLC is knowledge of base consisting of the If-Then rules. Fuzzy Logic is implemented to obtain the MPP operation voltage point faster with less overshoot and also it can minimize the voltage fluctuation after MPP has been recognized. The control objective is to track maximum power will lead consequently to effective operation of the PV panel. To design the FLC, variables which represent the dynamic performance of the system should be chosen as the input to the controller. The basic block diagram implemented in fuzzy logic controller is shown in Fig 8.

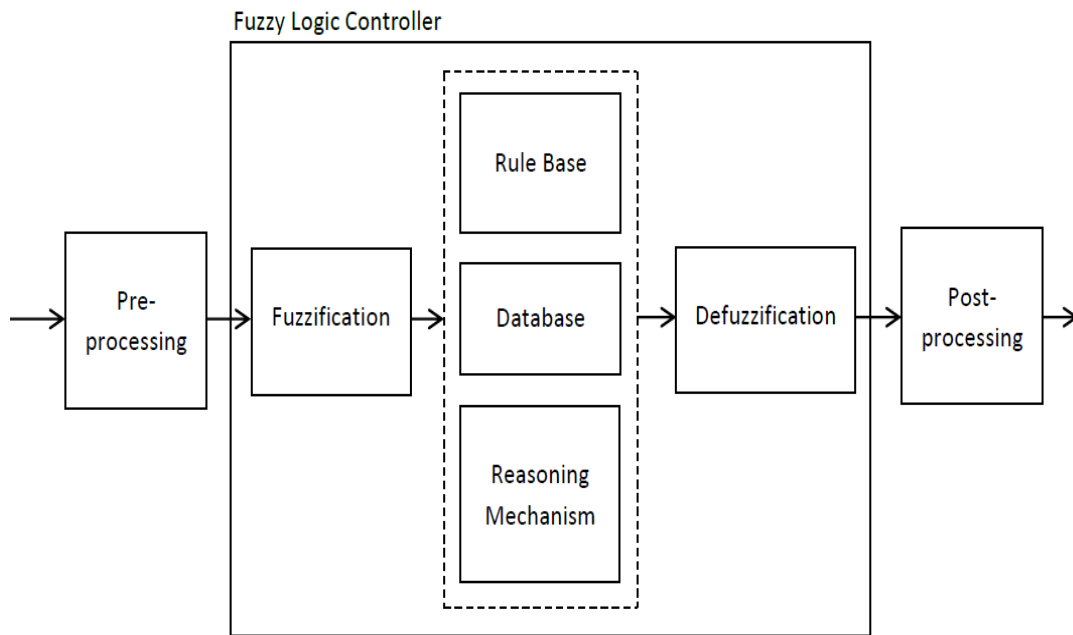


Fig.8 Basic block diagram of Fuzzy logic controller

Fuzzy logic controller is composed of three segments, these are:

A. Fuzzification

In the fuzzification stage, numerical input variables are calculated or converted into linguistic variables based on subset called membership function. To translate the value of change in voltage and change in power, fuzzy input “change in power” and “change in voltage” is designed with seven fuzzy variables called PB (Positive Big), PM (Positive Medium), NS(Negative Small), PS (Positive Small), ZE (Zero), NM(Negative Medium), NB(Negative Big).

Change in voltage and change in power are the input variables in the proposed system and the output from the fuzzy logic controller is the change in the duty cycle. The membership function of the each variable change in voltage and change in power and change in duty cycle is shown in Fig [8-12]

The limits of input and output membership function applied in the system are decided by the previous knowledge of the concerned system parameter variation.

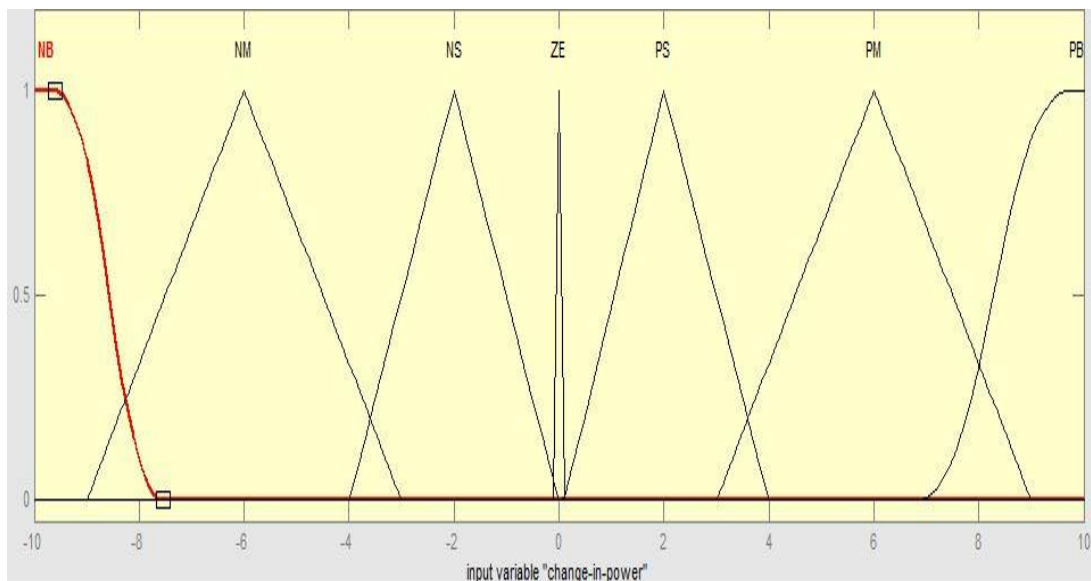


Fig.9 input of FLC change in voltage

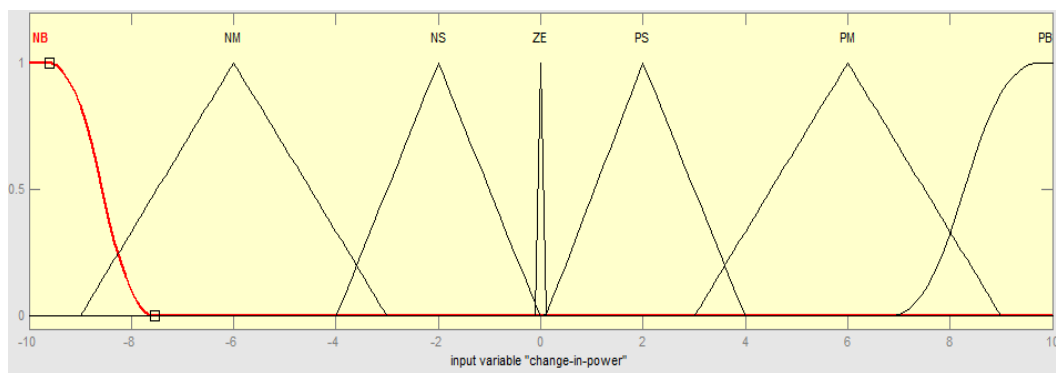


Fig.10 input to FLC as change in power

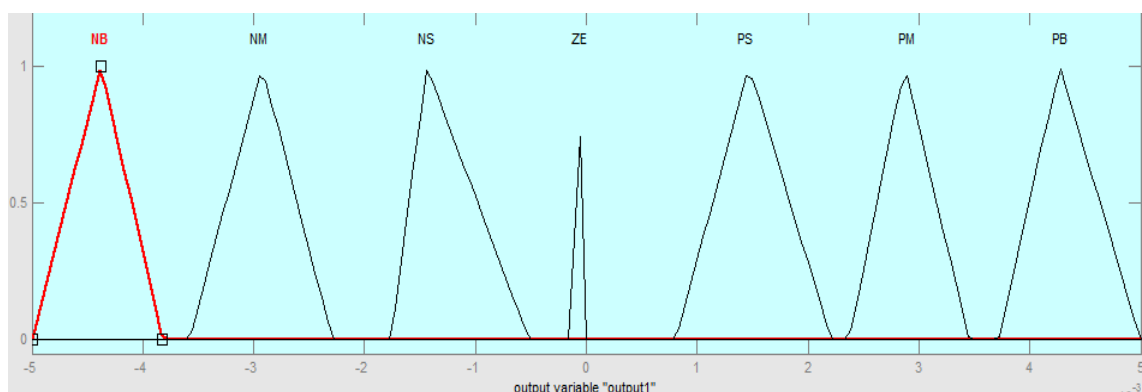


Fig.11 output of the FLC as change in duty cycle

B. Inference system

The fuzzy rule algorithm collects a set of fuzzy control rules in a specific order. These rules are used to control a system to meet the desired performance requirement and they are designed from the expert knowledge of the system under control. The fuzzy inference of the FLC is based on the Mamdani's method which is associated with the max-min composition.

The inference system in a fuzzy logic controller can be subdivided into three parts-

- i. Rule base: - It consists of a number of If-Then rules for the proper operation of the controller. The If side of the rule is called the antecedent and the Then side is called the consequence. These rules can be considered as similar responses made by human thoughts process and the controller uses the linguistic input variables, obtain after fuzzification for the operation of the rules.
- ii. Database:- It consists of all user defined membership function that are to be used in the rules.
- iii. Reasoning Mechanism:- It basically process the given rules and according to a particular rules and given condition provides us the required result.

The rule base defines the rules for the desired relationship between the input and the output variables is illustrated in table 2.

Table.2 rules implemented in the fuzzy logic controller

Dp \ Dv	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PM	PS	NS	NS	NM	NB
NM	PM	PS	PS	NS	NS	NS	NM
NS	PS	PS	PS	NS	NS	NS	NS
ZE	NS	NS	PS	ZE	ZE	NS	NS
PS	NS	NS	NS	PS	PS	PS	PS
PM	NM	NM	NS	PS	PS	PS	PS
PB	NB	NB	NM	PS	PS	PM	PB

C. Defuzzification

The input for the defuzzification process is a fuzzy set and the output is a single number that has to be applied to the system, for the final desired output according to the system a non-fuzzy value of control output is required thus a defuzzification stage is required. There are various defuzzification methods which are used nowadays but most common method are centroid of area and bisector of area. In the proposed scheme centroid defuzzification method is used for defuzzification.

D. Matlab /Simulink Model of fuzzy logic based MPPT

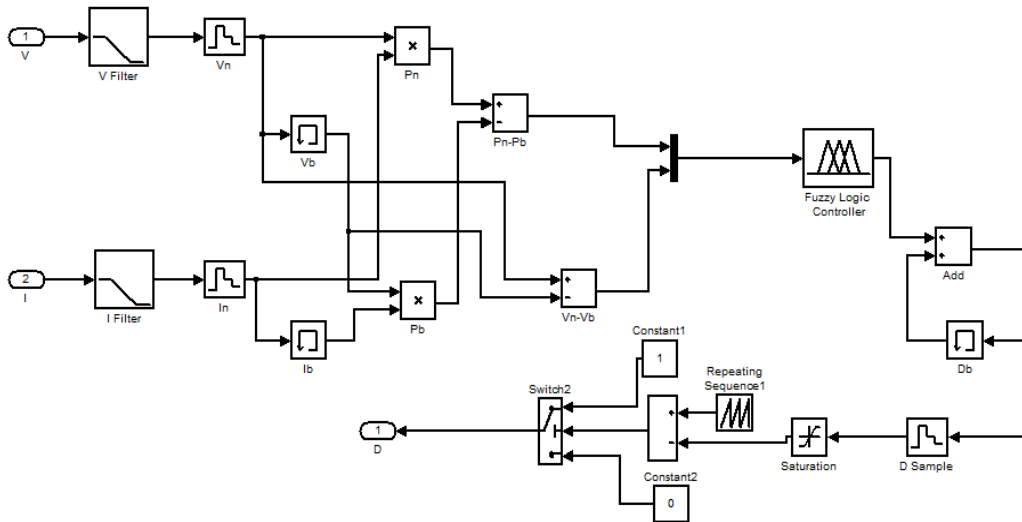


Fig.12 MATLAB/Simulink model of Fuzzy Logic Controller

VII. Simulation Results

The output power of PV module and converter with two different MPPT techniques are obtained in MATLAB/Simulink at irradiance of 400 W/m^2 and temperature of 25°C . The simulation results show the implementation of Fuzzy logic and P&O technique on tracking the maximum power point is given in Fig [13-14]. The corresponding voltage variations in V_{MPP} and V_O for these converters are shown in Fig [15-16].

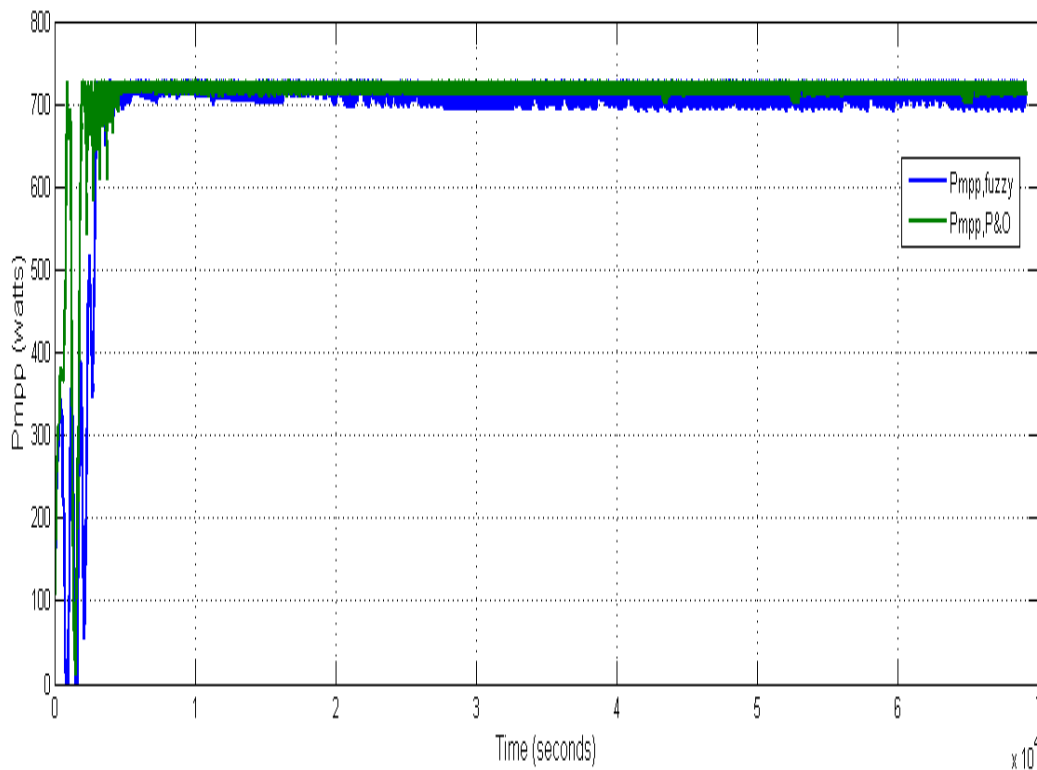


Fig.13 Maximum power of the PV array (P_{MPP})

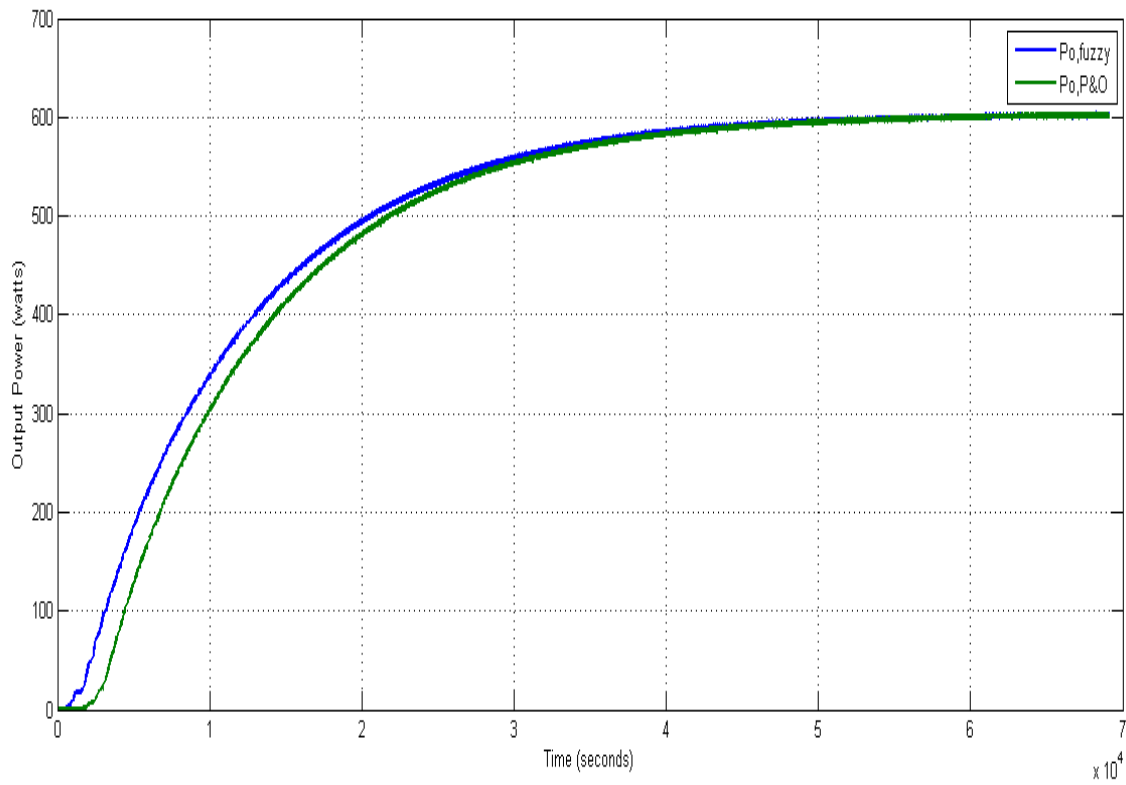


Fig.14 Output Power (P_o)

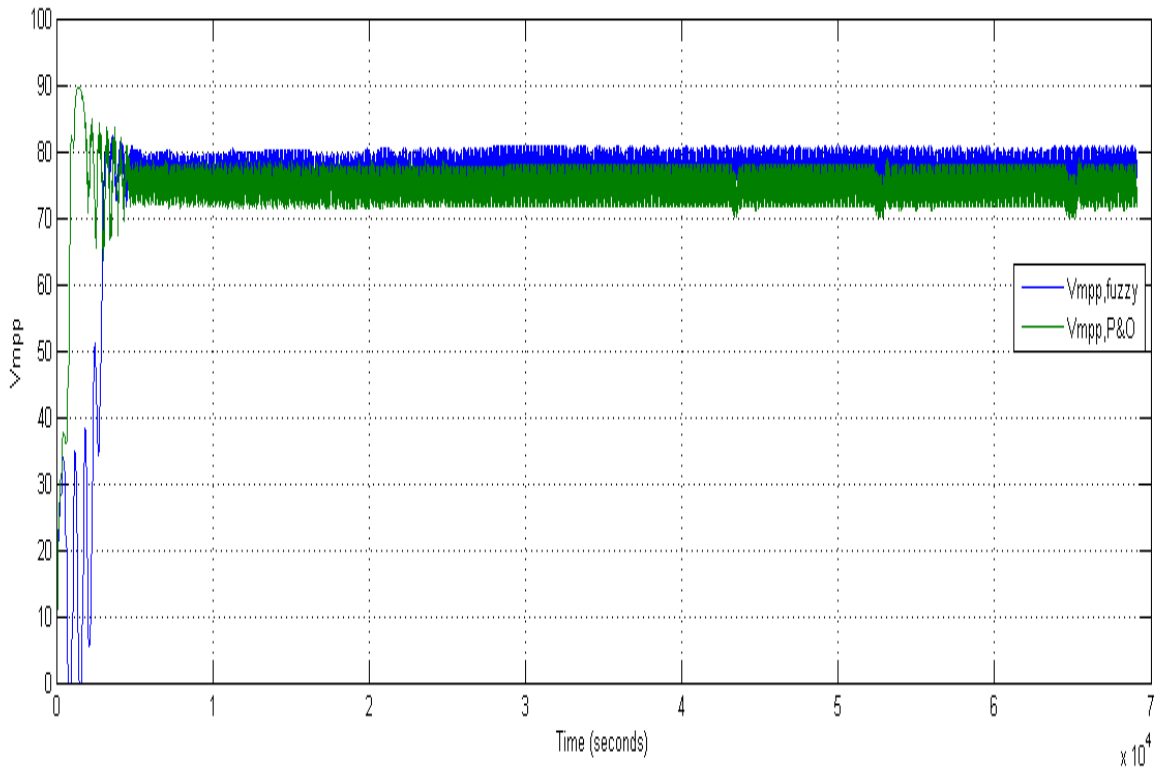


Fig.15 PV array output voltage (V_{MPP})

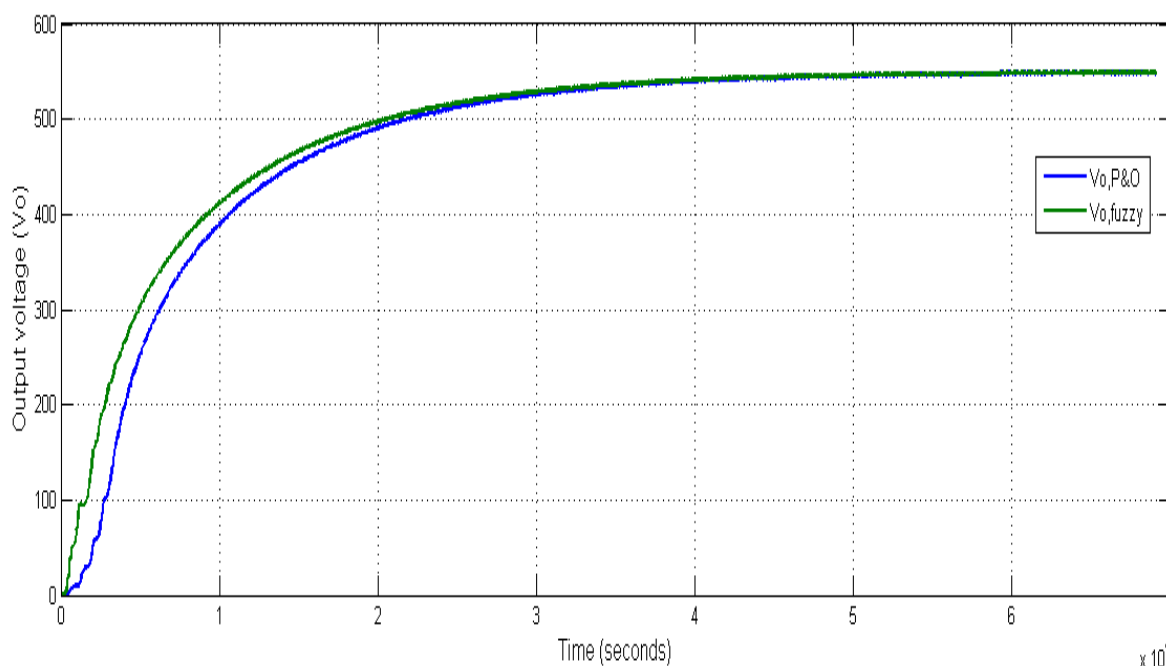


Fig.16 Output voltage (V_o)

VIII. Conclusion

In this paper V-I and P-V characteristics of PV module are obtained using MATLAB/Simulink at temperature of 25°C and irradiance of 400 W/m^2 . The analysis of Fuzzy logic controller and P&O based MPPT is done and the simulation results are presented. From the simulation results, Fuzzy based MPPT tracks the power continuously with less fluctuation also has less overshoot with fast tracking time compared to P&O MPPT algorithm.

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