Journal of Theoretical and Applied Information Technology
15th June 2022. Vol.100. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

A FUZZY LOGIC MPPT BASED CONTROL FOR A PHOTOVOLTAIC SYSTEM

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ABSTRACT

This paper presents the application of fuzzy logic in the MPPT control of a PV array generation system and a comparative analysis with the widely used P&O algorithm in MPPT in different solar irradiation conditions.

These techniques have been improved over time, for example, by improving solar cells, heat transfer liquids, and asynchronous generators, or by improving tracking control algorithms or power electronic components in inverters.

The optimization of energy production power from solar photovoltaic systems will be the emphasis of this article. Thus the fuzzy logic control is directly implemented in the MPPT and control a DC-DC boost converter. The simulation is performed using MATLAB Simulink tool and a comparative analysis of results is given with the MPPT based on the P&O algorithm with various steps. The FLC used in this paper demonstrates the relevance of the choice of the input variables and the importance of the use of an optimal number of rules. Those parameters show better performance and faster response than other methods even in changing environmental conditions.

Keywords: *P&O, Fuzzy logic, Boost converter, MPPT, PV system, Matlab / Simulink.*

1. INTRODUCTION

Among the main modes of production from renewable energies, there are hydraulics, wind power, tidal, wave energy, Geothermal, solar energy, … in this paper, we will focus on the optimization of energy production power from solar photovoltaic due to the fact that this technology is relatively mature for use on a large scale and in large areas, as well as its rather expected behavior on a daily and annual scale: two parameters which are fully owned in Morocco

The main disadvantage of producing electrical energy from solar panels is that solar radiation and temperature change over time. There are thus many algorithms that allow the extraction and preservation of the maximum power point of the PV panels. Among the most widely used algorithms, we distinguish the P&O algorithm and the INC. Together they have the advantage of not being complex and require less maintenance. However, these algorithms have limitations in the event of an instantaneous change in temperature and irradiation. thus, there are several possibilities for improving these classic algorithms and which allows better efficiency and faster response than conventional algorithms.

Many papers were conducted to improve PV systems efficiency using different methods, for example, some researches were focusing on a simple analysis [15] or comparison of the results of power tracking of different MPPT algorithms, namely P&O and Inc based on fuzzy logic control [9] [14], and even for applied grid connected PV systems [10] [11][12] or suggesting a better performance of the P&O algorithm with some improvements which permitted increasing the efficiency and fast-tracking response than conventional P&O [2] other studies performed the implementation of one or two MPPT command systems controlled by FLC based on conventional P&O algorithm which allowed reducing the steady-state oscillations and enhances the operating point convergence speed [7] [8][16].

Other researchers opt for different intelligent techniques like an adaptive neuro-fuzzy inference system based on MPPT with PI controller [17] or an improved low disturbance generating FL voltage and current control system [13] in order to increase the performance of the PV power generation system.

The contribution of this paper lies in the direct integration of an improved fuzzy logic command into the MPPT process, and the importance and relevance of the choice of the input variables *(e, de)* and the importance of the use of an optimal number of rules.

In this article, only three membership functions that have been used because this number has reduced the sampling time and simplifies the simulation.
We could have used more than three membership functions (five or seven) but the use of more than three membership functions has made our algorithm very complicated.

All simulations are performed using MATLAB / SIMULINK software. The issues of the simulation are compared with those acquired by a well-known technique which is perturb and observe P&O. the results of the simulation confirm the advantages that allow the use of the FLC in terms of precision and stability.

In the present paper, we propose a developed Fuzzy logic-based control to achieve the maximum power point tracking. The paper is organized as follows: the first part describes a simplified model of the PV system with a DC-DC boost converter, the second part describes the FLC used and a comparison with the P&O MPPT with two different steps and gives a comparison analysis and discussion of the simulation results.

2. BLOCK DIAGRAM OF A PHOTOVOLTAIC SYSTEM

The block diagram of the MPPT control of a system for producing photovoltaic electricity is composed of the photovoltaic panel module, the DC-DC boost converter, the MPPT controller, and the load to be powered. The output voltage of the solar panel supplies the DC boost converter according to which a direct load is connected. Measurements of panel voltage and/or current are introduced to the input MPPT controller, then the MPPT algorithm. [5]

The following figure shows the block diagram of the system.

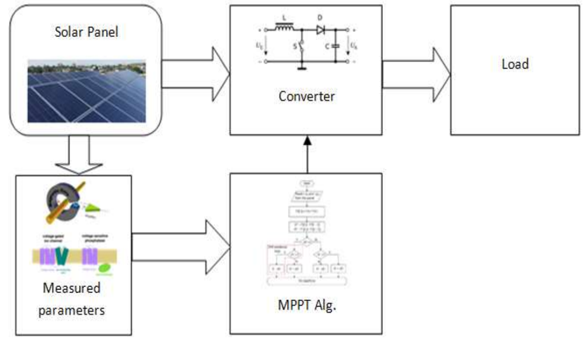

Fig. 1: Block diagram of a photovoltaic system

3. PHOTOVOLTAIC PANEL MODEL

Photovoltaic considered block, consists of an array of photovoltaic (PV) modules. The matrix consists of strings of modules connected in parallel, each string consisting of modules connected in series.

The Photovoltaic system object of our simulation is a five-parameter model using an **IL** current source (current generated by solar irradiation), a diode, a series resistor **Rs** and a shunt resistor **Rsh** in order to represent the dependent characteristics of the module illumination and temperature. [3]
The equivalent diagram is as follows:

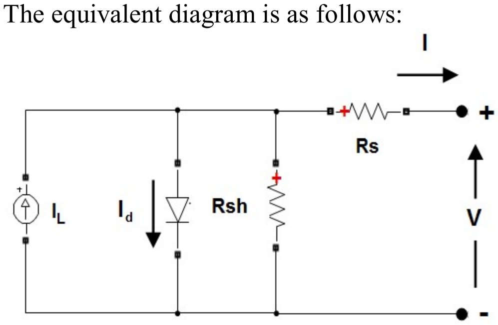

Fig. 2: Equivalent circuit of a photovoltaic panel

The equation of the solar PV is given as below:

$$I = I_L - I_{Rsh} - I_d \quad (1)$$

$$I = I_L - I_{Rsh} - I_s e^{\left(\frac{q(V+IRs)}{akT}\right)-1} \quad (2)$$

$$I = I_L - \left(\frac{V+IRs}{Rsh}\right) - I_s e^{\left(\frac{q(V+IRs)}{akT}\right)-1} \quad (3)$$

Where:
a: diode ideality factor

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

T: temperature
Is: reverse saturation current
q: electric charge

The simulations subject of this paper are based on an ascending adjustment of the irradiation from 600 to 1000 W / m², and a fixed temperature of 25 ° C, for an MPPT based on the P&O algorithm with a fixed step at 0.3 and 2 respectively. The increment in steps is carried out to test the stability of the system.

The comparison is made with a fuzzy logic control developed for the same physical characteristics with an overlay of the output power curves to allow a reliable comparison of the results.

In a second step, a downward adjustment of the irradiation from 1000 to 600 W / m², and a fixed temperature of 25 ° C, was carried out for the MPPT based on the P&O algorithm with a step fixed at 0.3 and 2 respectively and the same settings for the MPPT based on fuzzy logic.

The opposite case was also tested for the same MPPT control blocks, namely, constant solar irradiation at 1000 W / m² and the stepwise variation of the temperature from 25 to 50 ° C ascending and likewise descending.

The characteristic of power as a function of voltage is given in the following figure: [9]

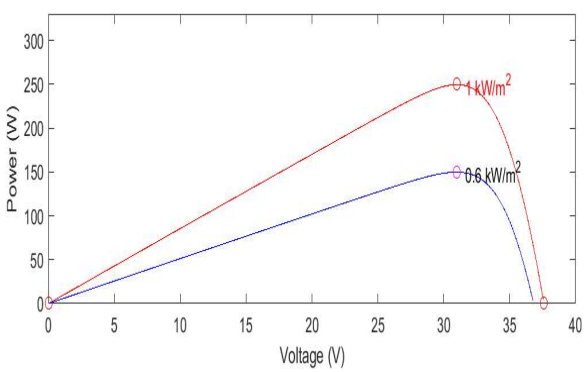

Fig. 3: power characteristic as a function of voltage for variable solar irradiation

The characteristic of the current as a function of the voltage is given by the following figure:

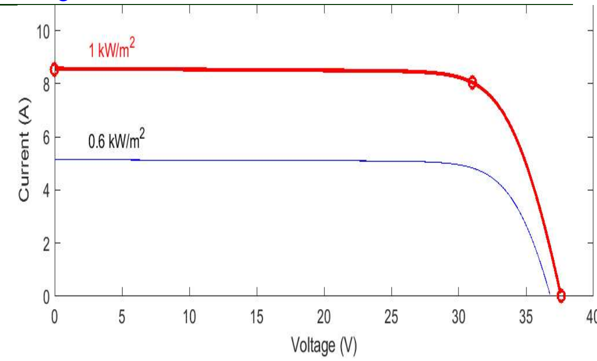

Fig. 4: characteristic of current as a function of voltage for variable solar irradiation

The characteristic curves of the case of fixed solar exposure and of a temperature variation of the PV are given below (the variations are given in steps to allow characterization of the dynamic behavior of the system):
The characteristic of the power according to the voltage is given by the following figure:

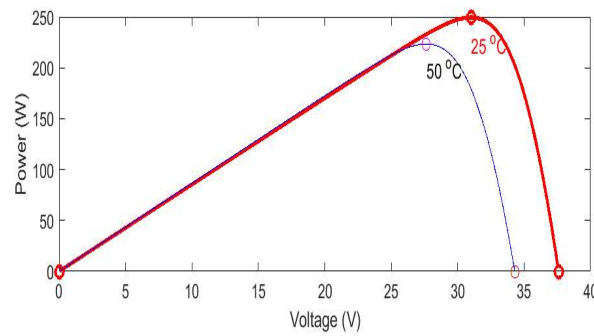

Fig. 5: power characteristic as a function of voltage for a variable temperature

The characteristic of the current as a function of the voltage is given by the following figure:

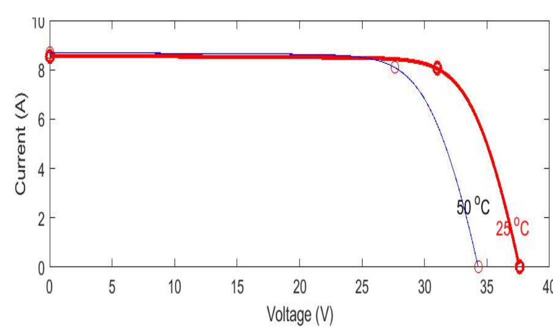

Fig. 6: variation of the current as a function of the voltage for a variable temperature

Journal of Theoretical and Applied Information Technology
15th June 2022. Vol.100. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

4. BOOST CONVERTER

The boost converter circuit used in this simulation is a simple DC/DC power converter, with one high frequency switch and a diode, operating in an asynchronous mode which steps up the voltage from its input to the output (load). The circuit diagram is shown in the figure below.

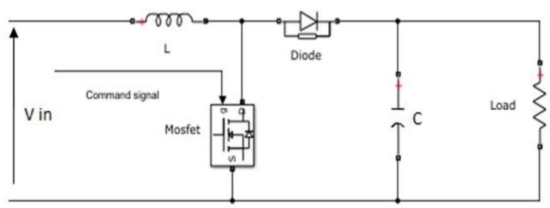

Fig. 7: Boost converter circuit

Where V_{in} is the voltage of the PV panel and the command signal is generated by the MPPT module.

The transfer function of the boost converter in continuous conduction mode configuration is:

$$\frac{Vout}{Vin} = \frac{1}{(1-\alpha)} \quad (4)$$

Where α is the duty cycle.

The command signals of both methods used actually drive the gate of the power switch (MOSFET).

5. MPPT BASED ON THE P&O ALGORITHM

The main objective of this algorithm is to extract the maximum power generation from the PV modules; in fact, it performs a disturbance on the voltage of the PV panel while acting on the cyclic α ratio. Indeed, due to this disturbance, it determines the power supplied by the PV module at time k, which is compared to the previous value at time (k-1). If the power increases, we approach the point at maximum power (PMP) and the variation of the duty cycle is maintained in the same direction. Otherwise, if the power decreases, we move away from the PMP. Then, we will have to reverse the direction of the variation of the duty cycle and so on. [2] [6] [16]

The P&O algorithm is given by the following figure:

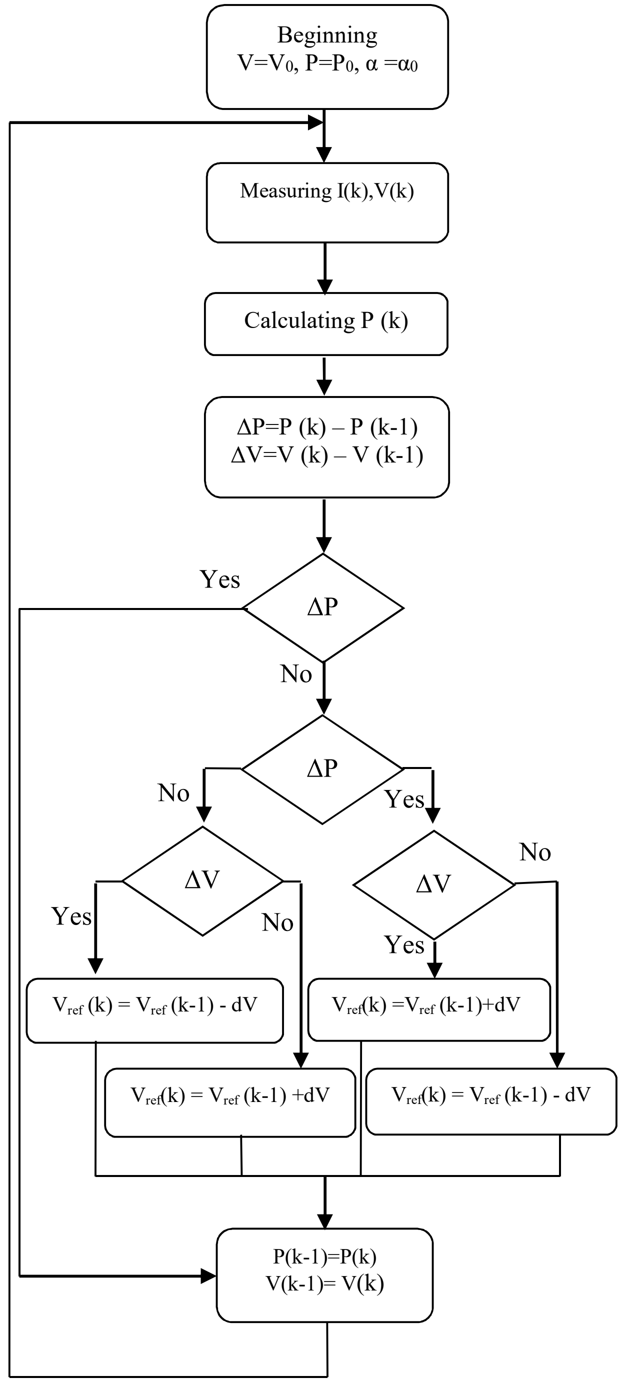

Fig. 8 : P&O algorithm

6. MPPT BASED ON FUZZY LOGIC

The fuzzy logic-based control has been used in overpower point tracking systems, this control offers the advantage of being a robust control and

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15th June 2022. Vol.100. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

does not require exact knowledge of the mathematical model of the system.

In particular, this command is adapted to nonlinear systems.

It operates in three blocks:

1. Fuzzification,
2. Inference
3. Defuzzification.

Where the fuzzification block allows the conversion of physical input variables into fuzzy sets. [7][9][14]

Below is the diagram of the fuzzy logic used in this paper.

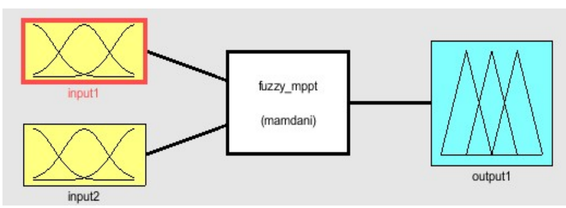


Fig. 9: diagram of the fuzzy logic used

In this paper, we have considered two inputs:

$\frac{dP}{dV}$ and the variation of this same parameter.

As :

Input 1 : $e = \frac{dP}{dV}$ and Input 2 : $\frac{de}{dt}$

They are defined as follows:

$$\frac{dP}{dV} = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \qquad (5)$$

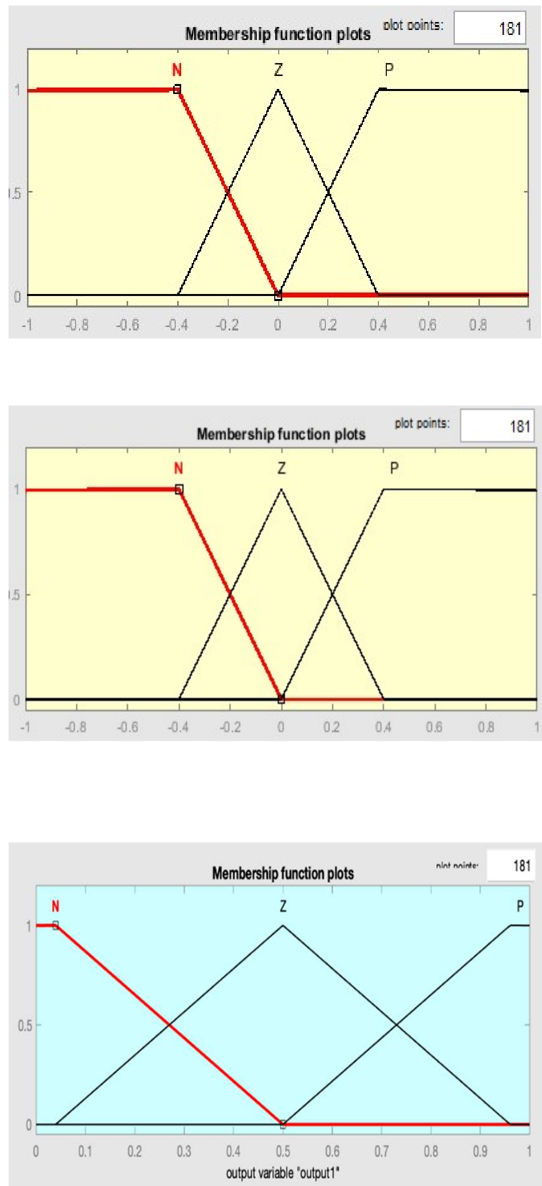
$$e = E(k) - E(k-1) \qquad (6)$$

The corresponding fuzzy sets are:

N = negative,
Z = zero,
P = positive.

For the Defuzzification, we have considered the centroid method over the Mamdani inference [1][13].

The membership function plots are given below:



(a)

(b)

Fig. 10: a) Membership functions plots for the variable: e , b) Membership functions plots for the variable : de , c) Membership functions plots for the variable α

In our simulation, we have considered triangular membership functions for the inputs and the output so as not to make the equivalent system more complex and in order to decrease the running time.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

In fact, we aim to improve the duty cycle estimation using fuzzy logic-based control so that we have considered the error and its variation as the inputs of the fuzzy logic blocks, for which we have imposed the range [-1, 1].

In the next step, we establish logical relationships between the inputs and the output while defining the membership rules. Then, we draw up the table of rules (Table 1).

The following table shows the basis of the rules (9 rules) set for the fuzzy logic mechanism considered:

Table 1: table of rules

		de		
		N	Z	P
e	N	N	N	Z
	Z	N	Z	P
	P	Z	P	P

7. SIMULATION RESULTS AND DISCUSSION

The simulation was performed based on the two algorithms mentioned above, with a temperature set point fixed at 25 ° C, and a solar irradiation set point in steps of 600 to 1000 W / m², and the opposite case by fixing the temperature at 25 ° C and applying a solar irradiation set point of 1000 to 600 W / m² to test the stability of the system for different cases and to be able to compare the behavior in the different configurations.

The MPPT set point based on the P&O algorithm has been tested for two different values of the increment step, namely 2 and 0.3.

The general parameters are given in the table below:

(c)

Table 2: Table Of Parameters Considered

PV power	250 W
V_{pm}	31 *V*
I_{SC}	8,55 *A*
C	2 μF
L	0,05 *mH*
Switching frequency	10 KHz

The simulation results are given by the curves below. They are superimposed to allow the distinction between the different behaviors.

First case:

The first case treated is a constant temperature of 25°C and an irradiation incremented from 600 to 1000 W/m²:

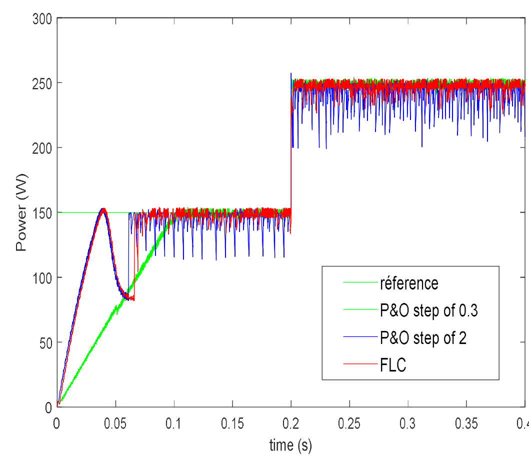


Fig. 11: The evolution of output powers for irradiation varying from 600 to 1000 W / m²

The above illustration represents the response of the MPPT based on the P&O algorithm. The curve representing a step of 0.3 is given in green and shows a great slowness in the dynamic response of the system. The step of 2 is displayed on the curve in blue with greater distortion and finally, the response based on the algorithm using fuzzy logic is given in red. The behavior using fuzzy logic has fewer ripples compared to the P&O with a step of 2 which in turn allows better response speed to the system than the P&O with a lower step.

Second case:

The second case treated is a constant temperature of 25 °C and solar irradiation decremented from 1000 to 600 W/m²:

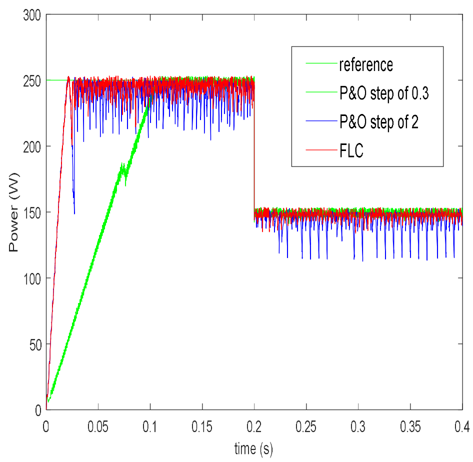


Fig. 12: The evolution of output powers for irradiation varying from 1000 to 600 W / m²

The figure above represents the response of the MPPT based on the P & O algorithm with a step of 0.3 which is given in Green and displays a very slow dynamic response of the system. The step of 2 is displayed on the curve in blue with less stability and finally, the response based on the algorithm using fuzzy logic is given in red. The behavior using fuzzy logic has fewer ripples compared to the P&O with a step of 2 which in turn allows more speed to the system than a slower step.

Third case:

The third case treated is a constant solar irradiation of 1000 W/m², and a temperature decreasing from 50°C to 25°C:

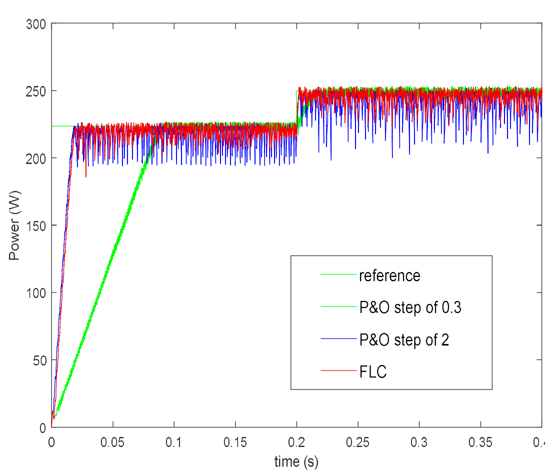


Fig. 13: The evolution of output powers for a temperature varying from 50°C to 25°C

The figures at the top represent the response of the MPPT based on the P&O algorithm with a step of 0.3 which is given in green and shows a very slow dynamic response of the system. The step of 2 is displayed on the curve in blue and finally, the response based on the algorithm using fuzzy logic is given in red. The behavior using fuzzy logic has fewer ripples compared to the P&O with a step of 2 which in turn allows more speed to the system than a slower step.

Fourth case:

The fourth case treated is a fixed solar irradiation of 1000 W/m², and a temperature incremented from 25 °C to 50 °C:

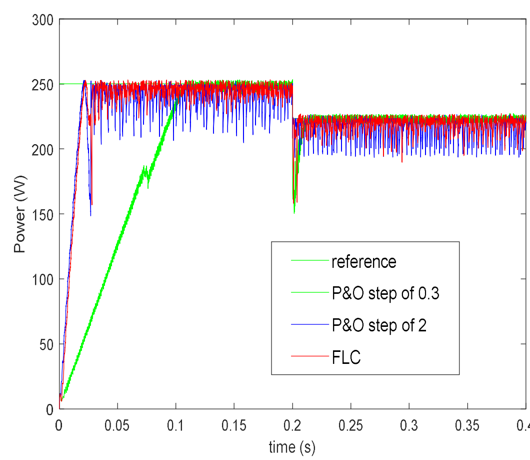


Fig. 14: The evolution of output powers for a temperature varying from 25°C to 50°C

The figures above represent the response of the MPPT based on the P&O algorithm with a step of 0.3 which is given in green and shows a very slow dynamic response of the system. The step of 2 is displayed on the curve in blue and finally, the response based on the algorithm using fuzzy logic is given in red. The behavior using fuzzy logic has fewer ripples compared to the P&O with a step of 2 which in turn allows an agile response to the system than a slower step. Fuzzy logic, therefore, makes it possible to gain in terms of the speed of convergence of the system [18] and the quality of the signal.

This approach shows that the behavior of the system with an MPPT control based on fuzzy logic remains better in the two cases of variation of the temperature of the panel and of the solar irradiation.

8. CONCLUSION

In conclusion, we will be able to deduce that the integration of the fuzzy logic at the MPPT level clearly improves the behavior of the photovoltaic system compared to the control using the P&O algorithm and which is the most widespread. Indeed, it depends on the value's initial conditions of the test, and has several disadvantages in terms of speed of response in the event of a change of set points, while fuzzy logic, even with 9 rules, is characterized by a clear improvement for different requests and makes it possible to gain in speed of convergence towards the optimum power curve and wave form quality [19][20].

Indeed the contribution of this method lies in the application of an optimized fuzzy logic control and allowing to achieve better performance with an optimal number of inputs and a well-defined output parameters for the system.

this represents an interesting compromise allowing gaining in dynamic behavior without losing too much in wave quality.

Finally, the implementation of fuzzy logic control, although optimal for maximizing the yield of photovoltaic panels, can likewise be integrated at the level of the voltage adaptation stage in the event of injection of PV production at the distribution grid. Indeed, this command, although robust, could well replace the type of controls currently used and this at the lowest cost.

The FLC is also used more for the control of electric motors and generators and therefore serves a wide range of applications in the field of renewable energies (wind turbines in this case)

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