Fuzzy logic controller in Optimizing of Power Management in Stand-alone Photovoltaic System

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Abstract—**the objective of this work is to develop strategies for energy management of photovoltaic installations. An intelligent controller with improved algorithms management associated with a stand-alone photovoltaic system in order to manage battery performance when there are variations of insolation and temperature. In a first step, we implement simulation scheme using solar energy extracted by photovoltaic panels, which are connected to the storage device. We present a photovoltaic system. Then a study of DC-DC converters, which can supply the battery, is completed. The objective is to identify the most appropriate storage device for this type of application. The second part is devoted to photovoltaic panels. Its operation, its topology, its characteristics and modelling are determined; the technique of fuzzy logic MPPT method is also explained. The performance of the latter is compared with those of conventional methods (observation and incremental conductance disturbance) through various simulations in Matlab / Simulink. At last, the synthesis of a stand-alone photovoltaic system and its control is presented.**

***Keywords*— Solar panel, Solar regulator, accumulator, power converter, MPPT, Fuzzy logic, Matlab/Simulink.**

I. INTRODUCTION

There are many reasons why to conduct research in the field of renewable energies. Nevertheless, a more important issue is in the South. The number of people who will probably never have access to a large grid is estimated at over to two billion. In addition to environmental reasons, photovoltaic energy is a solution for isolated sites and rural areas. If today, the developing countries have no access to photovoltaic; this is mainly due to the cost of this technology. Therefore, it is essential to intervene on the world market and developing by self even technology related to photovoltaic systems in order to significantly reduce costs.

Renewable energy is one way to go, and in particular photovoltaic have proven to be a solution [1]. The arrival of the new power devices technologies, new circuit topologies and novel control strategies are contributing to the success of the renewable energy generation technologies.

Due to low energy conversion efficiency and high initial cost of the photovoltaic (PV) systems, it is desirable to work with the maximum possible efficiency and to optimize the design of all elements for such systems. In this environment, maximum power point tracking (MPPT) controllers are becoming an essential element in PV systems.

A significant number of MPPT algorithms have been presented in the literature such as the perturb and observe method and the incremental conductance method [2,3].

MPPT fuzzy logic controllers (FLCs) have the advantage of being fast robust and of having quiet good performance (time response, stability, tracking speed, small oscillations) under varying atmospheric conditions. MPPT FLCs are more effective under sudden changes of atmospheric conditions compared to the traditional algorithms. Our approach introduces more flexibility to the structure and design of MPPT algorithm. Flexible FLC means robustness against noise and parameter variations, simplicity and tolerance for imprecision [4].

The simulation results demonstrate the effectiveness of the proposed method and show that this approach can achieve a better maximum power operation under any atmospheric conditions compared to the other techniques such as classic MPPT methods like P&O and the incremental conductance method.

II. PHOTOVOLTAIC SYSTEM

A. *PV model characteristics*

The equivalent circuit of a PV cell is using a photovoltaic powersource, as depicted in Fig. 1.

The current source corresponds to the photocurrent that takesplace at the diode due to sunlight. This current depends on thespectrum and the intensity of the sunlight, as well as the temperatureof the cell. Thecurrent which produced by the current source is described in Eq. (1).

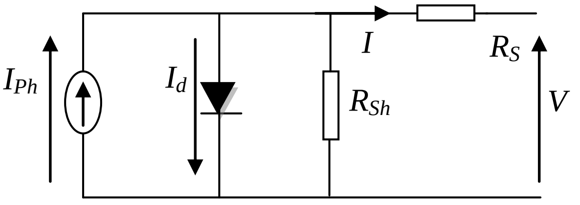

Fig. 1 Equivalent circuit for general PV cell model.

$$I = I_{Ph} - I_S\left[\exp\left(\frac{q\left(V + R_S \cdot I\right)}{nkT}\right) - 1\right] - \frac{V + R_S \cdot I}{R_{Sh}} \qquad (1)$$

I isdelivred current by PV source, *V* is the voltage across the PV source, k is the Boltzman's constant, *T* is the temperature on the photovoltaic surface. The factor n is related to the number of the cells. In this model, it is considered that the value of the parallel resistance R_{Sh}. It is also assumed that the value of the series resistance $R_S$is constant and equals to the series resistance at the maximum power point of 25°C and 1000 W/m^2 where Impp and Vmpp are the current and the voltage at the maximum power point respectively [5].

Indicatively, the characteristic P-V and I-V curves at the referencecondition of 25 °C and 1000 W/m^2 of the first PV source are shown. While the I-V and P-V characteristic curves forvarious solar irradiances and temperatures are presented in Figs. 2, 3, 4 and 5 respectively.

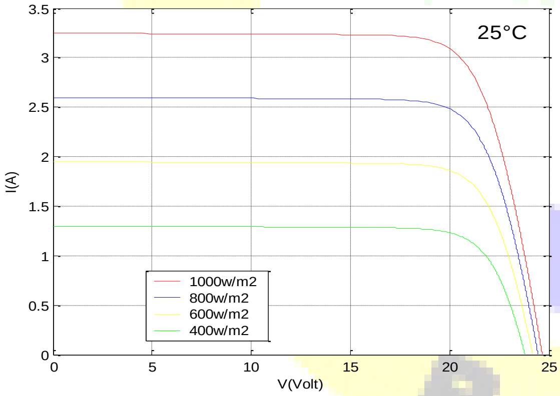

Fig. 2. I-V curve of the PV source for different values of irradiance

For various climatechanges, we perform the simulation using the software"MATLAB/ SIMULINK". We implementedthe model of the PV generator and got the characteristics (I-V)and (P-V).The power produced from the PVpanel is directly proportional to the irradiance and inversely proportional to the temperature.

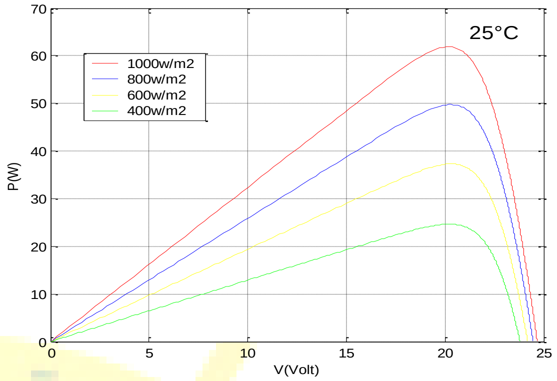

Fig. 3. P-V curve of the PV source for different values of irradiance

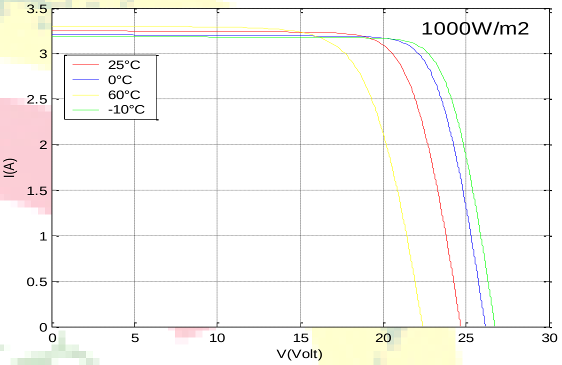

Fig. 4. I-V curve of the PV source for different values of temperature

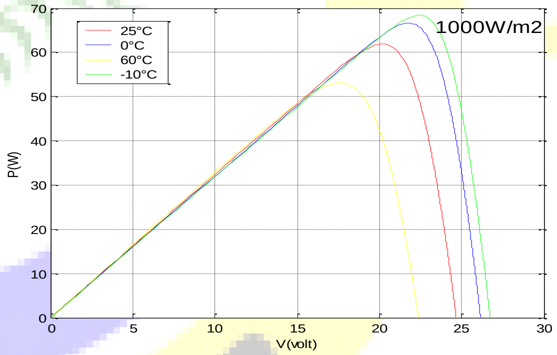

Fig. 5. P-V curve of the PV source for different values of temperature

B. DC/DC buck-book converter

Theusage of the DC/DC converter is essential for achieving MPPT, as it isthe element, which is driven by the controller in order to move theoperational point of a PV source to be coincident to the MPP. Fig. 6presents the circuit of the DC/DC converter.When a buck-boost converter is used for tracking the maximum powerpoint, its output voltage is defined by Eq. (2).

$$V_{out} = V_{in}\frac{-D}{1-D}\frac{1}{1+\frac{R_L I_0}{(1-\delta)^2 - V_0}} \qquad (2)$$

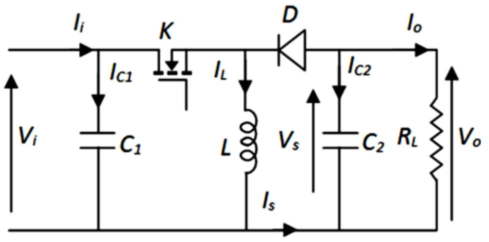

Fig. 6. Buck-boostconverter topology.

A buck-boost converter and a resistive load are connected in parallelwith the source. These three elements form the power circuit.

C. Electrical model of Battery

The system of storage is composed of lead-acid battery. The determination of the batteries' impedances is often made on stationary behaviour.

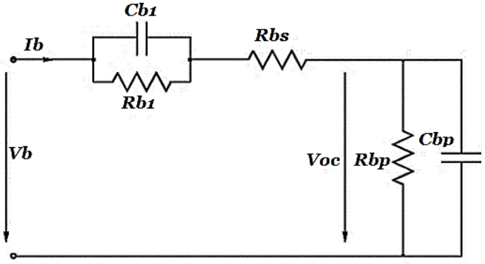

Fig. 7 Electrical model of lead-acid battery.

The circuit in Fig. 7 describes a lead-acid battery the characteristics completely and simplified. This circuit equivalent expresses the input impedance of a lead-acid battery by:

$$Z(s) = R_{bs} + R_{b1} // C_{b1} + R_{bp} // C_{bp}$$
$$= R_{bs} + \frac{R_{b1}}{R_{b1}.C_{b1}s+1} + \frac{R_{bp}}{R_{bp}.C_{bp}.s+1}. \qquad (3)$$

$$Z(s) = \frac{a_2 s^2 + a_1 s + a_0}{b_2 s^2 + b_1 s + b_0} \qquad (4)$$

The coefficients$a_i$and $b_j$are used to represent different components [6].

III. FUZZY LOGIC CONTROL STRATEGY

Several researchers have studied this type ofalgorithm, especially for its application in research and thepursuit of maximum power point tracking (MPPT). Thismethod uses a controller based on fuzzy logic applied to a DC-DC converter [7, 8].

A. Design of the FLC MPPT controller

Fuzzy logic controllers have the advantage of beingrobust and relatively simple to design because they do notrequire knowledge of the exact model. On the other hand,they require perfect knowledge and complete photovoltaicsystem by the operator for the establishment of rules ofinference.

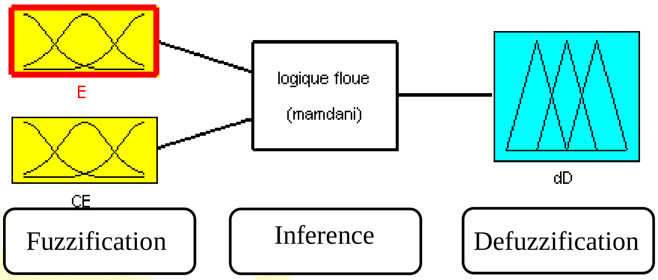

Fig.8. General Structure of a fuzzy logic controller

Generally, a fuzzy logic control consists of three blocks as shown in Fig. 8: Fuzzification, inference and eventually block of defuzzification.Fuzzification Membership function values are assigned to the linguistic variables, using fivefuzzy subsets:NB (negativebig),NS (negative small), ZE (zero), PS (positivessmall), and PB (positive big).The fuzzification itself is to define membershipfunctions for the different variables, making the passage of aphysical quantity to a quantity language. The inference rulesselected were obtained from general rules applied to anysystem that can be ordered.Defuzzification: the output of this fuzzy controller is afuzzy subset of control. To get anon-fuzzy value of control,a défuzzification stage is necessary.

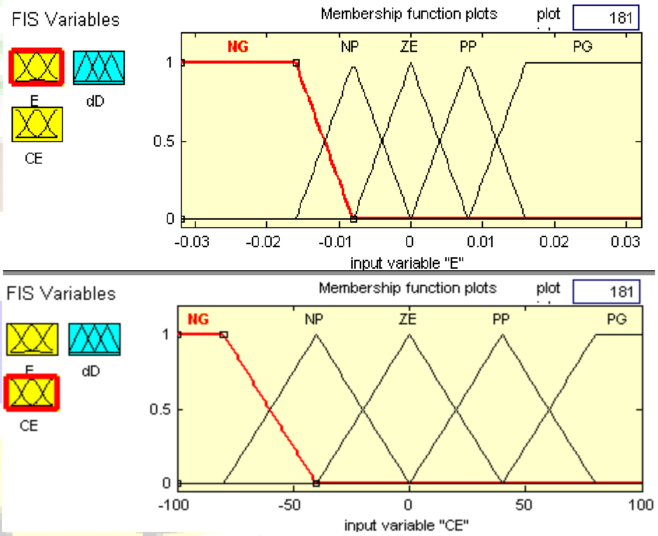

Fig 9. Memberships functions for input variables E and CE

The fuzzy controller proposed MPPT has two inputs andone output. The two input variables of the controller are theerror E and the error variation CE sampled at each samplingstep k. These two variables are defined by:

$$E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \qquad (3)$$
$$CE(k) = E(k) - E(k-1)$$

Where P (k) and V (k) are respectively: the power andvoltage of GPV.Fig. 9 shows the membershipfunctions of the fuzzy gain scheduler forthe inputs Eand CE,

TABLE I
RULE BASE FOR E, CE.

CE E	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZS	PP	ZE	ZE	ZE	NS
PS	PN	NS	PN	ZE	ZE
PB	GN	NB	NB	ZE	ZE

The approach taken here is to exploit fuzzyrules and reasoning to generate the controller parameters. Thefuzzy tuning rules are indicated in Table 1 with E(k) and CE(k) as theinputs and the output vector arethe fuzzy sets on the corresponding supporting sets of the FLC as shown in Fig. 10.

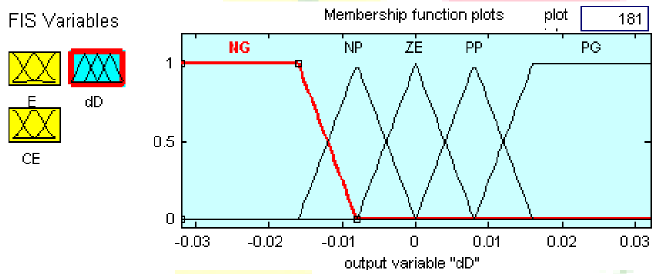

Fig. 10. Output variable dD

The elements of theoutput vector are the fuzzy sets on the corresponding supportingsets.

B. *Design methodology of the FLC MPPT implemented inMatlab/Simulink*

The model implemented in Matlab/Simulink is presented analytically in Fig. 11.The proposed system is composed of photovoltaic panel, DC-DC converter and storage battery.

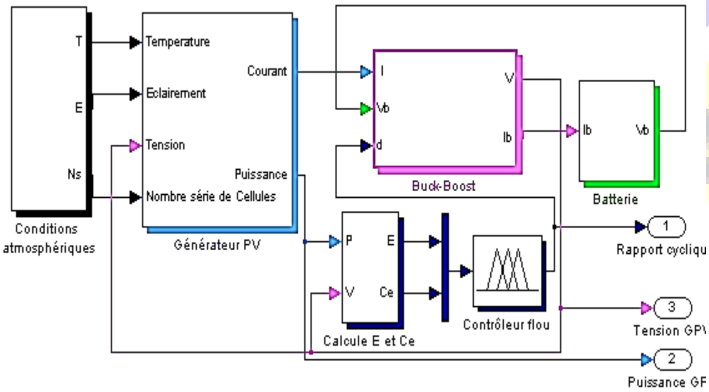

Fig. 11. Simulink model of the FLC MPPT controller in stand-alone photovoltaic system with battery storage.

Various simulations evaluate the performancesof the system. The various parts of the system (photovoltaic panel,DC/DC converter, battery and load), aremodelled by separate blocksthen related in a coherent way, while the MPPT is controlled bythe proposed fuzzy logic controller (FLC). The system components of Fig. 8are used in the simulation and itsparameters are described in Figs. 9, 10 and Table 1.

C. *The perturb and observe methodand the incremental conductance method*

In order to evaluate the performance of the proposed fuzzy logic controller in comparison with a classic method ofmaximum power point tracking, the Perturb and Observe method and incremental conductance method are used.

The P&O method is widely used because of its low implementation complexity [3]. The shortcoming of this method is that the operating point of the PV fluctuates around the MPP. Therefore, the available energy is decreased. Furthermore, if the solar irradiance changes rapidly, the P&O technique fails to track the real point of maximum power. This creates a slower tracking time response. The convergence speed is varied due to the slow trial and error process.The flowchart of the P&O algorithm is shown in Fig. 12. The voltage and the current produced by the PVarray are measured, in order to calculate the power that is generatedby the PV array. Then the power values of the present and previousstates are compared.If the power does not remain the same, the algorithmchecks if the differential between the power at the presentand previous state is negative or positive.

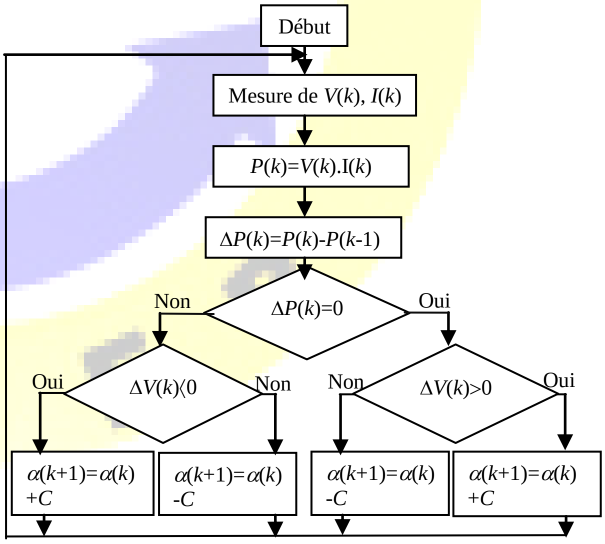

Fig. 12. Flowchart of P&O algorithm [9].

If the differential is positive then the duty cycle D is changing in order to keep the operationat the same direction of perturbation. If the power's difference isnegative the duty cycle is changing in order to reverse the direction of perturbation [9].

The incremental conductance MPPT method is based oncomparing the instantaneous conductance to the incrementalconductance. At the maximum power point, the values of conductance and incremental conductance are equal but with oppositesigns.

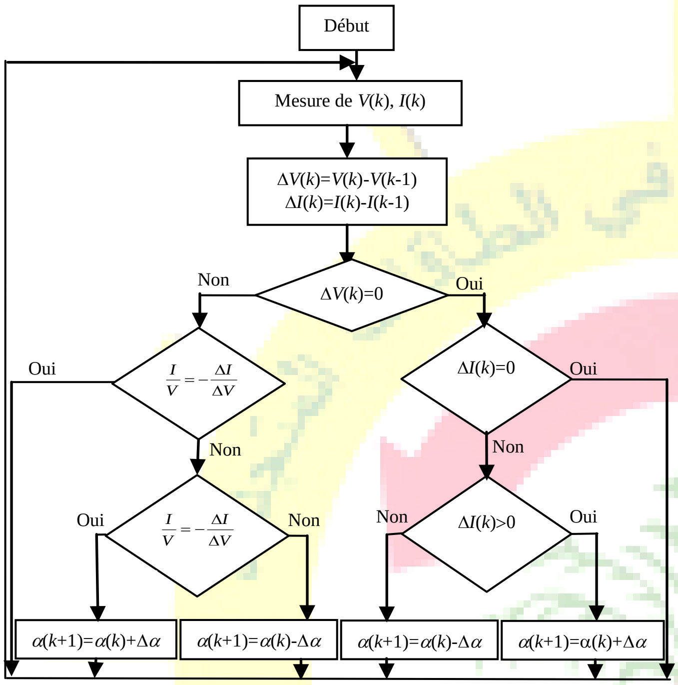

Fig. 13. Flowchart of incremental conductance algorithm [9].

This method has medium implementation complexitycompared to P&O [3]. The drawback of this technique is the oscillationsaround the MPP.

*1) Comparative between P&O method and incremental conductance method:*The Perturb & Observe (P&O) and Incremental Conductance (IncCond) methods are chosen to be implemented and tested in MATLAB simulations as presented in Fig. 14.

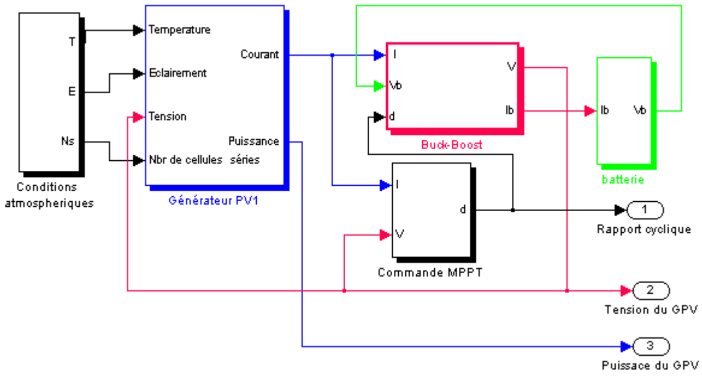

Fig. 14. Simulink model with MPPT for stand-alone photovoltaic system.

The characteristic P-V curves at the reference condition of 25 °C and 1000 W/m^{2}are shown in Fig. 14.

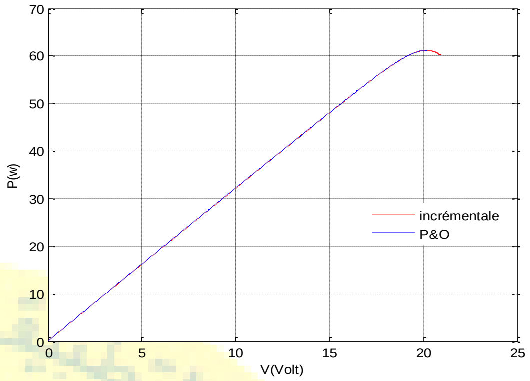

Fig.15. Characteristics *P*=f(*V*) at standards conditions.

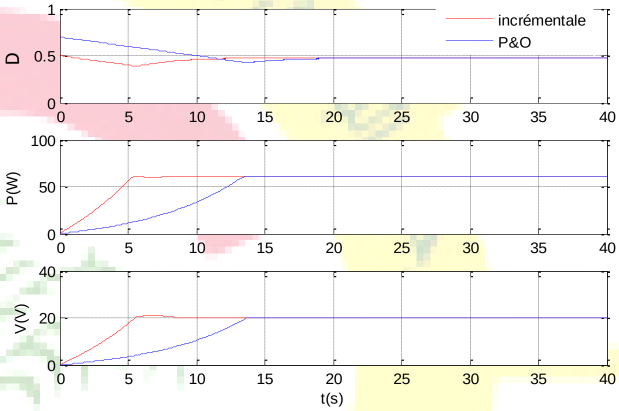

Fig. 16 variations of duty cycle D, power P and voltage of PV panel.

Comparative tests for the two MPPT algorithms, the perturbation and observation (P&O) algorithm and the incremental and conductance (IncCond) algorithm using variations of duty cycle, power and voltageof PV panel related to the timehave been undertaken as shown in Fig. 16.

TheIncCond algorithm shows slightly better performance in terms of efficiency compared to the P&O. Even a small improvement of efficiency could bring substantial savings if the system is large. However, it could be difficult to justify the use of IncCond algorithm for small low-cost systems, as the cost and availability are the two major aspect of system design.

*2) Comparative between incremental conductance and fuzzy logic controller:*In this section, the performance of Fuzzy logic controller for a PV system is presented. Different performance parameters, such as rising time (Tr), and energy production are studied in order to analyse the performance of FLC control system in comparison to the IncCond control system. The results are presented analytically on Figs.17 and 18.

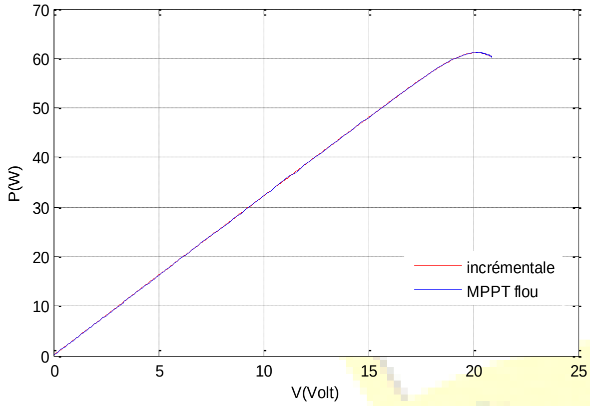

Fig. 17. Characteristics P=f (V) at standards conditions.

Fig. 17 presents solar panel power (P_{pv}) and solar panel voltage (V_{pv}) for the two MPPT controllers (incCond and FLC).

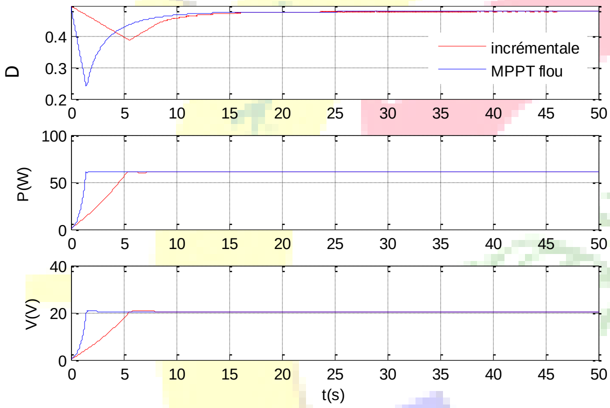

Fig. 18 Variations of duty cycle D, power P and voltage of PV panel.

The simulation results show that the system controlled by the FLC adapts to changes in external disturbances, and has a stability system. Moreover, the response time is relatively quick compared with IncCond controller.

IV. CONCLUSIONS

The present paper proposes an introduction of the research works conducted on the regulator solar system, control charge/discharge batteries applied to stand-alone photovoltaic systems. We presented a maximum power point tracker (MPPT) method, based on fuzzy logic controller (FLC), applied to a stand-alone photovoltaic system. The stand-alone photovoltaic system used in this paper includes DC/DC buck-boost converter and a lead-acid battery bank to overcome the scare periods. Converter works as an MPP tracker, in order to regulate the batteries state of charge and compensates the power deficit to provide a continuous delivery of energy to the load. The Obtained simulation results show the effectiveness of the proposed fuzzy logic controller. It was shown that the FLC is perfectly adaptable to our regulation system; the FLC measures instantaneously PV voltage and current variations and determines quickly the optimal increment required to have the operating voltage for tracking the MPP even when the operating environmental conditions change rapidly and in a wide range. The photovoltaic current I_{pv} develops according to the variations of solar radiation corresponding to the battery current charge I_{batt}. When PV power is greater than load's power, the batteries will charge (batteries charge mode). During periods of insufficient generation, the battery bank postpones its recharge cycle and supplements the generation at the expense of its stored energy (power compensation mode). The load's voltage, it is well controlled to keep it at a constant value whatever the environmental conditions and the load change.It uses a sampling measure of the PV array power and voltage then determines an optimal increment required to have the optimal operating voltage, which permits maximum power tracking. This method carries high accuracy around the optimum point when compared to the conventional one.

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