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Fuzzy logic for tracking maximum power point of photovoltaic generator

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Abstract – *This work presents an intelligent approach for the performance improvement and optimization of the control of a photovoltaic system to track maximum power point under variable temperature and isolation conditions. First, we present the controller referring to traditional approach based on the perturbation and observation (P&O) methods, then the MPPT controller with fuzzy logic is developed and compared with the classic algorithm. The results obtained under various conditions of functioning shown the good tracking and fast response to different change in meteorological conditions of intelligent controllers comparing with the conventional one.*

Résumé - *Ce travail présente une approche intelligente pour l'amélioration des performances et l'optimisation de la commande d'un système photovoltaïque pour suivre le point de puissance maximale à température variable et à des conditions d'insolation. Tout d'abord, nous présentons le contrôleur en se référant à l'approche traditionnelle basée sur la méthode perturbation et observation (P&O), ainsi que le contrôleur MPPT en utilisant la logique floue, développé et comparé avec l'algorithme classique. Les résultats obtenus dans les diverses conditions opératoires ont montré le bon suivi et une réponse rapide aux changements des conditions météorologiques comparée aux contrôleurs intelligents avec le classique.*

Keywords: Photovoltaic - Maximum power point tracking - P&O - Fuzzy logic.

1. INTRODUCTION

The problems of energy supply met globally are not solely due to environmental destruction and climate change arising, but also to growth in global consumption is rising, especially as regards electrical energy. Therefore, solutions to this problem are being sought and must be technically feasible while meeting the requirements of sustainability [1].

In this sense, and over the last decade, the use of renewable energy such as solar energy has shown that these might contribute to a large scale to find a solution to the problems mentioned [2].

However, the characteristics output of photovoltaic systems are nonlinear and change with variations of temperature & irradiation, so we need a controller named maximum power point tracker MPPT to extract the maximum power at the terminals of PVG. The most famous one is called perturbation and observation (P&O) controller.

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But this method has presents limitations to track maximum power point as fast as possible to reduce oscillations in output power systems.

In this paper, we propose to study the modeling of a photovoltaic system and to find a method for optimizing the operation of the PV generator using the new intelligent Fuzzy logic controller.

2. PHOTOVOLTAIC POWER GENERATION

The photovoltaic solar energy comes from the direct conversion of a portion of solar radiation into electrical energy carried through a photovoltaic cell based on physical phenomenon called photovoltaic effect [3].

The latter's role is to produce an electromotive force when the surface of the cell is exposed to light [2].

The voltage generated is little varying depending on the material used for the manufacture of the cell.

Fig. 1 shown the model of photovoltaic cell that is used here, it is called model with two diodes.

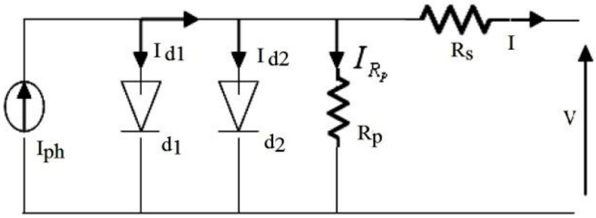


Fig. 1: Two diodes cell model

The equation for the current and voltage of solar cell is given by:

$$I = I_{ph} - I_{s1} \times \left(e^{\frac{q(V + I \times R_s)}{n_1 \times k \times T}} - 1 \right) - I_{s2} \times \left(e^{\frac{q(V + I \times R_s)}{n_2 \times k \times T}} - 1 \right) - \frac{V + I \times R_s}{R_p} \quad (1)$$

$$I_{ph} = S \times I_{ph.max}$$

S : Percentage of irradiation; I_{s1} and I_{s2} : Saturation currents of the diodes; n_1 and n_2 : Purity factors of the diodes; R_s and R_p are respectively the series resistance and the parallel resistance; T : Absolute temperature.

The equation also contains the elementary charge constant q (1.602×10^{-19} C) and the Boltzmann constant k (1.380×10^{-23} J/K).

The photocurrent $I_{ph.max}$ is reached at the maximum insolation.

The association of several PV cells in series-parallel gives rise to a photovoltaic generator (GPV), which has a current-voltage ($I - V$) non linear with an operating point (MPP) which depends on the illumination level and temperature and aging of all [7].

It is obvious of the equation (1), that the characteristic current-tension depends strongly on the irradiation and temperature.

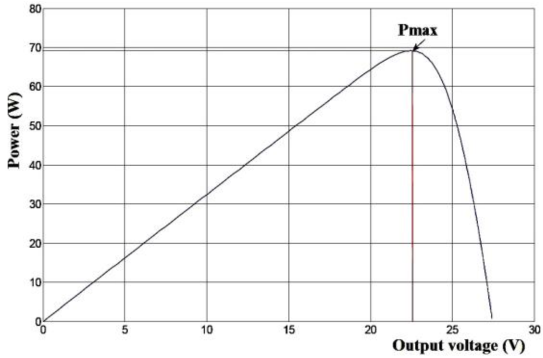


Fig. 2: Power curve under constant irradiation and temperature

The complete block diagram of a PV module can be represented as shown in figure 2 with a MPPT controller which feed power to the load through a dc/dc converter.

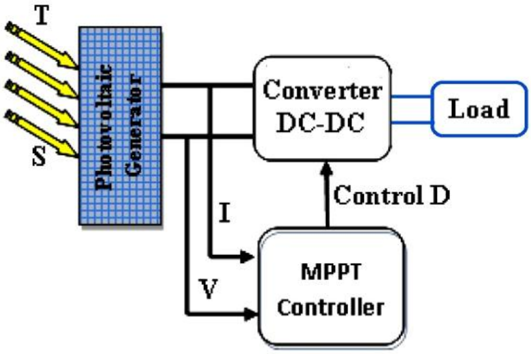


Fig. 3: Photovoltaic systems

In the following, the effectiveness of two controllers are thoroughly investigated and compared via numerical simulation.

3. P&O CONTROLLER

The perturbation and observation (P&O) algorithm is probably the most frequently used in practice, mainly due to its easy implementation [2].

As the name suggests it is based on the perturbation of system by the increase or decrease in V_{ref} where acting directly on the duty cycle of the converter DC-DC, then observation of the effect on the output power of the panel. If the current value of the power $P(k)$ panel is greater than the previous value $P(k-1)$ is then retains the same direction of previous disturbance or we reverse disruption of the previous cycle. The figure 4 shows the flowchart of this algorithm.

4. FUZZY LOGIC

Fuzzy logic was introduced in 1965 with work of L. Zadeh. The latter formalizes the representation and processing of imprecise or approximate knowledge to deal with systems of great complexity or unfamiliar. Fuzzy logic is involved in the handling of imperfect knowledge, and it occurred as an effective alternative for such systems [4].

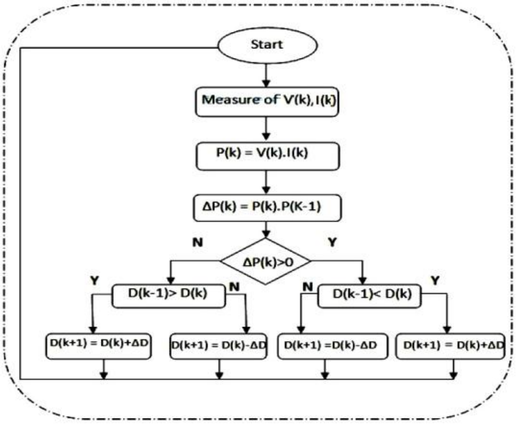


Fig. 4: Chart of the algorithm Disturbance and Observation (P and O)

Fuzzy logic permits to define control laws of any process starting from linguistic description of the control strategy to be adopted. Fuzzy logic using controller is a rule-based controller; it consists of an input, processing, and output stages [5].

The structure of a process controlled via a fuzzy controller is shown in Fig. 5, which emphasizes the basic components of a fuzzy controller: a fuzzification interface, a knowledge base, a data base, inference procedure, and a defuzzification interface.

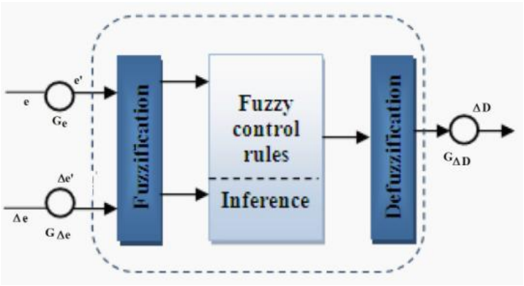


Fig. 5: Basic structure of fuzzy logic control

The basic constitutive components are briefly presented below [6]:

- The *fuzzification interface* gets the values of input variables, performs a scale mapping to transfer the range of values of input variables into corresponding universes of discourse, and performs the function of fuzzification to convert input crisp data into fuzzy values.

- The *knowledge base* comprises a rule base characterizing the control policy and goals.

- The *data base* provides the necessary definitions about discretization and normalization of universes, fuzzy partition of input and output spaces, MF definitions.

- The *inference procedure* process fuzzy input data and rules to infer fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

- The *defuzzification interface* performs a scale mapping to convert the range of values of universes into corresponding output variables, and transformation of a fuzzy control action inferred into a nonfuzzy (crisp) control action

<u>*Description and architecture the proposed fuzzy controller*</u>

A fuzzy controller proposed is show in Fig. 6.

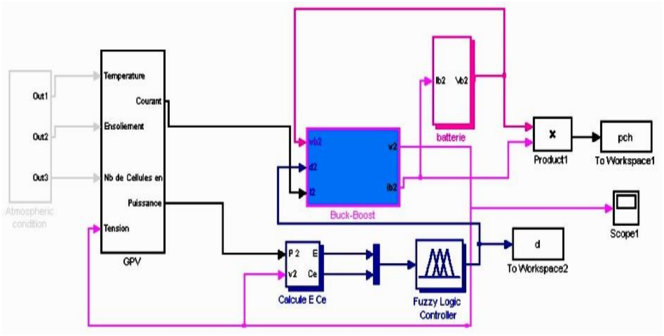


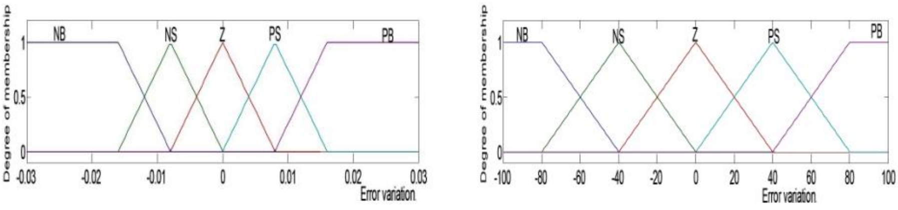
Fig. 6: Model SIMULINK of MPPT controller flou

The inputs to a MPPT fuzzy logic controller are error E and a change in error ΔE defined by:

$$\begin{cases} E(n) = \dfrac{P(n) - P(n-1)}{V(n) - V(n-1)} \\ \Delta E(n) = E(n) - E(n-1) \end{cases} \quad (2)$$

where: E and ΔE are the error and change in error, n is the sampling time, $P(n)$ is the instantaneous power of the PVG, and $V(n)$ is the corresponding instantaneous voltage.

The input $E(n)$ shows if the load operation point at the instant n is located on the left or on the right of the maximum power point on the PV characteristic, while the input $\Delta E(n)$ expresses the moving direction of this point. The output variable is the duty cycle D, which is transmitted to the boost DC/DC converter to drive the load.



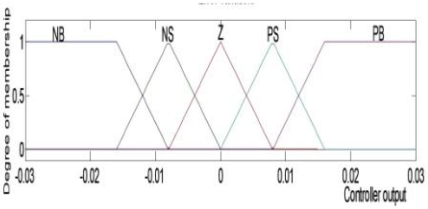


Fig. 7: Membership function of FLC

The MPPT using the Mamdani FLC approach, which uses the min–max operation fuzzy combination law, is designed in a manner that the control task try to continuously move the operation point of the solar array as close as possible to the maximum power point (MPP), and the defuzzification uses the centre of gravity to compute the output of this FLC.

These two variables and the control duty cycle D used in our application are illustrated in Fig. 7.

Table 1: Fuzzy table rules

E↓ →ΔE	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

5. SIMULATION STUDY

Once our photovoltaic chain designed, and to verify the ability of our fuzzy controller to improve the performance obtained under the conventional MPPT controller, numerical simulation was performed for different conditions as follows:

The first test consists to compare the performance of this controller in standard condition: solar irradiation = 1000 W/m^2 and temperature of 25 °C. Fig. 8 shows the result of the tracked power by the two controllers.

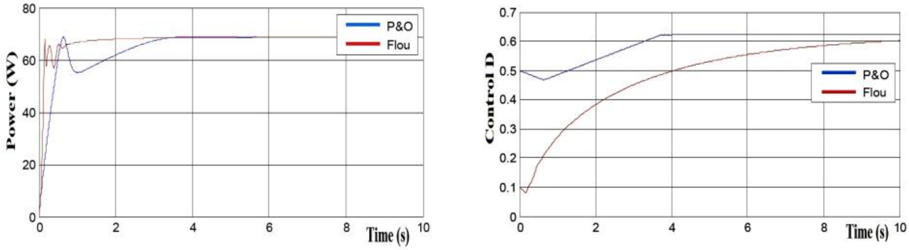
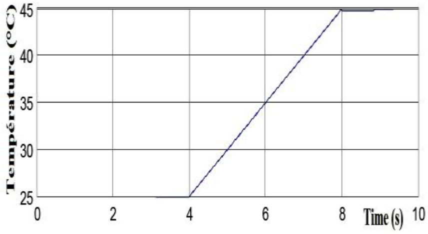
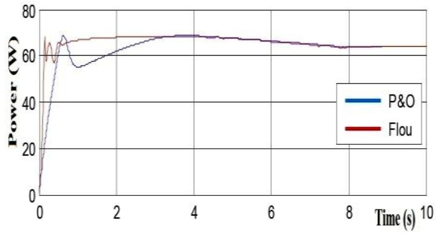


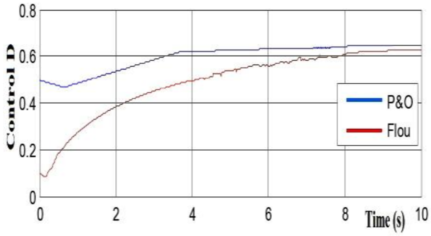
Fig. 8: Provided power from P&O tracker
and FLC Controller in a standard condition

As can be seen, the FLC is faster then the P&O tracker and the two controllers presents oscillations before achieve the MPP.





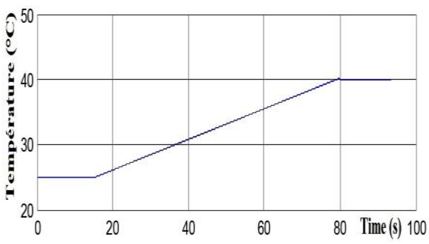
(a1) (a2)

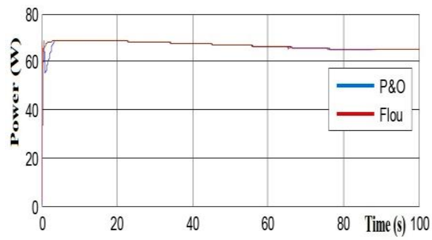


(a3)

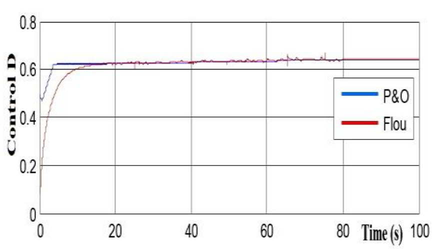
(9.a-)

The next simulation is under rapid variation of temperature (increasing the temperature of 25 °C to 45 °C in 2 s), (Fig. 9.a-).





(b1) (b2)

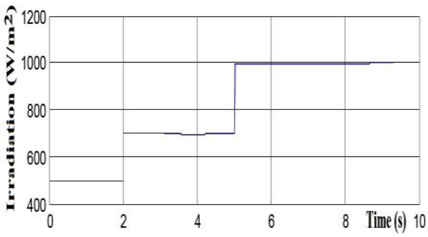


(b3)

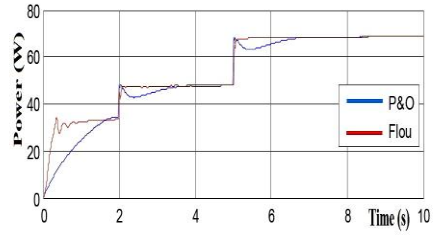
(9.b-)

Fig. 9: Output power of PV for different temperature

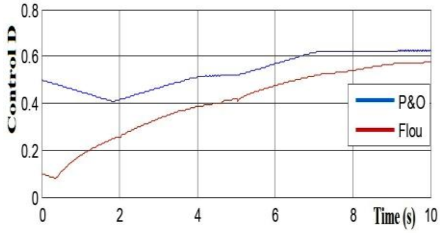
After that the FLC is also tested for long variation of temperature (increasing the temperature of 20 °C to 40 °C in 60 s) the results are shown in Fig. 9.b-.



(a1)



(a2)

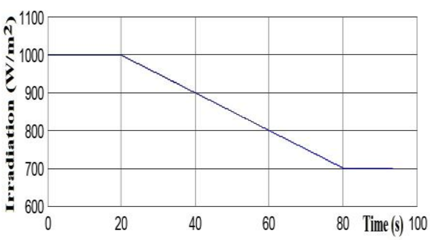


(a3)

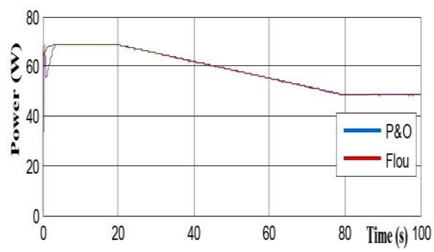
(10.a-)

Another simulation is under the rapid variation of solar irradiation (from 500 W/m^2 to 1000 W/m^2 through 700 W/m^2). The results are shown in Fig. 10.a-.

After that in under long variation of solar irradiation (decrease of solar irradiation (from 1000 W/m^2 to 700 W/m^2), (Fig. 10.b-).



(b1)



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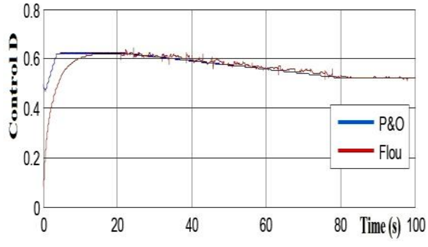

(b3)

(10.b-)

Fig. 10: Output power of PV for different solar irradiation

According to the responses obtained by the fuzzy logic controller, we can see that the MPPT controller fuzzy is very powerful in the normal operating conditions, not only for the continuation of the maximum power point photovoltaic system but also the side time response.

MPPT fuzzy logic controllers have been shown to perform well under varying atmospheric conditions. However, their effectiveness depends a lot on the knowledge of the user or control engineer in choosing the right error computation and coming up with the rule base table. Results show fast convergence to the MPP and minimal fluctuation about it.

5. CONCLUSION

Photovoltaic conversion of solar energy is one of the alternative technology solutions since the advent of major space programs; it has shown a great flexibility and ability to function in rural hostile, this is an interesting solution to conventional way of production. To guarantee the operation of a photovoltaic generator and its point of maximum power, MPPT controllers are often used. These controllers are planned to further MPP and minimize the error between the power operation and the maximum power.

In this paper we have investigated the intelligent control techniques to control the voltage of the solar panel in order to obtain the maximum power possible from a PV generator, whatever the solar irradiation and temperature conditions.

It is clear that our controller based fuzzy logic is more effective than the traditional controllers. Obviously, it can deduce that the fuzzy controller is faster than the P&O controller and present no oscillations in permanent state and also it is robust to climatic conditions change.

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