Modeling, Development and Analysis Performance of an Intelligent Control of Photovoltaic System by Fuzzy Logic Approach for Maximum Power Point Tracking

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Abstract: In this paper, we present an intelligent algorithm based upon Fuzzy Logic method for optimizing and improving the control performance of a photovoltaic system. The main objective of the proposed system is to pursuit the maximum power point (MPPT) under different conditions like the change of sunshine and temperature. The system consists of a photovoltaic solar module connected to a DC-DC step-up converter "Boost" and a battery - like a load . The converter parameters and the inference rule table are determined to ensure maximum output power. The effectiveness of the proposed system is validated through computer simulations using MATLAB / Simulink software and the obtained results shows that our proposed system has the best performance in term maximum power.

Keywords: Model Solar, Photovoltaic system PV, Fuzzy logic controllers, the Pulse width modulation (PWM), Chopper Boost.

1. Introduction

Photovoltaic (PV) systems are a promising alternative to replace fossil fuels. To encourage industry to use this new resource, the design of all parts of the photovoltaic system must be improved, thereby increasing its energy efficiency. To do so, it is imperative to optimize the DC/DC (direct to direct) converters used as an interface between the photovoltaic generator and the load in order to extract the maximum power and thus operate the GPV generator at its maximum power point (MPP) using an MPPT (maximum power point tracking) controller[1,2]. As a result, we obtain maximum electrical current under varying load and atmospheric conditions (temperature and brightness).
Many MPPT reliable control techniques have been developed, starting with simple techniques such as MPPT controllers based on voltage and current feedback, to more powerful controllers using algorithms to calculate MPP of the GPV[3,4,5,6,7], among the most frequent techniques:

- ✓ Disturbance and Observation (P&O)
- ✓ Incrimination of Conductance (IC)
- ✓ Open circuit voltage (OPV)
- ✓ Neural networks (RN)

In this work, an intelligent Control of photovoltaic system based on Fuzzy Logic has been modeled and verified to ensure the maximum power point tracking.

The remainder of this paper is organized as follows: Section 2 discusses the proposed Photovoltaic System, modeling system, simulation results and performance analysis are discussed in Section 4. Finally, a conclusion is given in Section 5.

2. The Proposed Photovoltaic System

The Figure 1 shows us that a photovoltaic system consists of a: photovoltaic panel, static DC-DC converter and control system.
The main role of the static converter is to make an impedance adaptation so that the panel can deliver the maximum energy.

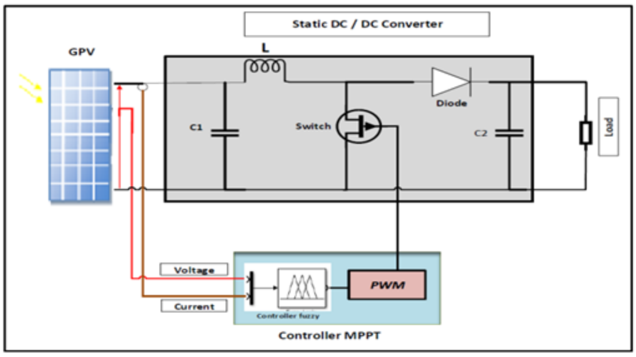

Figure 1. Photovoltaic system

2.1 Photovoltaic Cell Model

The elementary component of the photovoltaic panel is the photovoltaic cell [8].
It is considered an ideal source of current providing a current proportional to the incident light power, in parallel with a diode which is represented by the P-N junction.

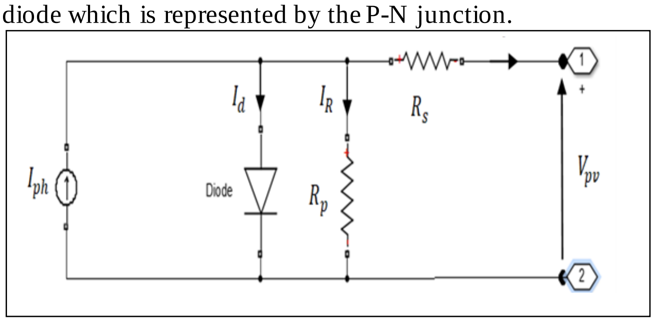

Figure 2. Equivalent PV Cell Diagram

The PV cell can be modeled by Figure 2 whose corresponding equations are as follows [9]:

$$I_{pv} = I_{ph} - I_d - I_R \tag{1}$$

The current I_{ph} is given by the following equation:

$$I_{ph} = \left(I_{cc} + K_i \Delta T\right)\frac{E}{E_n} \qquad (2)$$

The current at the junction is as follows:

$$I_d = I_s\left[\exp\left(\frac{V_{pv} + R_s I_{pv}}{nV_T}\right) - 1\right] \qquad (3)$$

The current in the resistor R_p is equal to:

$$I_R = \frac{V_{pv} + R_s I_{pv}}{R_p} \qquad (4)$$

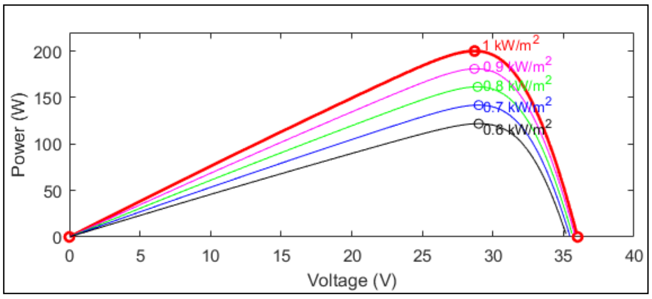

Figure 3. The P-V curve of GPV with varying brightness and temperature

The maximum power of a GPV Photovoltaic Generator is influenced by the variation in brightness and temperature. In the Figures 3 and 4, the GPV is subject to brightness Variations where the decrease in power and the change in the maximum power point MPP are clearly visible [10, 11].

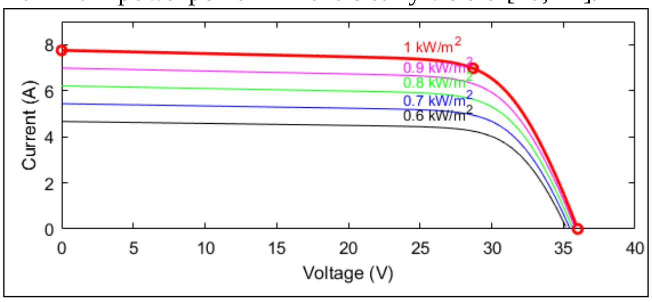

Figure 4. The I-V curve of GPV with varying brightness and temperature.

2.2 Static Converter (BOOST Chopper)

The DC-DC converter is an interface that allows adaptation between the PV panel and the load in order to extract the maximum power from the panel [12, 13, 14].For t between [0,αT], the transistor is on. Subsequently, the converter can be modeled by the following equations [15]:

$$\frac{dI_L}{dt} = \frac{V_1}{L} \qquad (5)$$

$$\frac{dV_2}{dt} = -\frac{V_2}{C_s R_L} \qquad (6)$$

For t between [αT, T], the transistor is blocked. Subsequently, the converter can be modeled by the following equations:

$$\frac{dI_L}{dt} = \frac{V_1 - V_2}{L} \qquad (7)$$

$$\frac{dV_2}{dt} = \frac{i_L}{C_s} - \frac{V_2}{C_s R_L} \qquad (8)$$

T is the period of the static converter and α is the duty cycle.

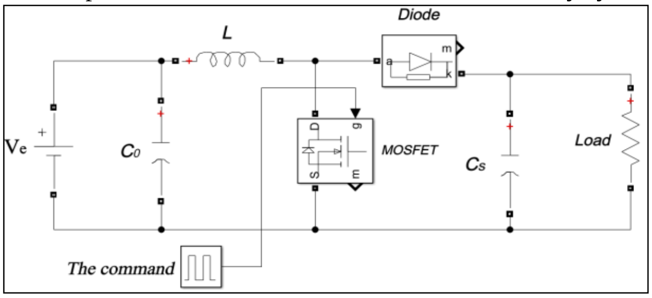

Figure 5. DC-DC BOOST converter

The Table 1 shows the Parameters of the BOOST DC/DC converter:

$$L = \frac{V_e\left(V_0 - V_e\right)}{f_s \Delta I_L V_0} \qquad (9)$$

With (V_0 with is the Nominal Voltage)

$$C = \frac{I_0 D}{f_s \Delta V_s} \qquad (10)$$

Table 1. Boost converter parameters

Variable	Description	Units	Value
fs	Frequency	Hz	10000
V0	Nominal Voltage	V	48
RS	Nominal Resistor	Ω	60
L	Inductance	H	4,56E-03
C	Capacity	F	4,10E-05
ΔV	Voltage variation	%	3
ΔI	Current variation	%	10

3. The Fuzzy MPPT Controller

Recently, fuzzy logic control has been used in MPPT maximum power point tracking systems. This control has the advantage of being a robust control that is fairly simple to develop and does not require precise knowledge of the model to be regulated.

This approach is based on two essential concepts: that of the decomposition of a range of variation of a variable in the form of linguistic nuances: "low", "medium", "high", and rules coming from the expertise of the human operator, who express, in linguistic form, how the commands of the system must evolve as a function of the variables observed: If the error is positively large and the variation of the error is positively large then the variation of the output is very negative.

These concepts are based on part of the theory of fuzzy subsets introduced by Zadeh.

The implementation of a fuzzy controller is done in three steps which are: fuzzification, inference and defuzzification Figure 6 [16, 17].

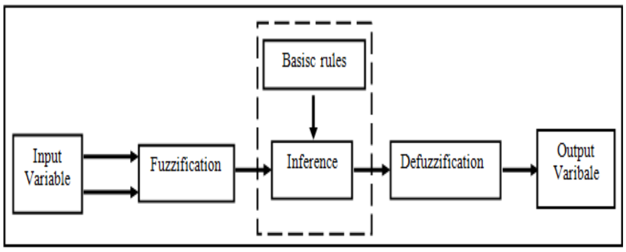

Figure 6. Fuzzy logic control block diagram

3.1 Fuzzification

During the process of fuzzification, the real variables of the inputs/outputs are transformed into fuzzy variables sets.
The fuzzification which allows to switch from real variables to fuzzy variables. The heart of the controller represented by the rules linking the inputs and outputs, and finally the inference and defuzzification which allow, from the input fuzzy combinations, to determine the actual output value. In our case, we have two input variables which are the error E(k) and the error variation CE at time k which are defined as follows:

$$E = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \tag{11}$$

$$CE = E(k) - E(k-1) \tag{12}$$

The Figures 7 and 8 illustrate the membership functions of the fuzzy subsets of the input variable .Also, the Figure 9 shows the output variable.

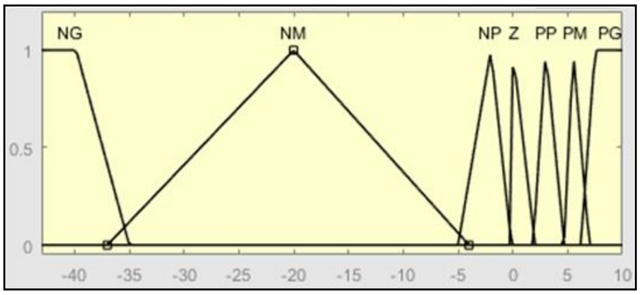

Figure 7. Input variable E

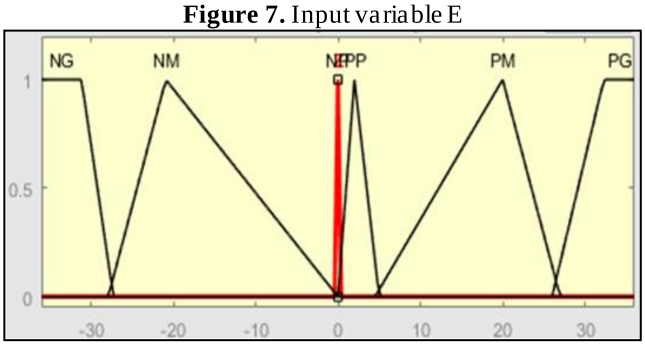

Figure 8. Input variable CE

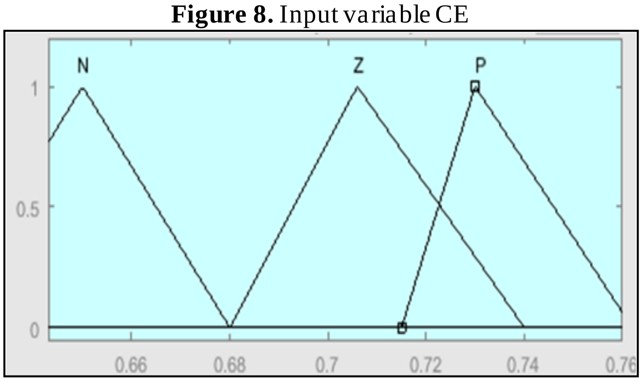

Figure 9. Output variable dD

3.2 Inference Method

Inference is the decision stage because logical relationships are established between inputs and outputs while determining the rules of membership. Next, the table of inference rules is set up Table 2.

Table 2. Table of inference rules

E \ CE	PG	PM	PP	Z	NP
PG	**P**	**P**	**P**	**P**	**P**
PM	**Z**	**N**	**Z**	**Z**	**Z**
PP	**N**	**Z**	**N**	**N**	**N**
Z	**Z**	**N**	**Z**	**P**	**N**
NP	**Z**	**Z**	**P**	**P**	**P**

For our case, we have chosen the Mamdani method for fuzzy inference with MAX-MIN operation, which consists in using the MIN operator for AND and the MAX operator for OR.[18].

3.3 Defuzzification

The purpose of defuzzification is to perform the reverse operation of fuzzification, here we need to calculate a numeric value understandable by the external environment from a fuzzy definition. To represent the sampled data, the mean is calculated by:

$$dD = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \tag{13}$$

The output values are multiplied by the scaling factor using the PWM to generate the control signal. The pulse width modulation (PWM) technique consists of generating a square signal with cyclic ratio modulated according to a control signal. The generated signal is used to control the switch to get PPM tracking.

4. Modeling System and Simulation Results

4.1 Modeling of Photovoltaic System Using Simulink

In this section, we have designed and simulated our model using these photovoltaic panel type API156P200 with an intelligent MPPT control using fuzzy logic as shown in Figure 10. The DC/DC adapter block with a static load on the output is described in Figure 11.

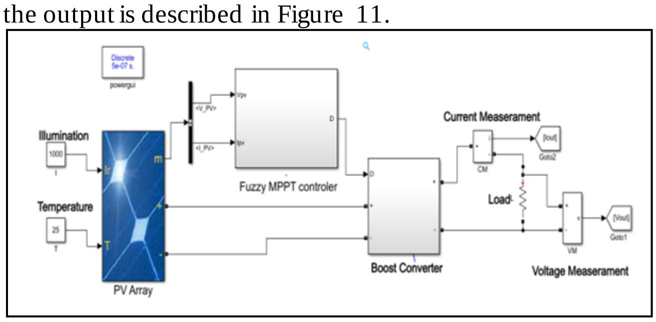

Figure 10. Simulink model of PV 200W controlled by MPPT

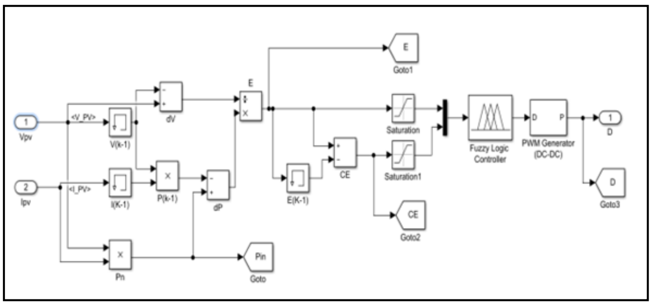

Figure 11. Simulink schema of intelligent MPPT calculator

4.2 Simulink Schema of Intelligent MPPT Calculator

The simulation results regarding the proposed intelligent photovoltaic system were carried out with MATLAB / Simulink software as shown in the figures Figure 12 to Figure19. We presented the input and output power of the converter with a fixed load, as well as the voltage delivered at the outputs in front of a change of illumination from 1000W/m² to 600W/m² with a temperature fixed at 25°C. Then we change the temperature from 15°C to 35°C with an illumination fixed at 1000W/m².

In order to carry out our project we have studied the correct operation of our chopper, by determining the operating parameters that allow us to obtain maximum power at the output. Its summary and the obtained simulation results are presented and compared in Table 3.

Table 3. Converter output power with variable temperature and light

Illumination (W/m²)	T (°C)	P_{pv} (W)	Cyclical report D (%)	P_{Load} Theoreticel (W)	P_{Load} Practical (W)
1000	5	216	73,1	203.23	206.6
1000	15	208.1	73,8	195.80	198.7
1000	25	200	74,5	188,18	193.5
1000	35	191.8	72,5	180,46	182.5
900	25	180,9	72,5	170,21	175
800	25	161,5	70,6	151,96	156.3
700	25	141,8	68,6	133,42	136.9
600	25	121,9	66,1	114,70	117.4

Where, the duty cycle D is calculated as follows:

$$D = 1 - \sqrt{\frac{R_0}{R_s}} \quad (14)$$

Where, $R_0 = \frac{U_{PM}^{\;2}}{P_{PM}}$, U_{PM} and P_{PM} represent respectively the voltage and power at maximum point.

4.2.1 Results With Varying Illumination at 25°C

The Figure13 shows the power response delivered by the GPV to a variation of luminosity at 25 °C, the power converges towards the MPP and remains stable, Figures 14 and 15 show the results of the simulation of the voltage and the output power of the fuzzy system in the face of a rapid change in illumination of 1000W/m² at 600W/m² at 25°C, the system reacts with finesse with a convergence time of 5 ms and a weak ripple in the permanent state.

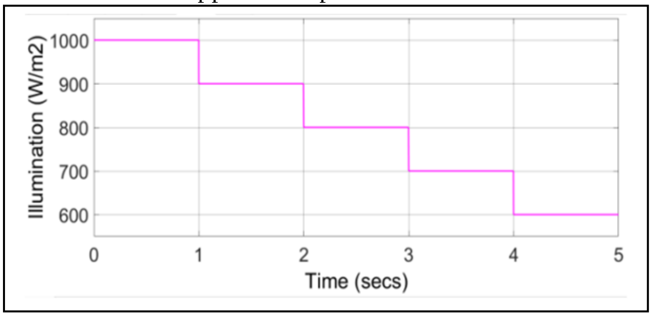

Figure 12. Change of illumination at 25 °C

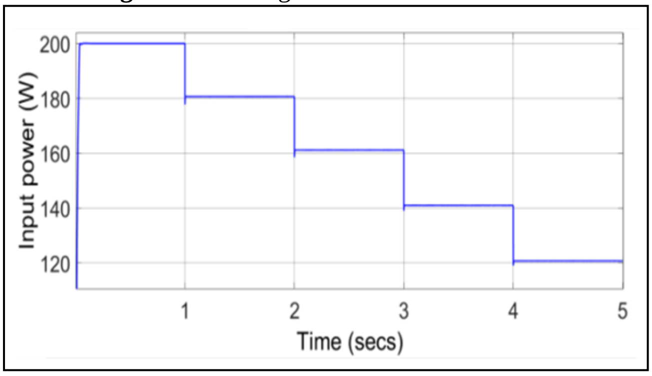

Figure 13. Input Power at 25°C

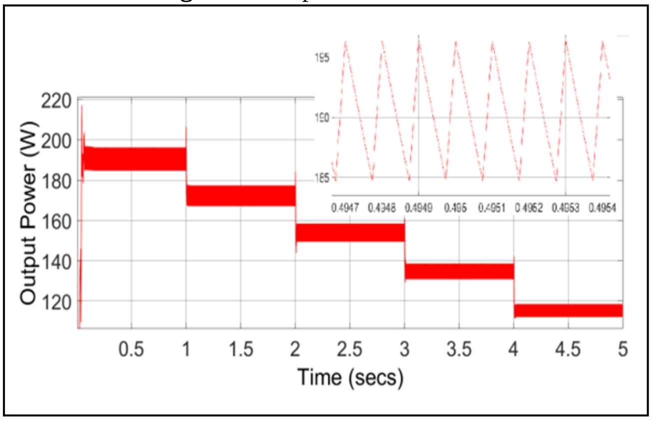

Figure 14. Output Power at 25°C

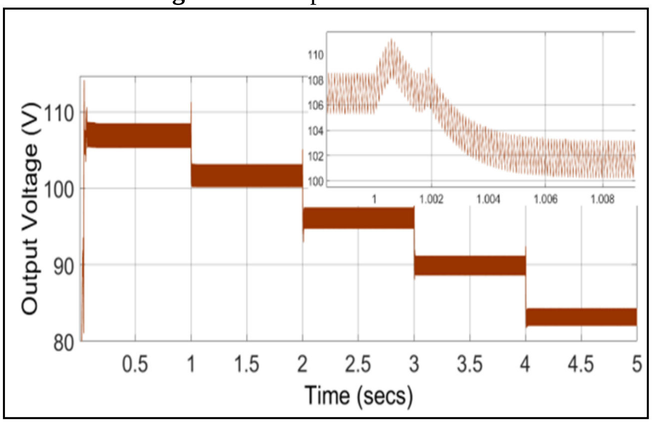

Figure 15. Output voltage at 25°C

4.2.2 Results With Varying Temperature at 1000W/m²

In the scenario of a variation caused by a rapid change in temperature from 5°C to 35°C under an illuminance of 1000 W / m², the system converges rapidly with a low ripple rate as shown in Figures 17 , 18 and 19.

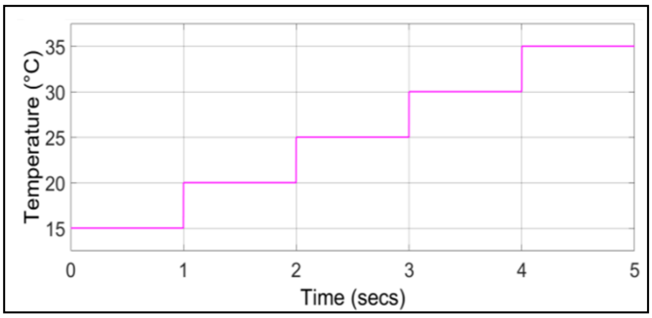

Figure 16. Change of illumination at 1000W/m²

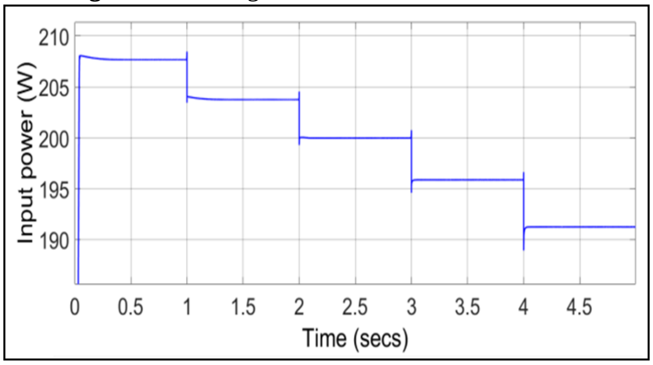

Figure 17. Input power at 1000W/m²

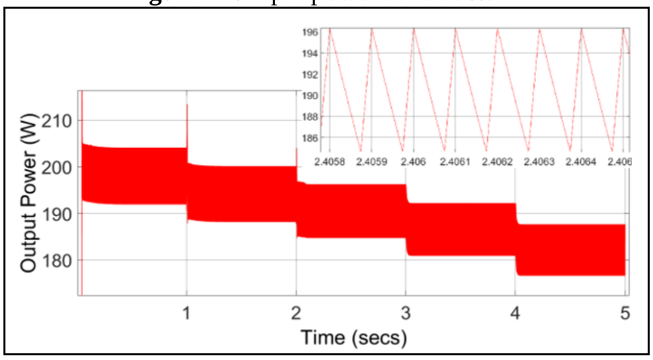

Figure 18. Output Power at 1000W/m²

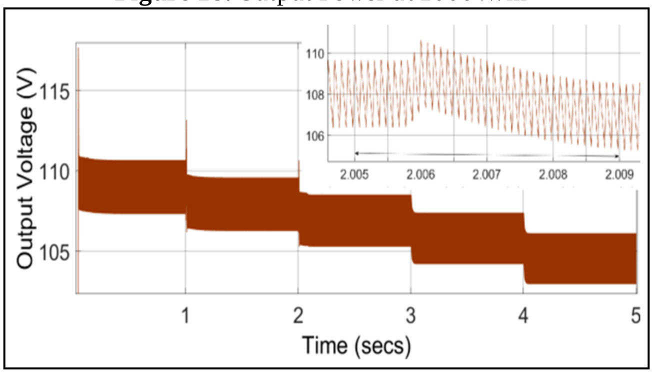

Figure 19. Output Voltage at 1000W/m²

The simulations performed in this work using fuzzy logic under different atmospheric conditions showing that it is precise and powerful. Indeed, this algorithm can operate at the optimal point without oscillations. It is specified by a good behaviour in transient state.
However, the implementation of this kind of algorithm is more difficult than classical algorithms. The usefulness of this algorithm depends a lot on the inference table. The maximum point tracking by fuzzy logic has a fast response speed with a low ripple rate.
Finally, the proposed intelligent model was evaluated by using the efficiency criteria [19]. It is calculated by using the following formula:

$$\eta = \frac{P_{load}}{P_{pv}} \tag{15}$$

The Table 4 below shows the system efficiency enhancer in term power at 25°C .

Table 3. Power efficiency comparison

Illumination	**1000**	**900**	**800**	**700**	**600**
Practical Ppv	200	180,6	161,3	141	120,7
Theoretical Ppv	200	180,9	161	141,8	121,9
Practical P_{Laod}	193,5	175	156,3	136,9	117,4
Theoretical P_{Load}	188,18	170,2	151,95	133,41	114,7
Efficiency (%)	96,75	96,90	96,90	97,09	97,27

The results obtained confirmed our expectations, in fact, when the irradiation gradient changes, the controller follow the MPP on all the ramps, with better efficiency reaching up to 97%, with a minimum response time of 5 ms and oscillation around 10 W.

5. Conclusion

In this paper, Fuzzy Logic technique has been effectively used for the development of the intelligent control model for photovoltaic system. The proposed system can contribute to ensure the maximum power point tracking.
Simulation results on real photovoltaic panel type API156P200 with varying Illumination and temperature show that the proposed method is robust in term power efficacy, very low error and fast response time.

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