FUZZY LOGIC BASED ADAPTIVE PERTURBATION AND OBSERVATION MPPT FOR PHOTOVOLTAIC SYSTEM

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ABSTRACT

The I-V and P-V characteristics of Photovoltaic system are non-linear and affected by the change in atmospheric conditions like temperature, Irradiance. For any given atmospheric condition, there is only one operating point where the available power is maximum and known as maximum power Point (MPP). The perturbation and Observation (P&O) MPPT is commonly used to adjust the duty cycle of DC-DC converter and facilitates the PV system to operate at MPP. Due to operational limitations of P&O, there is unwanted power loss during tracking. In this paper Fuzzy Logic Controller (FLC) based P&O MPPT is proposed. The proposed controller used the same principle of P&O, but increase the robustness of the system. The results with P&O and FLC are also compared to find the efficiency improvement in the system by using the FLC MPPT controller.

Keywords- Photovoltaic System, Maximum Power Point Tracking, Fuzzy Logic Control, Adaptive Perturbation and Observation, Solar Energy Conversion.

1. INTRODUCTION

The major electricity demand is fulfilled by fossil fuels, but due to some major issues like environment pollution, global warming, depletion of natural resources and skyrocketing oil cost, renewable energy is allowed to replace the part of conventional electricity production sources. The renewable energy is an abundant source of energy, but unreliability and low efficiency are the major issue associated with it. In general, the reliability of the system is increased by operating the renewable energy and conventional energy plant side by side [1].

Among all the renewable energy sources, solar energy has a significant share. The Photovoltaic (PV) system is used to convert solar energy into electricity. After number of research and development, the efficiency of Solar PV panel is still in the range of 20-25%. The efficiency is further degraded by improper load and weather conditions like temperature, Irradiation, dirt etc. [2]. The I-V and P-V are the two important characteristics of the PV system where I, V and P are the current, voltage and power of the PV module respectively. The point of operation is the crossing point between I-V curve and load line, and for specific atmospheric condition, there is only one point on I-V or P-V curve, where output power is maximum, known as maximum power point. The corresponding load resistance is known as optimal load.

Generally, load is not constant and vary with time. The DC-DC converter with controllable duty cycle is used to adjust the load at PV side. The Maximum Power Point Tracking (MPPT) controller is used to sense the characteristics of PV system and operate the PV system near MPP. The P&O is the simplest, accurate and most widely used MPPT. However, it has some major drawbacks as follows:

- Power tracking speed during rapid change in Irradiance [3]
- Higher oscillation near MPP [4]
- Duty step selection is an issue, which causes slow time response and higher oscillation loss. [5]

The adaptive P&O is generally used to mitigate the drawbacks of the P&O. In [4]-[6], adaptive P&O is proposed and hardware implementation is verified. The decision and logic for the adaptive P&O is complex and need a rigorous analysis of the PV system characteristics. The artificial intelligence based control scheme is the latest and accurate solution for the implementation of MPPT. In [7], [8], error and change in error are used as input signals for generating appropriate control signal using a fuzzy logic controller. The calculation process is the major drawback of this MPPT and it causes significant error in term of time response and accuracy to track MPP.

In this work, the adaptive P&O is implemented using fuzzy logic control. It improves the time response and reduces the oscillation near MPP. The paper is divided into five sections. In section-2, PV system model is discussed and DC-DC converter for implementation of the MPPT is presented. A section-3 discusses the proposed fuzzy logic controller. The simulation and result are presented in section-4. Brief summary of the system is concluded in section-5.

2. PHOTOVOLTAIC SYSTEM AND CONVERTER

The PV module is the solid state p-n semiconductor device which works on the principle of photo effect and converts sun energy into electricity. The basic unit of the PV system is PV cell. The solar energy in the form of photons is falls on the surface of PV cell and generate the moving charge particles (current flow). The junction between p-n works to produce appropriate voltage across the PV cell. The voltage and current rating of the cell are not appropriate for commercial application. Therefore, the number of cells are connected in series and parallel, known as PV module. The PV module is the Irradiance control current source with a lossy diode and series-shunt loss component. The single diode PV model for mathematical implementation is shown in Fig. 1.

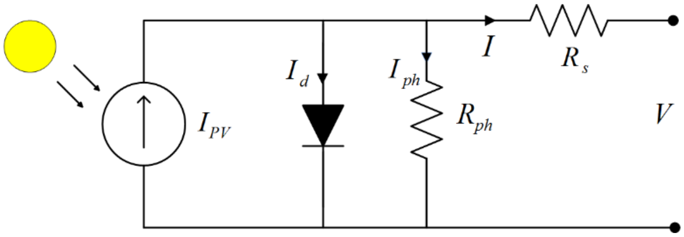

Figure 1. Single diode mathmatical model of PV module

The standard relationship between current and voltage of the module is given by (1).

$$I = I_{PV} - I_o\left(\exp\left(\frac{q(V+R_sI)}{aN_skT}\right) - 1\right) - \frac{V+R_sI}{R_{ph}} \tag{1}$$

where, I_{PV} : Photo current $=I_{scn}((R_p + R_s)/R_{Ph})(G/G_n)$

I_{scn} : Short circuit current at STC

G: solar Irradiance (kW/m^2), G_n: Irradiance at STC

I_o : Diode saturation current, a: Ideality factor

R_s : Series resistance, R_{ph} : Shunt resistance

N_s : No. of series cell, k: Boltzman constant

STC: Standard Test Condition (1000 kW/m^2, 25^o C)

The manufacturer provides some of the important specification of the module like open circuit voltage (V_{ocn}), short circuit current (I_{scn}), maximum power (P_m), V_m and I_m. The rest of the parameters can be calculated easily by using some standard and analytical method. The datasheet of Vikram 200W panel used in this paper, is given in appendix 1. The diode saturation current is calculated by equating (1) at zero current and given as follow:

$$I_o = \frac{I_{scn}+K_I\Delta T}{\exp\left(\frac{V_{ocn}+K_V\Delta T}{V_t}\right)-1} \tag{2}$$

where K_I and K_V are the temperature coefficient of the short circuit current and open circuit voltage respectively. For modeling of PV module, still there are three unknown: a, R_s and R_{ph}. The ideality factor of Si-PV is fixed and the approximate value of 1.22 is reported in many research papers [9]-[10].

In some paper [9]-[10], R_s and R_{ph} are calculated by assuming either R_s=0 or R_{ph}=inf. The analytical method to calculate R_s and R_{ph} by using I-V curve is presented in [11]. The iterative method of parameter calculation is reported in [12]-[13]. In this paper, datasheet value is used to calculate R_s and R_{ph}. The R_{ph} at MPP is given as follow:

$$R_p = \frac{V_{mp}(V_{mp}+I_{mp}R_s)}{\left(V_{mp}I_{mp}-V_{mp}I_o\exp\left(\frac{V_{mp}+I_{mp}R_s}{V_t}\right)+V_{mp}I_o-P_{m,e}\right)} \tag{3}$$

```
1.  Initialize with G,T, datasheet value, n_imax=10000
2.  Set Rs = 0
3.  Calculate Rph = Rpmin from equation (3)
4.  Loop iteration
    A.  Calculate Rph
    B.  Solve I=f(V) for (0<V<Voc) from equation (1)
    C.  Calculate P for (0<V<Voc)
    D.  Choose the maximum power (Pmth)
    E.  Find Perror =Pme - Pmth
    F.  If Perror < tol, than go to step 5
    G.  If n > n_imax, than go to step 6
5.  Print Rs and Rph and exit
6.  Print Rs = 0 and Rph =Rpmin and exit
```

Figure 2. Pseudo code for the calculation of R_s and R_{ph}

An iteration is performed for the variable R_s, start from zero and theoretical maximum power (P_{mth}) for each new set of R_s and R_{ph}, is compared with actual maximum power (P_{me}). For the appropriate value of R_s and R_{ph}, P_{mth} is approximate equal to P_{me}. The Pseudo code of the implemented algorithm is given in Fig. 2. The appropriate value of R_s and R_{ph} are 0.16Ω and 192.12Ω respectively.

The output power of the module is depends upon the Irradiance. The I-V and P-V characteristics of KC200GT 200W PV module at different Irradiance are shown in Fig. 3. Similarly, temperature also affect the I-V and P-V characteristics, but it effect is not much significant.

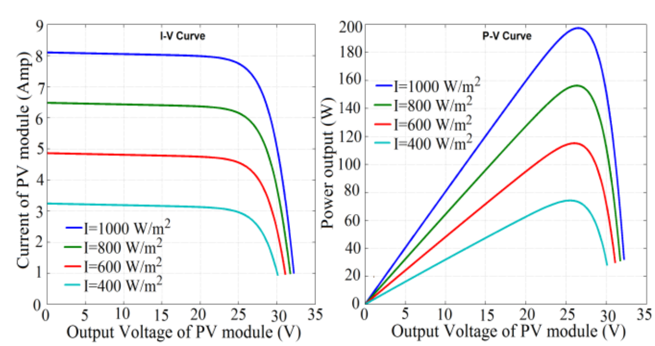

Figure 3. I-V and P-V curve of 200 W at different Irradiance and constant temperature of 25^o C

The load resistance and Irradiance are variable in nature and there is only one specific load resistance, at which PV power is maximum. The DC-DC converter is used to adjust the duty cycle and simultaneously change the apparent resistance at input side. The Buck, Boost and Buck-Boost are the three basic DC-DC converter. Table I shows the basic details of the converter [14].

Table I. Basic relationships for DC-DC converter

	Buck	Boost	Buck-Boost
$\frac{V_o}{Vin}$	D	$\frac{1}{1-D}$	$\frac{D}{1-D}$
R_{in}	$\frac{R_{load}}{D^2}$	$(1-D)^2 R_{load}$	$(\frac{1-D}{D})^2 R_{load}$

In this paper, buck converter is used for MPPT. The basic configuration of Buck converter is shown in Fig. 4. The converter works in two steps: (1) when switch S is close, than current in inductor L increase linearly and (2) when switch is open, inductor release the store energy through diode. The working frequency of 10 kHz, output voltage ripple of 0.5% and ripple of 0.5% in inductor current are considered and the appropriate inductor (L) and capacitor (C) are given by (6) and (7) respectively [14]-[15].

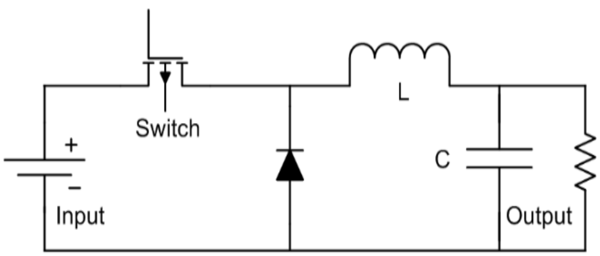

Figure 4. DC-DC Buck converter circuit diagram

A one panel of 200 W is used for the analysis of the controller. So, the maximum output power is 200 W and for the 12 V output voltage, load resisrance is given as:

$$R_{load} = \sqrt{V_{out}^2/P_{max}} = 0.8485\ \Omega \quad (4)$$

$$D = \frac{V_{out}}{V_{in}} = 0.456 \quad (5)$$

$$L = \frac{V_o(1-D)}{2\Delta I_{pv} f_{sw}} = 0.65\ \mu\text{H} \quad (6)$$

$$C = \frac{V_o D}{2\Delta V_o R_{load} f_{sw}} = 228\ \mu\text{F} \quad (7)$$

The MPPT controller regulates the duty cycle of the converter and adjust the apparent output resistance of PV module. The P&O MPPT detects the slope of dP/dV and accordingly adjust the duty cycle. The working principle of P&O is demonstrated in Fig. 5.

3. PROPOSED FUZZY LOGIC MPPT CONTROL

The trends of Artificial Intelligence (AI) controller are increasing due to its ability to solve the complex mathematical model in an easier way. The fuzzy logic (FL) is a most widely used AI, which works on human behavior and there is no need to know the actual mathematical model for generating the result. The FL controller is more flexible than conventional controller, as it is able to solve and design non-linear system [16].

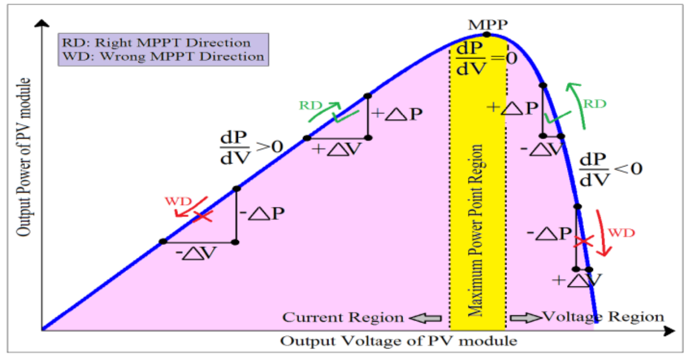

Figure 5. Working demontration of Perturbation and Observation MPPT

The oscillation at MPP and tracking time are the major issue of conventional P&O MPPT. The adaptive P&O is used to remove the drawback of conventional MPPT, but it increases the mathematical computation during controller design. The FL controller works exactly like adaptive P&O and adjust the duty cycle according to the requirement. The FLC helps to reduce oscillation near MPP by decreasing the duty cycle step [17]-[19]. The working algorithm of fuzzy logic MPPT controller is shown in Fig. 6.

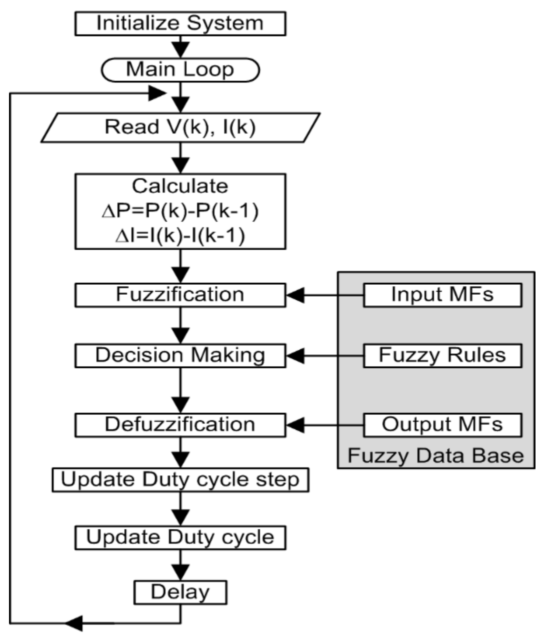

Figure 6. Algorithm for FLC MPPT

The fuzzification, fuzzy logic inference system and defuzzification are the three major stages of FLC. The fuzzification is the conversion of real data into fuzzy linguistic variable based on the membership function (MF). A defuzzification is the conversion of the output linguistic variable into a suitable control signal. The IF-THAN relations between input variable and output signal are set in the fuzzy inference system block. In the proposed controller, change in PV current ($\Delta I(k)$) and change in PV output power ($\Delta P(k)$) are the two input of FLC and defined as:

$$\Delta I(k) = I(k) - I(k-1) \tag{8}$$

$$\Delta P(k) = P(k) - P(k-1) \tag{9}$$

where k represent instantaneous time, P represent PV array output power and V is the output voltage of PV array. The input and output variable are: Positive Big (PB), Positive Medium (PM), Positive Small (PS), Positive (P), Zero (ZE), Negative Small (NS), Negative Medium (NM), Negative Big (NB) and Negative (N). The input and output MFs are shown in Fig. 7. Generally, the range of input and output variables is decided by past experience, experimental result and hit & trial method. For the proposed controller, a range of ΔI(k) and ΔP(k) is from [-.5,0.5] and [-2,2] respectively. The duty cycle step is allowed to vary from -0.01 to 0.01. The FL controller works on the principle of P&O and the adaptive nature of FLC is due to vide range of MFs. The rule of FLC is shown in Fig. 8. The basic set of rules for fuzzy operation are as follow:

$$\begin{cases} if\ ((\Delta P(k) > 0 \,||\, (\Delta I(k) > 0 & than \quad \Delta D\ is\ either\ PS, PM, PB \\ if\ ((\Delta P(k) > 0 \,||\, (\Delta I(k) < 0 & than \quad \Delta D\ is\ either\ NS, NM, NB \\ if\ ((\Delta P(k) < 0 \,||\, (\Delta I(k) > 0 & than \quad \Delta D\ is\ either\ NS, NM, NB \\ if\ ((\Delta P(k) < 0 \,||\, (\Delta I(k) < 0 & than \quad \Delta D\ is\ either\ PS, PM, PB \end{cases} \tag{10}$$

The FLC controller is designed on Matlab simulink using simple (Min-Max) Mamdani interference system. The various methods of defuzzification are available, but in this Centre of Gravity (COG) is used due to its better result. The mathematical form of COG is given by equation (10).

$$D_{out} = \frac{\sum_{i=0}^{n} \Delta d * \mu_{out}(\Delta d)}{\sum_{i=0}^{n} \mu_{out}(\Delta d)} \tag{11}$$

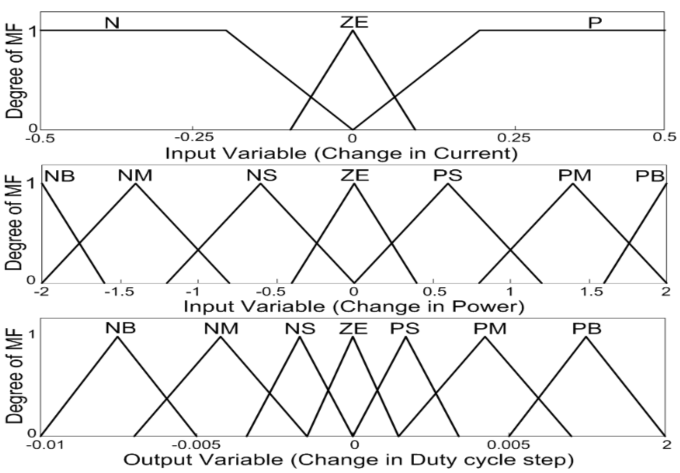

Figure 7. Input and output memebership function (set 1)

ΔP(k) / ΔI(k)	NB	NM	NS	ZE	PS	PM	PB
N	PB	PM	PS	NS	NS	NM	NB
ZE	NB	NM	NS	ZE	PS	PM	PB
P	NB	NM	NS	PS	PS	PM	PB

Figure 8. FLC rule table (set 1)

4. SIMULATION AND ANALYSIS

The Matlab Simulink model used for the performance analysis of P&O and FLC controller is shown in Fig. 9. The model consists of 200 W PV panel, Buck converter and a controller. The variable Irradiance signal for the analysis is shown in Fig. 10. The test signal is suitable enough to check the performance of MPPT under rapid and slow varying atmospheric conditions. A Fuzzy MFs and Fuzzy rules shown in Fig. 7 and Fig.8 are modified and the updated set of FLC MFs and Fuzzy rule are shown in Fig. 11 and Fig. 12 respectively.

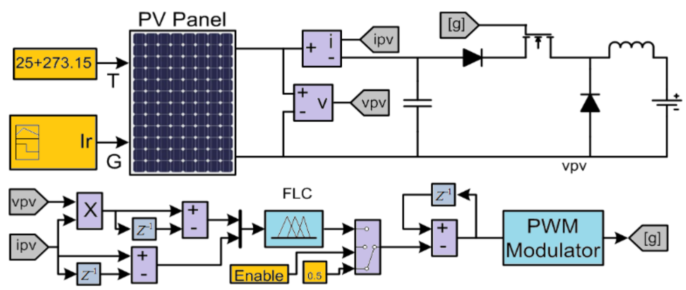

Figure 9. Simulink model for the testing of FLC controller

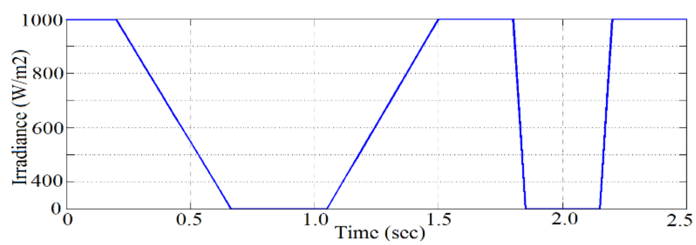

Figure 10. Irradiance signal used for the analysis

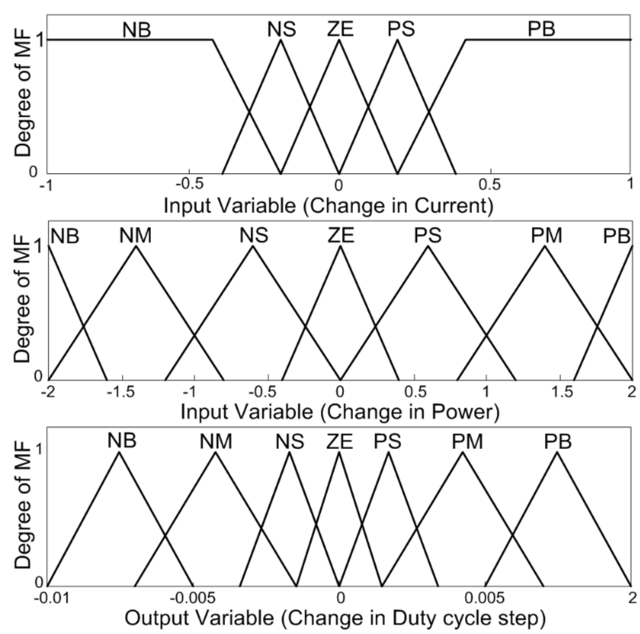

Figure 11. Input and output membership functions (set 2)

ΔI(k) \ ΔP(k)	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	NM	NM	NB	NB
NS	PB	PM	PS	NS	NS	NM	NB
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NB	NM	NS	PS	PS	PM	PB
PB	NB	NB	NM	PM	PM	PB	PB

Figure 12. FLC rule table (set 2)

The Simulation result of P&O is shown in Fig. 13. It shows that there is a continuois oscillation at MPP. Also, it is slow to track the MPP under rapid variation in Irradiance. As shown in Fig. 14, the FLC (set 1) MPPT reduces the oscillation significantly, but it faces unstability problem under low Irradiance condition. The simulation result for slightly modefied FLC (set 2) is shown in Fig. 15. The FLC (set 2) redcues the tracking time and also reduces the osicllation at MPPT. The close view of P&O and FLC (set 2) controller response to track MPPT under sudden change in Irradiance is shown in Fig. 16.

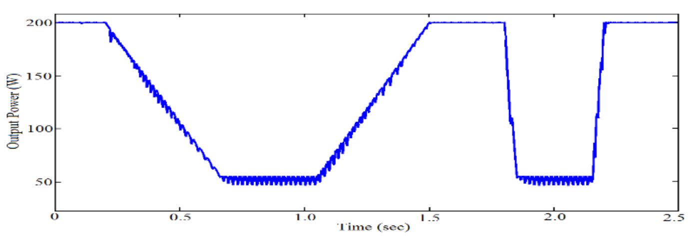

Figure 13. PV module utput power for P&O controller

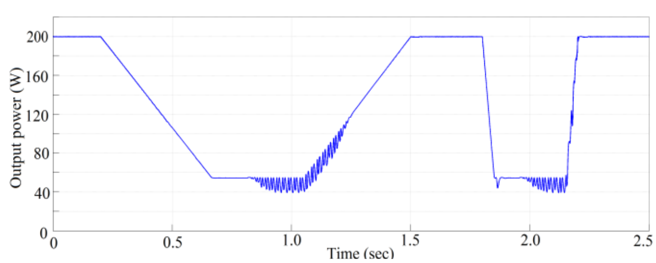

Figure 14. PV module utput power for FLC controller (set 1)

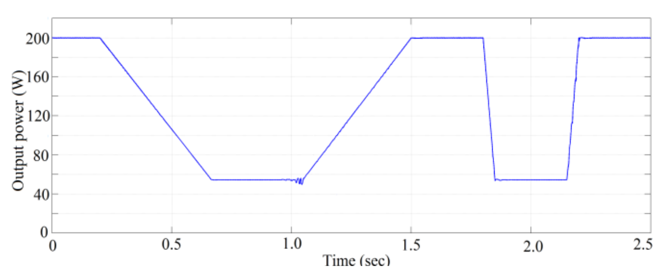

Figure 15. PV module output power for FLC controller (set 2)

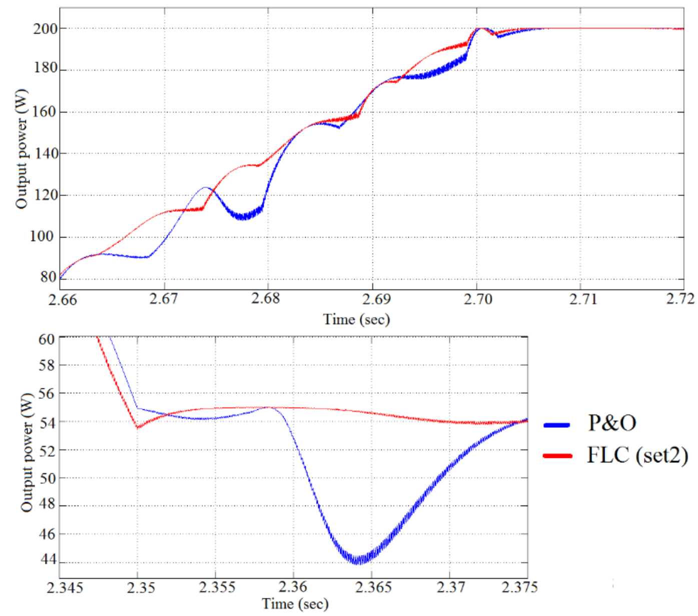

Figure 16. Comparison of tracking speed for P&O and FLC controller

5. CONCLUSIONS

In this paper, a Fuzzy Logic is used for the implementation of MPPT controller. For proper study, an accurate mathematical PV array model and appropriate converter are also presented in brief. A matlab simulink model is used for the analysis of MPPT controller. A P&O MPPT is compared with two different FLC controller. The results show that FLC based adaptive P&O improves the tracking time and reduces the effect of oscillation near MPP. The result also indicates that proper selection of MFs and rules are essential for the good result and the response can be improved further by adjusting the MFs and rules.

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APPENDIX

Datasheet of 200W KC200GT PV module A.1

P_{max}	200.1 W_p
$V_{oc,n}$	32.9 V
$I_{sc,n}$	8.21 A
I_{mpp}	7.61 A
V_{mpp}	26.3 V