Simulation of fuzzy-based MPP tracker and performance comparison with perturb & observe method

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Abstract - *Photovoltaic electricity is seen as an important source of renewable energy. The photovoltaic array is an unstable source of power since the peak power point depends on the temperature and the irradiation level. A maximum peak power point tracking is then necessary for maximum efficiency. In this work, a maximum power point tracker for photovoltaic panel is proposed. Fuzzy input parameters,* dP/dV *and variation of duty cycle* (ΔD)*, are used to generate the optimal MPP converter duty cycle, such that solar panel maximum power is generated under different operating conditions. A photovoltaic system including a solar panel, a DC-DC converter, a Fuzzy MPP tracker and a resistive load is modelled and simulated. Finally performance comparison between fuzzy logic controller and Perturb and Observe method has been carried out witch has shown the effectiveness of fuzzy logic controller to draw much energy and fast response against change in working conditions.*

Résumé - *L'électricité photovoltaïque est perçue comme une importante source d'énergie renouvelable. Le champ photovoltaïque est une source de puissance instable, dont le point de puissance crête dépend de la température et de l'irradiation. Un suiveur du point de puissance maximale est alors nécessaire pour une efficacité optimale. Dans ce travail, un tracker du point de puissance maximale pour un panneau photovoltaïque est proposé. Les paramètres flous d'entrée,* dP/dV *et la variation du rapport cyclique* (ΔD)*, sont utilisés pour générer l'optimum du point de puissance maximale et en convertissant le rapport cyclique, tels que la puissance maximale des panneaux solaires soit produite sous différentes conditions de fonctionnement. Un système photovoltaïque, composé d'un module solaire, d'un convertisseur DC-DC, d'un contrôleur MPP flou et d'une charge résistive, est modélisé et simulé. Enfin, une comparaison des performances a été effectuée entre un contrôleur flou et un contrôleur utilisant la méthode 'perturber et observer'. Elle a montré que l'efficacité du contrôleur flou est de tirer le maximum d'énergie et avec un temps de réponse rapide lors des variations dans les conditions de travail.*

Key words: MPPT Tracking – Fuzzy logic – Perturb & Observe – PV system.

1. INTRODUCTION

Nowadays, photovoltaic electricity has become of great interest especially with the availability of solar panels with acceptable prices and efficiencies. More over, power semiconductor switches are now available with high working frequency and power rate witch can perform energy conversion with high efficiency.

Stand alone and grid connected applications of solar energy have increased considerably over the last decades. These applications include water pumping, refrigeration air conditioning, light sources, electric vehicle, PV power plants, military and space applications. The efficiency of the solar energy conversion is related with the maximum power extraction of photovoltaic system [1].

Maximum power extraction can be obtained by realizing dynamic or static methods. In the dynamic method the maximum power (MPP) is achieved based on sun movement tracking. This approach may not be suitable for energy conversion at a small to medium power range due to its high cost and energy consumption. In the static method, witch is suitable for small power range; the maximum power is tracked using power converter with high frequency to adjust continuously the operating point at the MPP.

In the literature, there have been reported many methods to track the maximum power point of PV generator. The Perturb and Observe method 'P & O' is a widely used approach for tracking MPP coordinates. In this method the operating point of the solar panel is continuously changed by increasing or decreasing the panel operating voltage and observing the effect on the output power [2]. The voltage reference method is based on the minimisation of the error between a fixed or variable reference voltage and the output voltage of the PV panel [3].

The fuzzy logic controller can be more adequate in cases where the system is nonlinear. This method is also effective tool to deal with disturbances and uncertainties in term of vagueness, ignorance and imprecision. In addition, this method is effective in applications where there is wide experience operating the plant, due to the possibility of incorporating such knowledge in terms of qualitative rules [4].

In this work, firstly we derive the model of the photovoltaic panel and the average model of boost converter working in continuous conduction mode and then combined together with other bloc existing in the system. The operating point of the panel is set at MPP by adjusting the duty cycle of the boost converter using fuzzy logic control method. Finally, comparative simulation is carried out between fuzzy logic controller and 'P & O' method is carried out to compare their performance in the process of tracking the MPP.

2. SYSTEM DESCRIPTION

The circuit diagram of the energy conversion system is shown in Figure 1. The system consists of photovoltaic panel, a DC-DC boost converter, a control unit and a resistive load.

The first stage of the system is solar panel (Atersa 75). The I-V characteristic of a panel depends on the temperature and solar irradiance. The three most important characteristics of PV panel are the short circuit current, open circuit voltage and the MPP that is are function of temperature and irradiance.

The power stage is the well known Boost converter witch its duty cycle is continuously adjusted to track the maximum power point that can be delivered by the PV panel at a given irradiance and temperature.

The MPP tracker, witch is based on fuzzy logic control, has the objective to draw as much power as possible from the PV module by adjusting continuously the duty cycle of the DC-DC converter. This point corresponds to the maximum power point (MPP) on the PV curve.

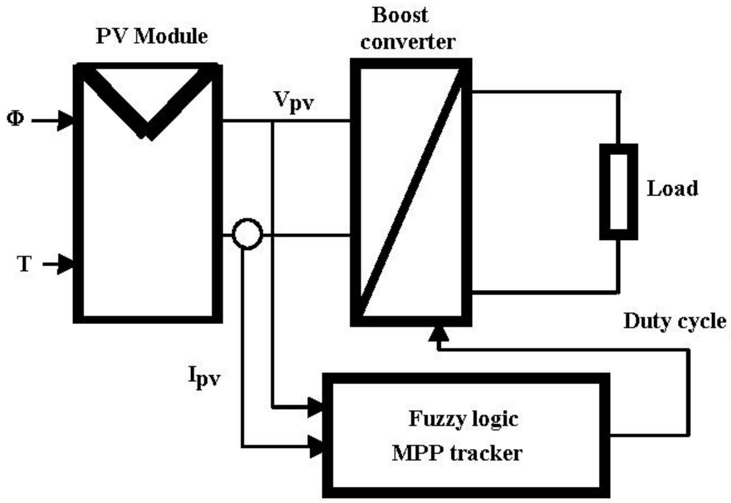


Fig. 1: Schematic diagram of the proposed power conversion

The following sections deal with modelling of the different parts of the conversion system and validation of the methodology by simulations.

3. PV MODELLING

The most general model for solar cell, derived from physical characteristics, is the so called one diode model. In Figure 2 it is shown the equivalent circuit of photovoltaic cell, where the current source is the light generated current witch 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 [5].

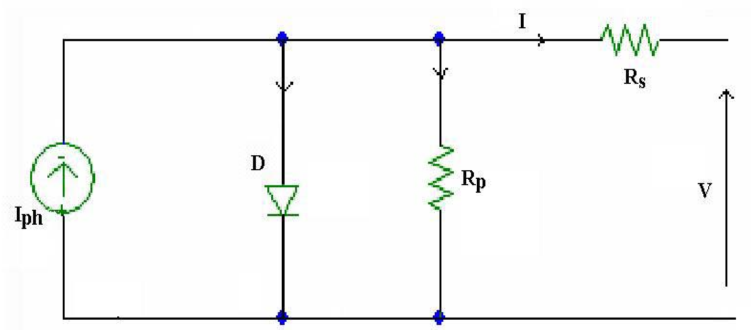


Fig. 2: Equivalent circuit of PV cell

The mathematical model witch relates the output current to the output voltage is given by the following expression:

$$I = I_{ph} - I_0 . \left[\exp \left(\frac{V + R_s . I}{m \, V_t} - 1 \right) \right] - \frac{V + R_s . I}{R_{sh}} \quad (1)$$

where I_{ph} is the photo generated current, I_0 the diode leakage current, V_t the thermal voltage, m the ideality factor of the diode, R_s and R_p are the series and shunt resistance respectively.

In Figure 3 and 4 it is reported the $I-V$ and $P-V$ characteristics, under different level of irradiation of the solar panel.

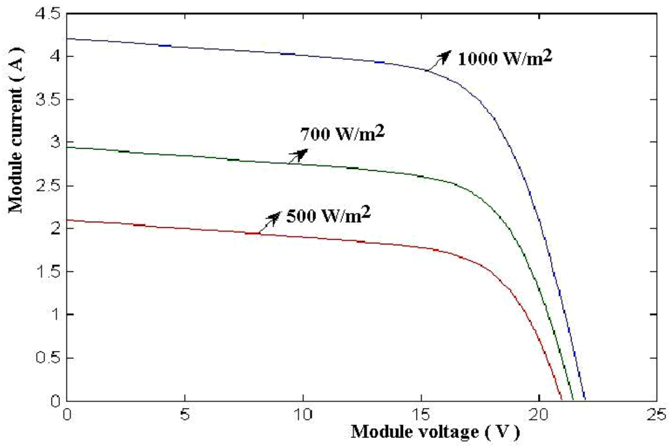


Fig. 3: The I-V characteristic of PV panel

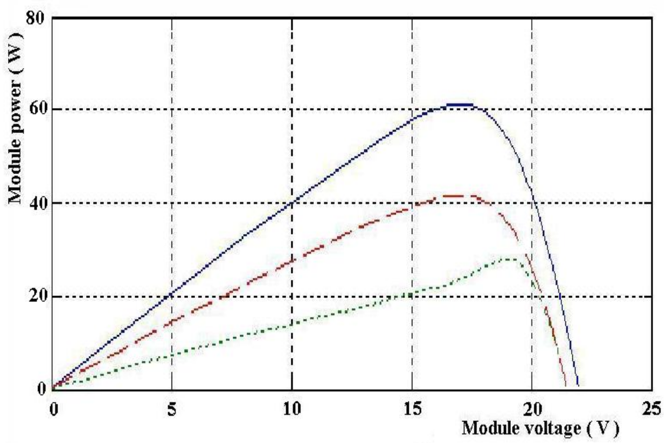


Fig. 4: The P-V characteristic of PV panel

4. DC/DC CONVERTER MODELLING

In Figure 5 it is shown the electrical circuit of a boost converter. The power switch is responsible to modulate the energy transfer from the input source to the load by varying the duty cycle D [6]. The relationship between input and output voltages of boost converter operating at steady state condition is given by:

$$\frac{V_0}{V_i} = \frac{1}{1 - D} \tag{2}$$

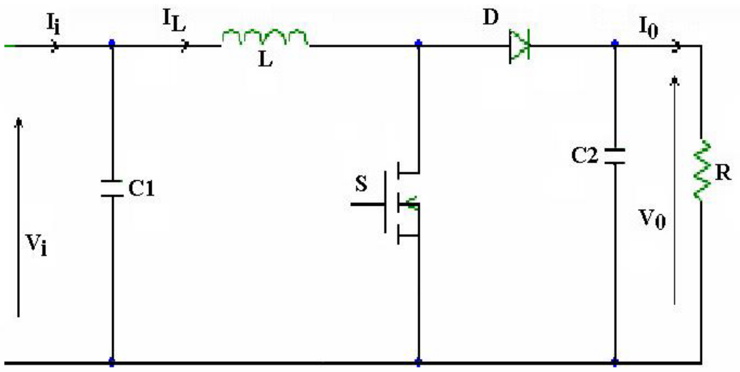
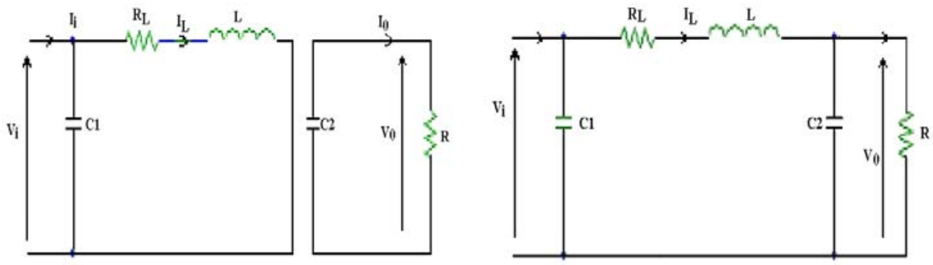


Fig. 5: Boost converter circuit

The relationship between the voltage gain of the converter and duty cycle is not linear. The voltage gain increase/decrease with increasing/decreasing the duty cycle of the converter. Thus increase/decrease in duty cycle of the converter causes the operating point of the solar panel to move to the right/left side of the I-V characteristic.

The equivalent circuit of the boost converter in the ON and OFF state of the power switch are shown in Figure 6.



(a) (b)

Fig. 6: Equivalent circuit of boost converter
(a) ON state – (b) OFF state

ON state

The ON state is described by the following equation.

$$\begin{aligned} i_{c1} &= C_1 \frac{d v_i}{d t} = i_i - i_l \\ i_{c2} &= C_2 \frac{d v_0}{d t} = - i_0 \\ v_L &= L \frac{d i_L}{d t} = v_i - R_L i_L \end{aligned} \tag{3}$$

OFF state

The OFF state is described by the following equations.

$$
\begin{aligned}
i_{c1} &= C_1 \frac{d\,v_i}{d\,t} = i_i - i_L \\
i_{c2} &= C_2 \frac{d\,v_0}{d\,t} = i_L - i_0 \\
v_L &= L \frac{d\,i_L}{d\,t} = v_i - v_0 - R_L\, i_l
\end{aligned} \tag{4}
$$

Assuming that the boost converter is working in continuous conduction mode, the average model is given by the following expression [8].

$$
\begin{aligned}
C_1 \frac{d\,v_i}{d\,t} T_s &= D\,T_s\left(i_i - i_L\right) + \left(1 - D\right)T_s\left(i_i - i_L\right) \\
C_2 \frac{d\,v_i}{d\,t} T_s &= -\,D\,T_s\, i_0 + \left(1 - D\right)T_s\left(i_L - i_0\right) \\
L \frac{d\,i_L}{d\,t} T_s &= D\,T_s\left(v_i - R_L\, i_L\right) + \left(1 - D\right)T_s\left(v_i - v_0 - R_L\, i_L\right)
\end{aligned} \tag{5}
$$

5. FUZZY LOGIC CONTROLLER

The method is based on perturb and observe technique, in witch the input variables are the slope of the **P-V** curve '$\Delta P / \Delta V$' and the previous perturbation in the duty cycle 'ΔD_{k-1}'. These variables are expressed as linguistic variables denoted **BP** (Big Positive), **BN** (Big Negative), **SP** (Small Positive) and **SN** (Small Negative).

The first step is the fuzzification of the input variables by using trapezoidal MFs. The second step, inference rules, where the fuzzified variables are compared with predefined sets in order to get the appropriate response. The last stage is defuzzication of the rules in order to obtain the crisp values of the duty cycle perturbations.

Figure 7 shows the schematic diagram of the proposed fuzzy logic controller and in **Table 1** it is summarized the different fuzzy rules used in the fuzzy controller to track the maximum power point.

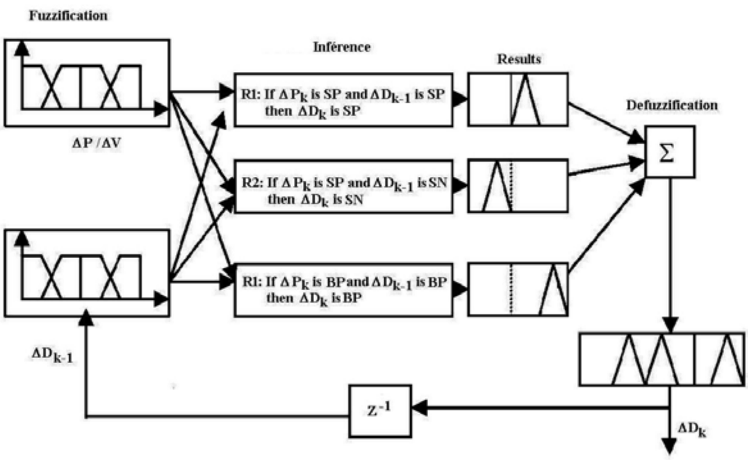


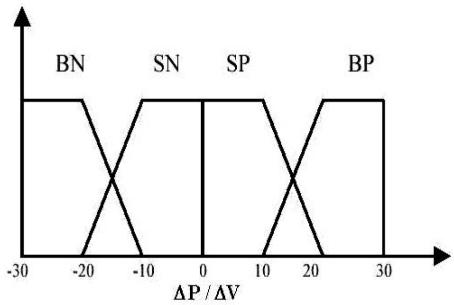
Fig. 7: Schematic diagram of the proposed fuzzy logic controller

Table 1: Base Rules used by the fuzzy logic controller

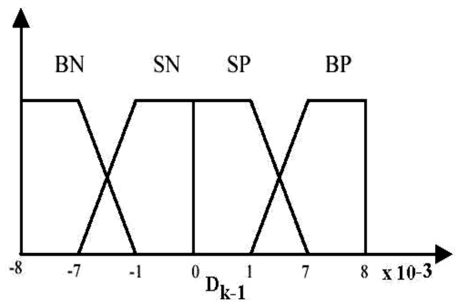
Rules	$\mu\left(\frac{\Delta P_k}{\lvert\Delta V_k\rvert}\right)$	$\mu(\Delta D_{k-1})$	$\mu(\Delta D_k)$	Rules	$\mu\left(\frac{\Delta P_k}{\lvert\Delta V_k\rvert}\right)$	$\mu(\Delta D_{k-1})$	$\mu(\Delta D_k)$
R1	SP	SP	SP	R9	SP	BP	SP
R2	SN	SP	SN	R10	SN	BP	SN
R3	BP	SP	BP	R11	BP	BP	SP
R4	BN	SP	BN	R12	BN	BP	BN
R5	SP	SN	SN	R13	SP	BN	SN
R6	SN	SN	SP	R14	SN	BN	SP
R7	BP	SN	BN	R15	BP	BN	SP
R8	BN	SN	BP	R16	BN	BN	SP

The member chip functions of the fuzzy variables were established from several simulation trials to get experience on the discourse domain of each variable of the fuzzy controller. It was found that in order to track continuously the MPP, SP and SN of the input variables must be very close at the origin.

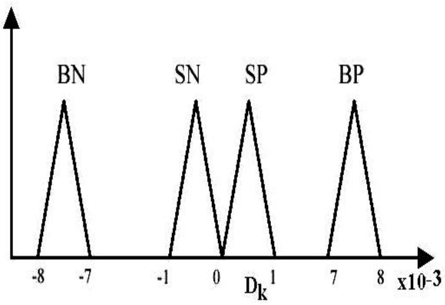
In Figure 8, it is reported the member chip functions of the fuzzy variables.



(a)



(b)



(c)

Fig. 8: (a, b) MFs of the input variables, (c) MF of the output variable

6. PERTURB AND OBSERVE ALGORITHM

It's the most used algorithm to track the MPP. It's principle is based on the perturbation of the system by the increase/decrease of the duty-cycle of the converter and the observation of the effect on the output power.

If the actual power $P(k)$ is higher than the previous power, $P(k-1)$, then the perturbation is kept in the same direction, otherwise the perturbation is inverted.

In Figure 9 it is given a flowchart witch describe the P & O technique.

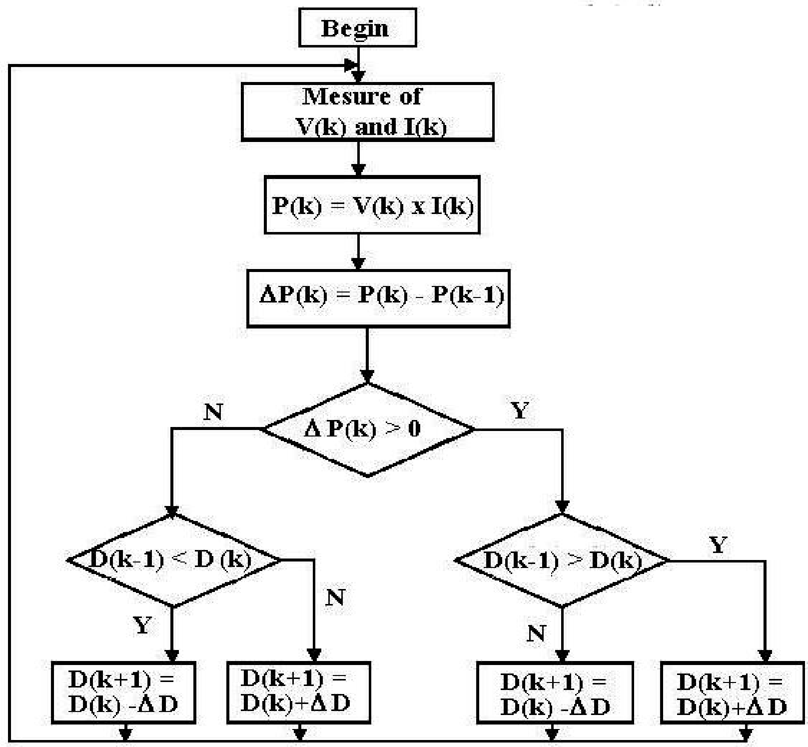


Fig. 9: Flowchart of the Perturb and Observe method

7. SIMULATION RESULTS

The proposed power conversion system was simulated using Matlab_Simulink simulation program to validate the control strategy and evaluate the performance of the system.

The output power is measured and evaluated in the control unit based on the fuzzy logic control approach to obtain a new value for the duty cycle required to produce maximum output power.

Figure 10 shows the bloc diagram of the plant incorporating fuzzy logic controller.

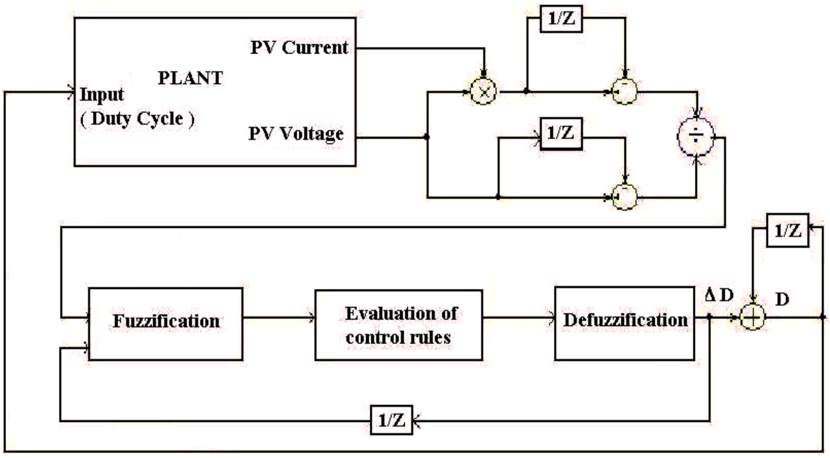
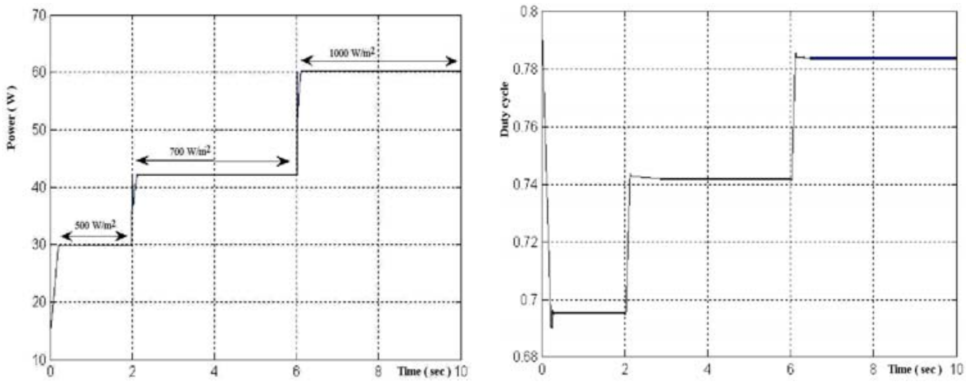


Fig. 10: Bloc diagram of the plant and fuzzy logic controller

In Figure 11, there are three periods of operation (0-2s, 2s-6s, 6s-10s), corresponding to irradiance values of 500, 700 and 1000 W/m^2, respectively in witch the sampling period is fixed at 1 ms.

During each period, the controller adjusts the duty cycle of the converter to produce maximum power corresponding to the irradiation of the given period. We note here the fast response of the fuzzy controller, thus the power losses due the search process are minimized.



(a) (b)

Fig. 11: Simulation results: (a) Maximum output power and (b) Duty cycle variation

In Figure 12 it is reported the simulation results of the output power of the PV panel using Perturb an Observe method and fuzzy logic controller. We note that both methods show converge to the same value of MPP at steady sate. However, when the irradiation changes rapidly the fuzzy logic controller shows a better time response than perturb and observe method. Thus there is a significant loss of energy when using P & O algorithm especially in large scale photovoltaic system.

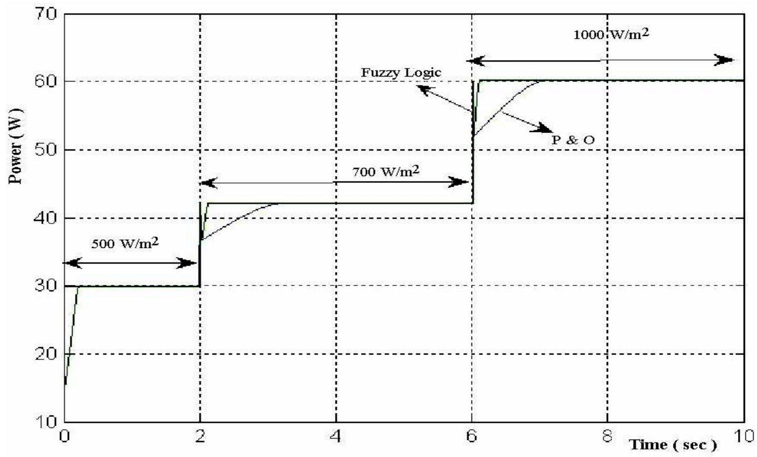


Fig. 12: Comparison of output power

8. CONCLUSION

In this work, an energy conversion system, witch includes a PV panel, a DC-DC converter and fuzzy logic controller to track the maximum power point is presented. The performance of the panel-boost converter was simulated employing fuzzy logic control strategy.

The results obtained from simulation employing fuzzy logic approach show a good dynamic performance of the controller to track the MPP of the PV panel even under rapid change of the irradiation.

The simulations have shown that the use of fuzzy logic controller can improve the efficiency of the overall system by minimizing the energy losses when the change of irradiation is frequent rather than the classical method such as perturb and observe technique.

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