COMPARATIVE STUDY OF MPPT ALGORITHMS FOR PHOTOVOLTAIC SYSTEM

Chrysostome ANDRIANANTENAINA[1], Solofanja Jeannie RAJONIRINA[2], Nirinarison Jean RAZAFINJAKA[3]

[1] *Phd Student, EDT-ENRE, University of Antsiranana, Madagascar*
[2] *Phd Student, EDT-ENRE, University of Antsiranana, Madagascar*
[3] *Professor, EDT-ENRE, University of Antsiranana, Madagascar*

ABSTRACT

Currently, several methods have been found and applied for the MPPT control of a photovoltaic energy system. In this paper we present four methods, Perturb and Observ (P & O), the control based on fuzzy logic, which requires two inputs such as the error and its variation, the P & O algorithm optimized by fuzzy logic where the voltage variation and the direction of movement is controlled by fuzzy logic. The decision of the controller depends on the operating power point position relative to the maximum power point. The specificity is that this technique requires only the "error (E)" as input and finally the control based on the artificial neural network having one input layer, one hidden layer and one output layer. For this technique, the input is the current (Ipv) and the voltage (Vpv). All these methods have the same output which is the duty cycle "dD". The simulation results comparison show the effectiveness of the three last methods on rapidity, stability and robustness in front of disturbance, especially the weather changes, simultaneous variation of temperature and solar irradiation. Especially, the P&O algorithm optimized by fuzzy logic presents the best performances.

Keyword: - *MPPT, P&O, Fuzzy logic, Artificial Neural Network, duty cycle, MPP, Converter, DC-DC, Boost*

1. INTRODUCTION

Solar energy is an intermittent energy source. Its optimal exploitation requires a control module integrated on the MPPT algorithm. Currently, several algorithms have been adopted to serve the extraction of maximum power point [1]-[2]. In this work, four algorithms have been studied. The first is the Perturb and Observ (P&O) which allows Maximum Power Point (MPP) to be sought by decreasing or increasing the voltage according to the operating point compared with the MPP [3]-[4]. Then, the algorithm based on the fuzzy logic with two inputs (the error and its variation) which allows to control the converter duty cycle [2]-[7]-[8]-[9]-[10]. Thirdly, the P&O optimized by fuzzy logic, which is a combination of two methods such as P&O and fuzzy logic, in order to optimize some weak points of the classical P&O algorithm and simplify the implementation of the algorithm based on fuzzy logic [1]-[5]-[6]. In this new technique, only one input (error) may be enough for the fuzzy parts. The duty cycle is always the fuzzy controller output. The last method is based on artificial neural network [12].

The Optimization methods presented in this paper have been studied and simulated using Matlab Simulink. After simulations, the results are presented in order to compare these four methods in terms of stability, speed and accuracy.

2. MPPT: PERTURB AND OBSERV (P&O)

In this algorithm, a slight perturbation is introduced. This perturbation involves the power of the solar module to change continuously. If the power increases, then the perturbation is continued in the same way [1]. The algorithm oscillates around the MPP when the steady state is reached. In order to keep small the power variation, the perturbation size is kept too very tiny. Fig -1 shows the usual P&O algorithm.

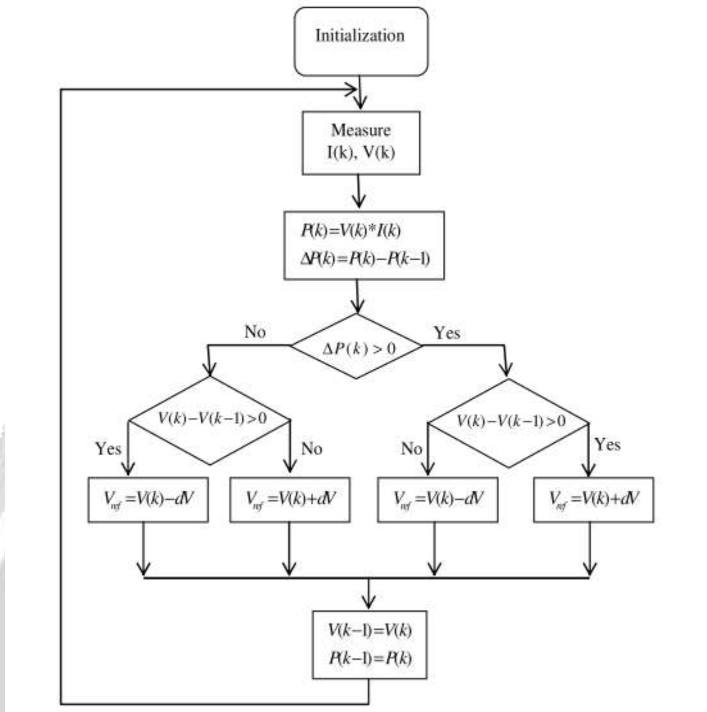

Fig -1: Classic P&O algorithm

Although, the P&O algorithm is simple to be implemented, it is less powerful to track the MPP under fast varying atmospheric conditions. The system is simulated by using the Matlab Simulink and we have the block as shown in Fig -2.

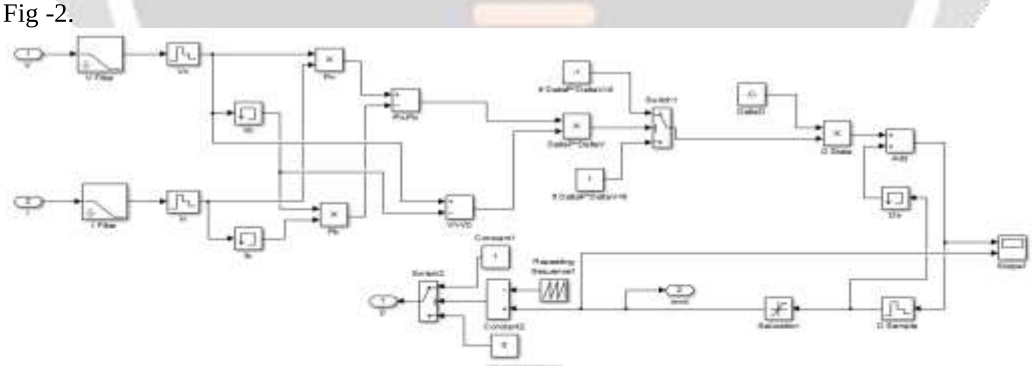

Fig -2: Simulink bloc of P&O algorithm

3. MPPT BASED ON FUZZY LOGIC

Currently, fuzzy logic control has been used in the maximum power point tracking systems. This command has the advantage to be a robust control and it does not require the exact knowledge of the mathematical model system [8]. The fuzzy logic controller design requires three stages: the fuzzification, the inference and the defuzzification. Fig.3 shows the basic scheme for fuzzy logic controller

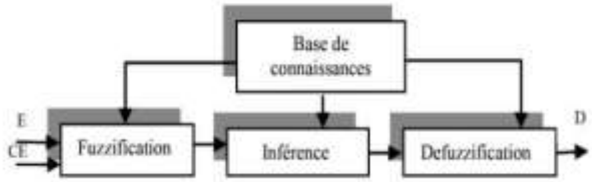

Fig -3: Fuzzy Logic basic scheme

A Fuzzification allows the transformation of real variables into linguistic variables. In our case, we have two entries [8]-[9]-[10]: the error E and the variation of the error dE defined by the following equation:

$$E = P(k) - P(k-1)/V(k) - V(k-1) \qquad (1)$$

$$dE = E(k) - E(k-1) \qquad (2)$$

Each variable has a degree membership on the linguistic variables: NL (Negative large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PL (Positive Large). Usually, standard triangular and trapezoidal membership functions are chosen.
Fig. 4 shows the membership function applied in this system.

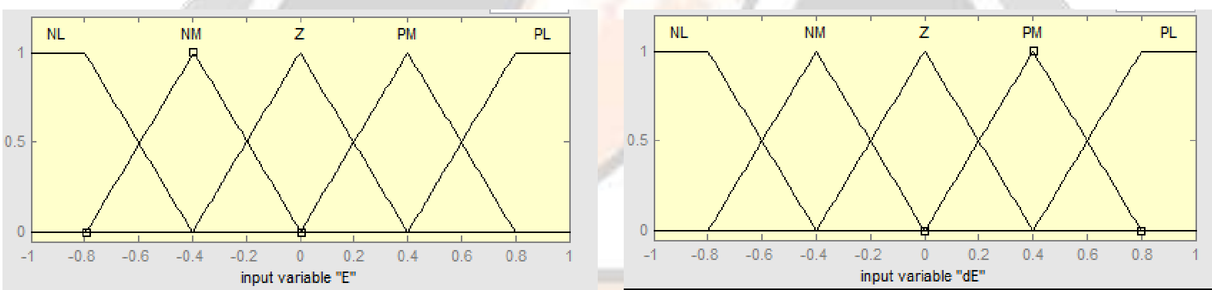

Fig -4: Membership function

At the inference or fuzzy rules, relations between inputs and outputs are established by reasoning from rules. Subsequently, the table of inference rules is drawn up (Table1).

Table -1: inference rules applied to MPPT based on fuzzy logic

dE E	NL	NM	Z	PM	PL
NL	PL	PL	PL	PM	ZE
NM	PL	PL	PM	Z	NM
Z	PL	PL	ZE	NM	NL
PM	PM	Z	NM	NL	NL
PL	Z	NP	NG	NL	NL

After creating a fuzzy inference rule under Matlab Simulink, we obtain the following figure:

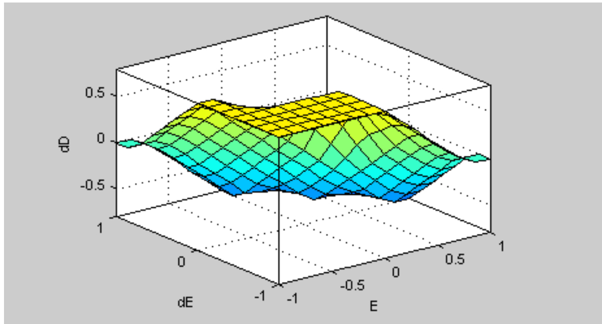

Fig -5: Fuzzy inference rule under Matlab Simulink

The output is the incrementing step of the duty cycle dD. Singleton membership is chosen for the output.

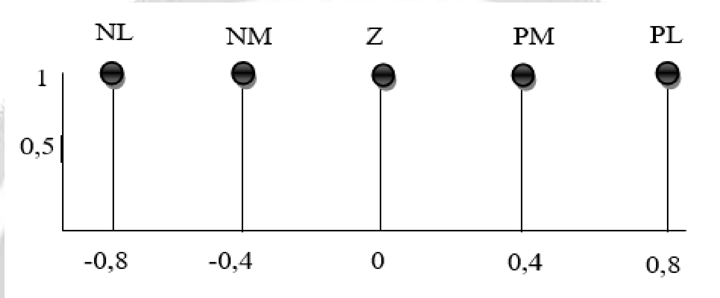

Fig -6: Output variable, duty cycle dD

4. MPPT P&O OPTIMIZED BY FUZZY LOGIC

This technique is the combination of the P&O algorithm and the fuzzy logic. In this method, fuzzy logic is used to optimize the P&O algorithm. The reasoning rests on the characteristic P-V as presented in Figure 7.

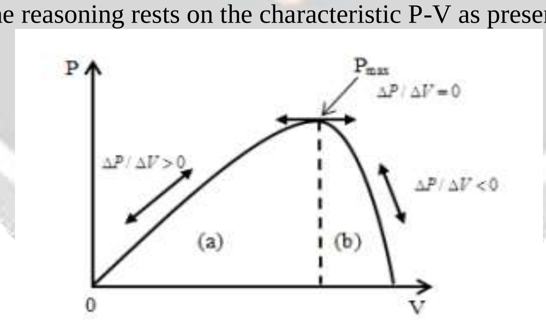

Fig -7: Characteristic P-V

The characteristic is divided by two areas: area (a) where $\Delta P / \Delta V > 0$, and area (b) with $\Delta P / \Delta V < 0$.
At any time, relation (3) is taken:

$$V(k) = V(k-1) + \Delta V \qquad (3)$$

For the duty cycle D,

$$D(k) = D(k-1) + dD$$

1) At the MPP, $\Delta P / \Delta V = 0$ the voltage is unchanged and the incrementing voltage $\Delta V = 0$. It means that the incrementing duty cycle is also kept unchanged. $\Delta V = 0 \Leftrightarrow dD = 0$
2) When $\Delta P / \Delta V > 0$, the voltage must be increased. $\Delta V > 0 \Leftrightarrow dD > 0$
3) When $\Delta P / \Delta V < 0$, the voltage must be decreased. $\Delta V > 0 \Leftrightarrow dD > 0$

This technique uses only one variable as the input variable E [1]. This variable is defined by the equation 5.

$$E(k) = \Delta P(k) / \Delta V(k) \qquad (4)$$

With: $\Delta P(k) = P(k) - P(k-1) \qquad (5)$

And $\Delta V(k) = V(k) - V(k-1) \qquad (6)$

In this study, Variable E, presents five linguistics variables such as:

- NL: operating point located farther to the left of the MPP.
- NM: operating point located on the left-hand side of the MPP.
- Z: operating point almost confused with the PPM.
- PM: operating point located on the right-hand side of the PPM.
- PL: operating point located farther to the right of the PPM.

Fig -8 shows the membership functions of input variable

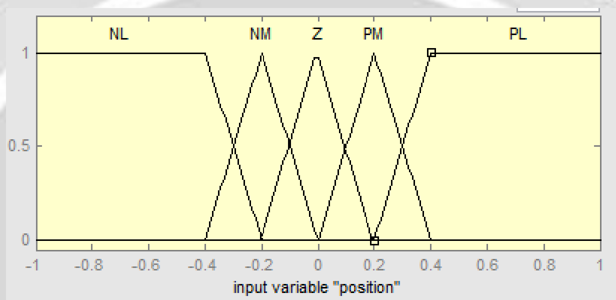

Fig -8: Membership function of input variable E

The inference rules for this corrector are shown in the following table 2.

Table -2: inference rules applied to the P&O optimized by fuzzy logic

Règle N°	E(k)	dD(k)
1	NL	PL
2	NM	PM
3	Z	Z
4	PM	NM
5	PL	NL

NL : Negative large,
PL : Positive large,
NM : Négative Medium,
PM : Positive Medium,
ZE : Zéro

By choosing the Takagi Sugeno method for defuzzification, we have a single output variable which is the duty cycle dD. The membership function is represented by Fig -9.

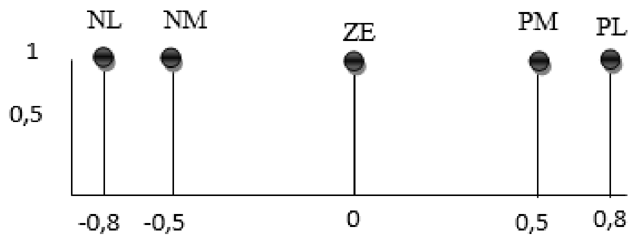

Fig -9: Output variable, duty cycle dD

Fig -10 shows the modified algorithm for optimization

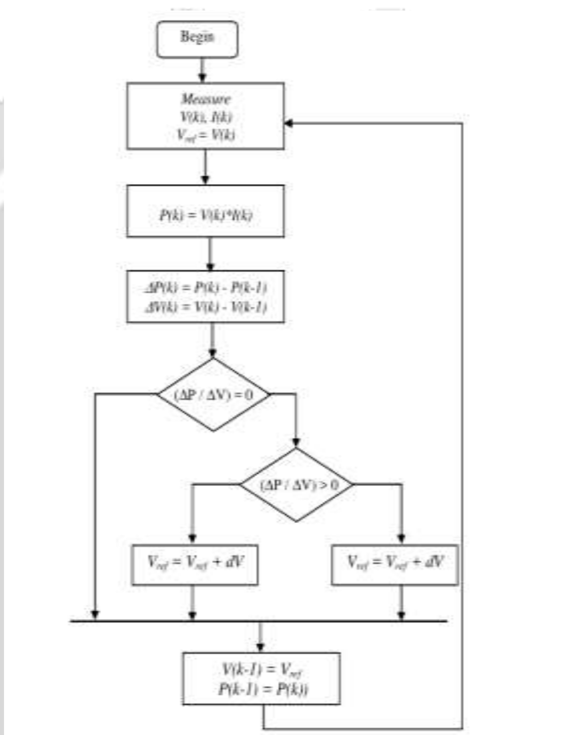

Fig -10: Modified algorithm

The reasoning is built from figure 7. At any case, as presented in (3), the duty cycle expression is:

$$V(k) = V(k-1) + \Delta V \Leftrightarrow D(k) = D(k-1) + dD$$

Here dD may be positive or negative, i.e. the duty cycle can increase or decrease. The fuzzy logic rules detect the position of the point in comparison by the PPM and decision is made consequently. This method generates a variable incrementing step thus and fixes its sign. Fig. 9 shows the realization of the MPPT P&O algorithm optimized by fuzzy logic in Matlab/ Simulink. It may be noted here that the input is only the error “E”.

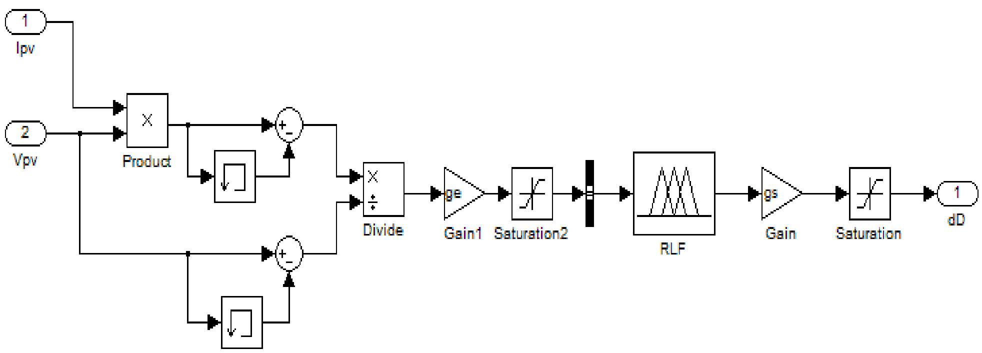

Fig -11: MPPT P&O algorithm optimized by Fuzzy Logic

4. MPPT BASED ON ARTIFICIAL NEURAL NETWORK

For the implementation of the neural network then, we need to:

- Determine the relevant inputs, i.e. the quantities that have a significant influence on the phenomenon that we are trying to model
- Collect the data needed to learn and evaluate the performance of the neural network
- Find the number of hidden neurons needed to obtain a satisfactory approximation
- Estimate the values of the parameters corresponding to a minimum of the function for learning (maximum error desired, the gradient of the error ...)
- Evaluate neural network performance after learning

4.1 Choice of neuronal structure

In the neural network implementation, the input variables chosen are the pair (Vpv, Ipv) as a function of the illumination (E) and the temperature (T), and the output is the reference voltage that will be used. in pulse width modulation because these variables are relevant to the variation of the output. In our work then, we built a network of multilayer neurons with:

- Two entries: Vpv and Ipv
- A hidden layer with ten neurons. (after several experimental trials)
- An output layer to a neuron, corresponding to the reference voltage

For the transfer function, the sigmoid function for the intermediate layers and the linear function for the output layer were used.

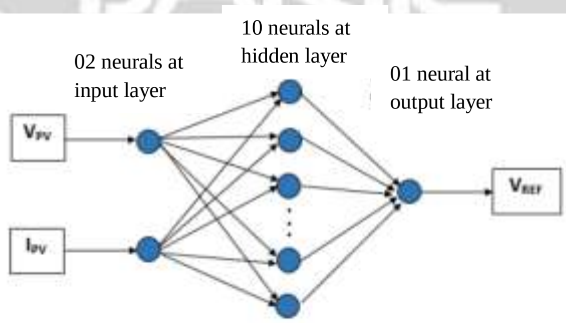

Fig -12: Neural structure for the MPPT command

4.2 Data collection learning

To create our neural network, we require a prepared learning basis. As previously shown, the results obtained by the MPPT P & O optimized by Fuzzy logic are much better compared to the two previous MPPT commands "Perturb and observes" and the fuzzy logic, so we will build our database with data from the P & O command optimized by fuzzy logic. From these data, we can then learn our network.

4.3 Data collection learning

After launching the simulation of the P & O optimized by fuzzy logic command, we can acquire the data (inputs: Vpv and Ipv, the target output: d). Having the input and output data, we can proceed to the creation of the network by launching the "file.m" which contains the functions of the Matlab toolbox for neural networks in order to carry out the learning. At the end of the learning, thanks to the command "gensim (net)", one obtains the following block:

Fig -13: Simulink block of the neural network

By introducing this block into the control system for the converter, we have this:

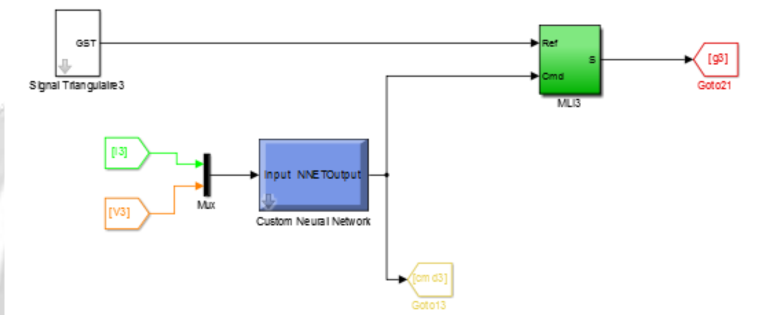

Fig -14: MPPT control block based on artificial neural network

- V is the voltage and I is the current coming from the PV generator
- g is therefore the switching command of the boost converter

5. SIMULATION

5.1 Generality of the system

The photovoltaic conversion system is constituted by blocks as indicated in Fig. 15.

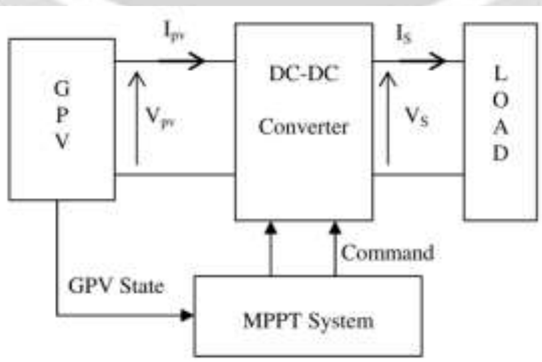

Fig -15: Model of the system

5.2 Photovoltaic module

The photovoltaic module used for this study is a polycrystalline type, under the reference MSX60 whose characteristic is summarized in the following table.

Table -3: Characteristic of the MSX60 Module

Parameters	Values
Maximum power	60W
Maximum power Voltage	16.8V
Maximum power current	3,56A
Guaranteed minimum power	58W
Short Circuit Current	3,87A
Open circuit voltage	21V

5.3 Converter

Between the GPV and the load, we used a DC / DC boost converter that is able to convert a DC voltage to another DC voltage whose output voltage can be greater than or equal to the input voltage. The relation linking the quantities to the entry and the exit is:

$$Vs = Ve\frac{1}{1-D} \qquad (7)$$

$$Is = (1-D).I_L \qquad (8)$$

D is the duty cycle of the converter which is to be controlled by the MPPT control in order to adjust the voltage to the load.

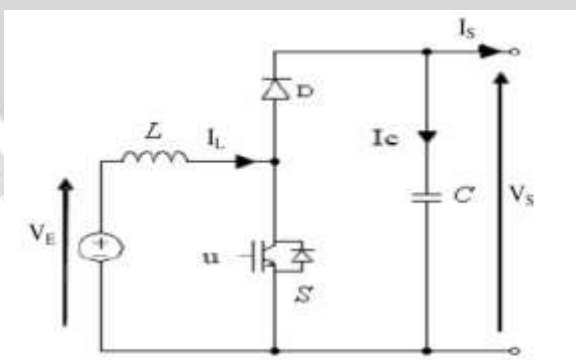

Fig -16: DC/DC Boost Converter

5.3 Results

The simulation results of the previously studied algorithms are given by the following figures. These figures show the power output values for a pair of temperature and solar radiation (fixed and variable).

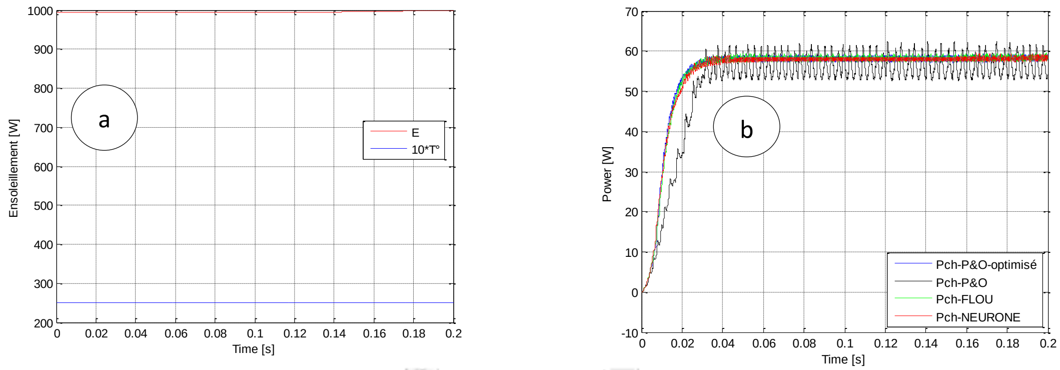

FIG. 17: result of simulation of algorithms for fixed T and E

(a) - Input: T and E fixed 25 ° C, 1000 W / m2. (b) - Power rate

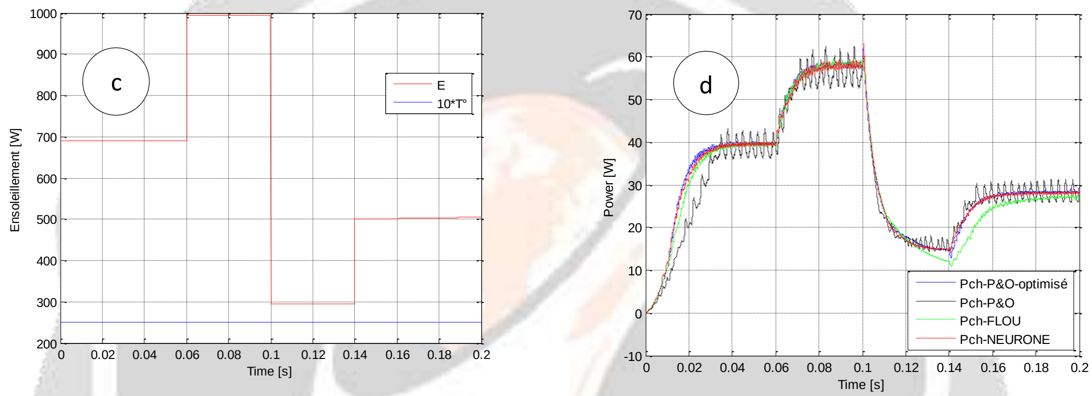

FIG. 18: result of simulation of algorithms for fixed T and variable E

(c) - Inputs: Fixed temperature at 25 ° C, and solar irradiation variation. (d) - Power curve.

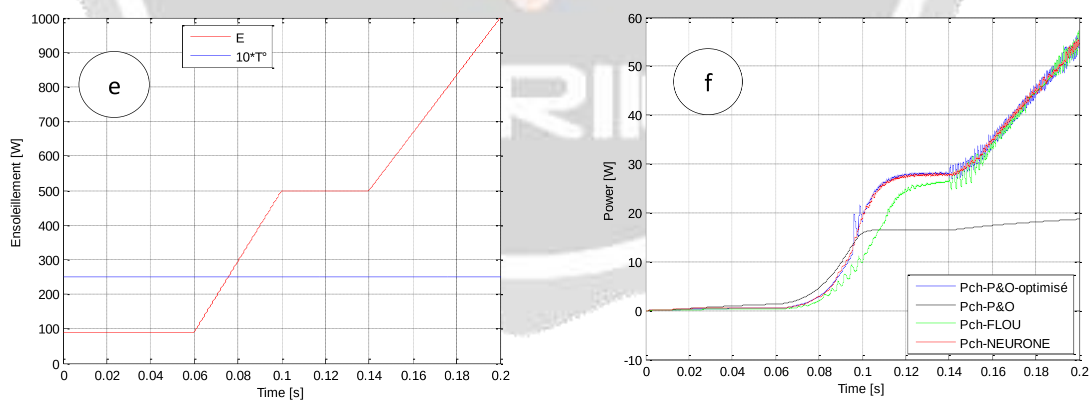

FIG. 19: result of simulation of algorithms for fixed T and variable E

(e) - Inputs: Fixed temperature 25 ° C, and solar irradiation. (f) - Power curve

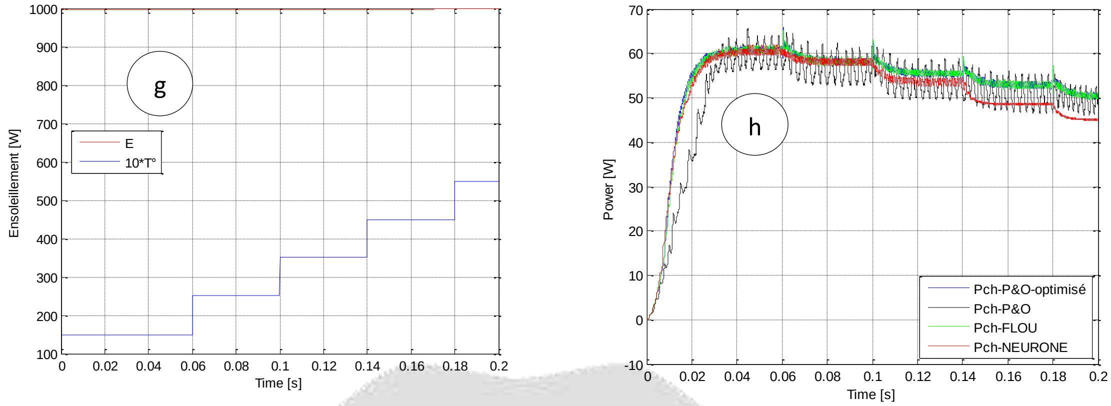

FIG. 20: result of simulation of algorithms for fixed T and E

(g) - Inputs: Variable temperature, and fixed solar irradiation, (h) – Corresponding power curve

5.3 Interpretations

In all cases of sunlight and temperature, for the four MPPT algorithms we applied in our system, we were able to find the maximum power point. The results in Figures 17, 18, 19 and 20 allow us to compare the algorithms studied as summarized in the table below. (The numbers 1, 2, 3 and 4 indicate the performance rank of the algorithms facing the characteristics mentioned in each row)

Table -4: Performance obtained by MPPT algorithms

MPPT Algorithms	P & O	FL	P & O Optimized by fuzzy logic	RNA
Speed	4	3	1	2
Precision	(4) 95.98%	(2) *99,10*	(1) 99,13	(3) 98.33%
Resistance to sunshine change	4	3	1	2
Resistance to temperature change	4	2	1	3

6. CONCLUSIONS

In this paper, we have described the main elements of the PV system. Then the principle of four MPPT algorithms used on the PV system is presented. Finally, we finished with a simulation of these different algorithms. At any condition, the results of the simulation show that the algorithm P&O optimized by fuzzy logic(P&O-FL) is the best technique compared with the other algorithms. It leads to better performances as best efficiency, best stability around the PPM, best speed and good behavior following solar irradiation and temperature variations. It is easy to be implemented. In contrast, the classical P&O algorithm has many more disadvantages compared with the other techniques.

7. REFERENCES

[1] ANDRIANANTENAINA Chrysostome, DONA Bruno Victorien, Jean Nirinarison RAZAFINJAKA, « MPPT P&O Algorithm Optimization by Fuzzy Logic », *International Journal of Engineering Research And Management (IJERM) ISSN: 2349- 2058, Volume-04, Issue-11, November 2017*

[2] H. Abbes, H. Abid, K. Loukil, A. Toumi et M. Abid, « Etude comparative de cinq algorithmes de commande MPPT pour un système photovoltaïque », *Revue des Energies Renouvelables,* Vol. 17 N°3 (2014) 435 – 445.

[3] A. Brahmi, A. Abounada et M. Ramzi, « Application de la commande ‘Perturb and Observe’ pour l’extraction de la puissance maximale des cellules photovoltaïques », *Revue des Energies Renouvelables* CER’07 Oujda (2007) 121 – 124

[4] N. Aouchiche, M.S. Aït Cheikh et A. Malek, « Poursuite du point de puissance maximale d’un système photovoltaïque par les méthodes de l’incrémentation de conductance et la perturbation & observation », *Revue des Energies Renouvelables* Vol. 16 N°3 (2013) 485 – 498

[5] Edmond Randriamora, Faly Ramahatana, Jean N. Razafinjaka, Yvon Andrianaharison, « MPPT P&O avec pas élastique appliqué au PV », *Mention Génie Electrique Ecole Supérieure Polytechnique d’Antananarivo Vontovorona, Antananarivo Madagascar*

[6] H.Othmani, H.chaouali, D.Mezghani, A.Mami, « Optimisation de la Technique de Perturbation et Observation par la logique floue » *3ème conférence Internationale des énergies renouvelables* CIER-2015, Université de Tunis El Manar, Ecole Nationale d'Ingénieurs de Tunis, LR-11-ES20 Laboratoire d’Analyse et Commande systèmes, 1002, Tunis, Tunisie

[7] « logique floue » MSM 2017

[8] N. Ould Cherchali, A. Morsli, M. S. Boucherit, L.Barazane and A. Tlemçan, « Application de la Logique Floue pour la Poursuite du Point de Puissance Maximale d'un Système Photovoltaïque », Laboratoire de Recherche en Electrotechnique et Automatique. Université de Médéa Algérie, *Laboratoire de commande des processus. Ecole Nationale Polytechnique, El Harrach, Alger, Algérie, Faculté d’Electronique, Université des Sciences et de la Technologie Houari Boumediene, ‘USTHB’, Alger, Algérie*

[9] Z. Ayache, A. Bendaoud, H. Slimani, B. Benazza, H. Miloudi, A. Bentaallah , « Commande MPPT et Contrôle d’un Système Photovoltaïque par la Logique Floue », *Laboratoire IRECOM, Université Djilali Liabès Sidi Bel Abbès 22000, Algeria*

[10] M. Ajaamoum, M. Kourchi, B. Bouachrine, A. Ihlal and L. Bouhouch « Comparaison du contrôleur flou Takagi-Sugeno et de la commande "P&O" pour l'extraction de la puissance maximale d'un système photovoltaïque [Comparison of Takagi-Sugeno fuzzy controller and the command "P&O" for extracting the maximum power from a photovoltaic system]”, *ERTAIER, ESTA, Université Ibn Zohr, BP 33/S, 80050 Agadir, Maroc Faculté des Sciences, Université Ibn Zohr, BP 8106, 80060 Agadir, Maroc*

[11] Kashif Ishaque, Zainal Salam « A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition », *Renewable and Sustainable Energy Reviews 19 (2013) 475–488*

[12] Gonzalo Joya, « Réseaux de Neurones Artificiels pour la Gestion d’un Système d’Énergie. Applicabilité et limitations des paradigmes principaux », *Dpto. Tecnología Electrónica, ETSI Telecomucicación, Universidad de Málaga, 29017 Málaga, París, le 29 mars 2001*