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Using Fuzzy Logic Algorithm for reaching the true Maximum Power Point and its Bypass Local of PVG partially shaded

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ABSTRACT

The role of MPPT controllers in a PV system is to extract the maximum of power; they are able to reach very good performances when it is about only one peak of power where the irradiation is uniform on all the Photovoltaic Generator (PVG). But if the PVG is partially shaded, the appearance of several peaks of power leaves the conventional controllers unable to find the true Peak of power.

This work presents a thorough study of the phenomenon of the partially shading; its origins, the methods of its evaluation, its modeling and its impact on the output of the PVG; it presents also a simulation under Matlab/Simulink environment of the partially shaded PVG.

MPPT Algorithms improved to detect the real maximum point of power in the case of partial shading, they are synthesized and analyzed and then their simulation of a fuzzy controller MPPT for different levels of shading summarizes the answers which can gives this type of standard controller with fuzzy logic algorithm under such operating conditions.

Keywords: DC/DC converters, photovoltaic generator, partially shaded, algorithms of maximum power point tracking, fuzzy controller.

INTRODUCTION

Solar cells are made of various semiconductors like, silicon (*Si*), cadmium sulfide compound (*Cds*), copper sulfur (Cu_2S), and gallium arsenide (*GaAs*). We have reviewed some main conventional algorithms such as; *P&O*, I_{nC}, C_V,O_V, S_C and R_{CC}, we also discussed the principles of artificial intelligence algorithms such as fuzzy logic, or neural networks[1-4]. Due to the inability of conventional algorithms to deal with the problem of partial shading, detailed in the literature, and to enrich this work and give the true extent of this phenomenon, we tried to group together the different approaches proposed by different authors with the aim to develop MPPT algorithms capable of achieving the true PPM. We were able to conclude that the main points of the algorithms studied in the literature can be summarized as follows:

In the first phase, the objective was to move the operating point to the most appropriate point (load line) to achieve proximity to the overall PPM [5], [8], [9], other initiatives [6], [7]and [10] prefer to let the algorithm reach a local PPM and then start the second phase.

The second phase for [5], [8], [9] takes effect as soon as the point is reached, it consists of a simple *P&O* or *Inc* algorithm to reach the overall PPM, taking as a security measure the comparison of the power measured to that stored, so as not to circumvent the real PPM by trying to reach a local PPM.

For references [6] [7] and [10] this step represents a scan of the P-V curve:
a) The scan starts from start to finish [6] or from an initially found PPM [7], [10].
b) The triggering of the scan is periodic [6 or governed by conditions [7, [10.
c) The scan step can be fixed [6], [7], or variable [10].
d) The direction of the scan is either unidirectional [6], or bidirectional [7], [10].
e) The search is stopped if an extrema is reached [6], [10], or if a less important PPM is located [35], then the algorithm makes the decision to go directly towards the proximity of the global PPM (of which the coordinates have already been stored) where it uses a simple P&O algorithm (6), (7) or an improved I*nc*

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algorithm with a variable step [10].
According to reference [11-18] MPPT algorithms that claim to achieve the global maximum in the presence of multiple peaks will need to support the following important points;
1 – Independence of tracking system parameters.
2 – Number of steps and time required to reach true PPM.
3 – The direction of pursuit for sudden changes.
4 – The complexity of the control circuit.

At the end we judged important to summarize the study carried out by R.Bruendlinger et al [11-21], to practically determine the real impact of non-ideal and irregular conditions of insolation or partial shading on the functioning of MPPTs. He took a sample of 13 MPPTs that are currently on the market, the practical results actually marketed, practical results have actually demonstrated that 70% (in some cases) of the total power can be lost due to the inability of the MPPT tracking system to recover the true PPM .

Simulation in Matlab/Simulink of parameters are already verified by other studies [12-32], [13-37].
The behavior of the fuzzy MPPT controller will be analyzed to choose the best topology and define the characteristics of an MPPT control capable to converging towards the true PPM in all operating conditions of a PV system.

As for all the MPPT tracking methods (seen in the literature), the FLC (Fuzzy Logic Controller) also works according to the same philosophy which is summarized in the variation of the search step in direction and in amplitude. The verification of the variation of the power then the variation of the search step in direction and in amplitude until the variation of the power is zero.

PHYSICAL BASIS AND MATHEMATICAL
Model of Photovoltaic

Figure (1) shows the equivalent circuit of partially shaded solar cell.

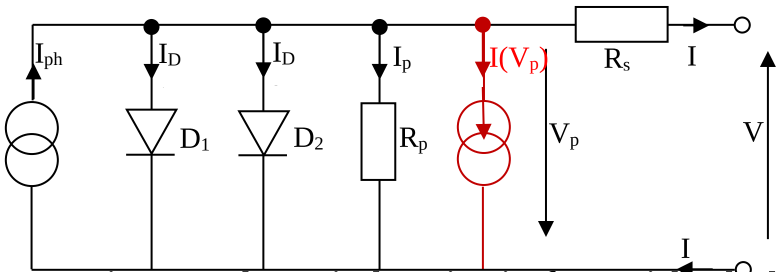

Figure 1: The equivalent circuit of a partially shaded solar cell.

$I\,(V_p)$ generates the avalanche voltage at high negative voltages. Using Kirchhoff's first law we obtain the following equation:

$$I = I_{Ph} - I_{S1}\left(exp\ q\left(\frac{V + IR_S}{m_1 kT}\right) - 1\right) - I_{S2}\left(exp\ q\left(\frac{V + IR_S}{m_2 kT}\right) - 1\right) - \frac{V + IR_S}{R_p}$$
$$- \mathbf{a}(\mathbf{V} + \mathbf{IR_S})\left(\mathbf{1} - \frac{\mathbf{V} + \mathbf{IR_S}}{\mathbf{V_{Br}}}\right)^{-\mathbf{n}} \qquad (1)$$

The MPPT Method Based on Fuzzy Logic Controller

Fuzzy logic is one of the most powerful control methods. It is known by multi-rules-based resolution and multivariable consideration. Fuzzy logic theory is an artificial intelligence method; it consists of three blocks which are: Fuzzification, Inference and Defuzzification. [18]

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3.1. Fuzziffication

It is assumed that the control is done by the satisfaction of two criteria relating to two input variables of the proposed fuzzy controller, which are: The error *E* and the change in the error *CE* at sampled instants n.

The variables *E* and *CE* are expressed as follows:

$$E(n) = \frac{P_{pv}(n) - P_{pv}(n-1)}{V_{pv}(n) - V_{pv}(n-1)} \quad (2)$$

$$CE(n) = E(n) - E(n-1) \quad (3)$$

Where P_{pv} *(n)* and V_{pv} *(n)* are respectively: the power and the voltage of the photovoltaic generator.

The *E(n)* input shows whether the load's operating point is at the left or the right of the maximum power point of the P-V curve, while the *CE(n)* input shows the direction of the operating point.

Linguistic variables

The fuzzy labels used in this study are negative big (NB), negative small (NS), equal zero (ZE), positive small (PS) and positive big (PB).

3.3. Membership functions

The generation of membership functions is done either in an iterative way, or with the method of trial and error or based on human experience. So far, there is no generalized method for formulating fuzzy logic strategies.

For the resolution of the maximum power point tracking problems, we define the following membership functions:

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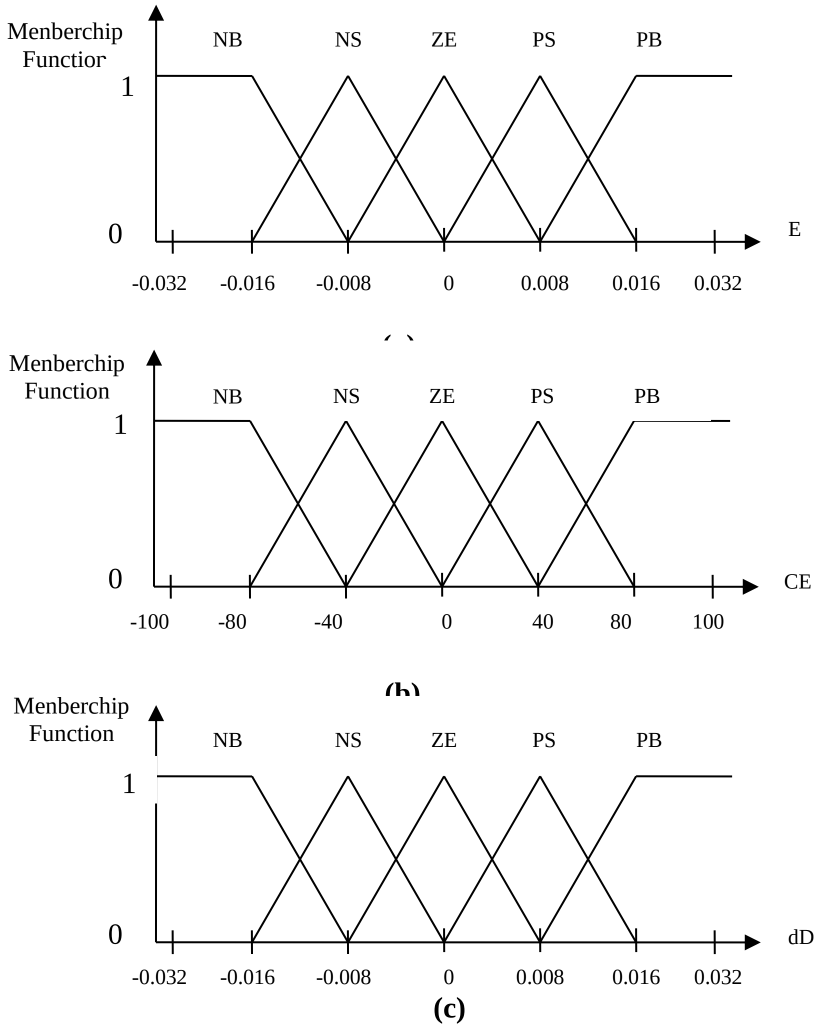

Figure (2): Membership functions of: (a) Input *E*, (b) Input *CE* (c) and Output *dD*.

3.4. Inference method

Table (2) show the FLC rules where:

The inputs of the matrix are: the error *E* and the change of the error *CE*.

The output is the change in duty cycle *dD*.

As remark, control rules must be designated so that the input variable *E* must always be zero.

Table (2) the FLC rules

E* / *CE	**NW**	**NS**	**ZE**	**PS**	**PW**
NW	ZE	ZE	PW	PW	PW
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PP	NS	NS	NS	ZE	ZE
PG	NW	NW	NW	ZE	ZE

PRESENTATION OF THE STUDIED PV SYSTEM

The PV system, shown schematically in Figure (3) consists of a photovoltaic generator, a fuzzy MPPT controller, a chopper and a battery.

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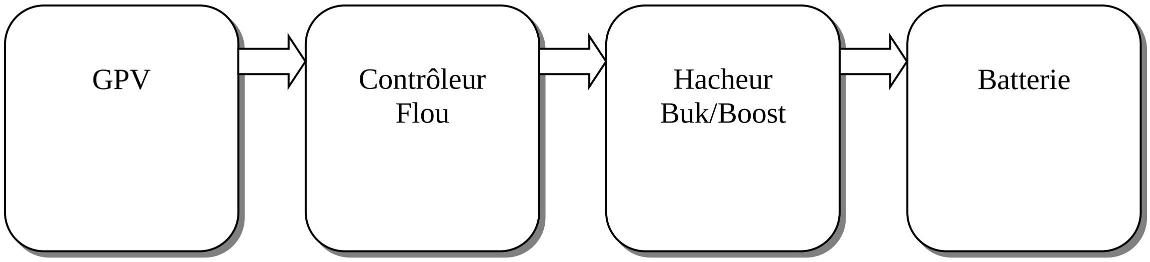

Figure (3) Schematic representation of the studied PV system

4.1. The photovoltaic generator

The photovoltaic generator consists of 14 modules, they are connected in parallel to provide the charging current necessary for the battery, the power of this generator is l order of 780 Watt for an insolation of 1000 W/m2 (at PPM) with an open-circuit voltage of 21v and a short-circuit current of 50 A.

4.2. Fuzzy MPPT Controller

The fuzzy MPPT controller has been studied explicitly in works [20], [23], [24] and [25], it is often used with neural networks. In the present work we use a simple fuzzy controller (as described previously) with symmetric membership functions and an average number of fuzzy sets [5].

4.3. Buck/Boost choppers

For their simplicity, we used in this simulation work; a boost chopper then a buck chopper; theirs respective parameters are: C_1=C_2= 5.6* 10-3 F , L= 3.5 *10-3 H, for the boost and C_1 =C_2= 560* 10-6F , L=350*10-6H for the buck [34].

So that the chopper block is easy to connect with the other blocks of the system, so the equations can be rewritten as follows:

For the Buck chopper:

$$i_b = i_l - C_2 \frac{dv_b}{dt} \quad (4)$$

$$i_l = \frac{1}{d}\left(i - C_1 \frac{dv}{dt}\right) \quad (5)$$

$$v = \frac{1}{d}\left(v_b + L\frac{di_l}{dt}\right) \quad (6)$$

$$i_l = i - C_1 \frac{dv}{dt} \quad (7)$$

For the Boost chopper

$$i_b = (1-d)i_l - C_2 \frac{dv_b}{dt} \quad (8)$$

$$v = (1-d)v_b + L\frac{di_l}{dt} \quad (9)$$

Or:

i_b: the input current of the battery; v_b: the battery output voltage; v: the GPV input voltage
i: the output current of the GPV; i_l: the current of the inductance.

4.4. Battery

The model of the equivalent circuit of a lead-acid battery is represented in figure (4) it is characterized by an input impedance *Z(s)* described as follows:

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$$Z(s) = R_{bs} + R_{b1} \| C_{b1} + R_{bp} \| C_{bp}$$

$$Z(s) = R_{bs} + \frac{R_{b1}}{R_{b1}C_{b1}s + 1} + \frac{R_{bp}}{R_{bp}C_{bp}s + 1} \quad (10)$$

This impedance must be represented by a single transfer function [8]

$$Z(s) = \frac{S^2 a_2 + S a_1 + a_0}{S^2 b_2 + S b_1 + b_0} \quad (11)$$

Where the coefficients a_i , b_j are given by the following expressions:

$$a_2 = R_{bs}R_{b1}R_{bp}C_{b1}C_{bp}$$
$$a_1 = R_{bs}R_{b1}C_{b1} + R_{bs}R_{bp}C_{bp} + R_{b1}R_{bp}C_{bp} + R_{bp}R_{b1}C_{b1}$$
$$a_0 = R_{bs} + R_{b1} + R_{bp}$$
$$b_2 = R_{b1}R_{bp}C_{b1}C_{bp}$$
$$b_1 = R_{b1}C_{b1} + R_{bp}C_{bp}$$
$$b_0 = 0$$

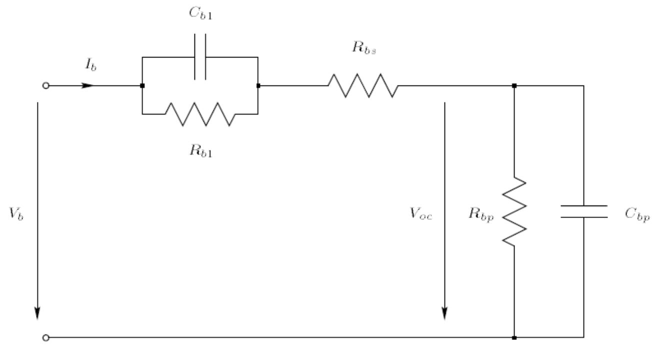

Figure (4): Model of the equivalent circuit of a lead-acid battery

STUDY OF P-V CHARACTERISTICS FOR DIFFERENT LEVELS OF SHADING

Figure 5: presents the Block diagram of the GPV studied under Matlab/Simulink.
For reasons of simplification; we will define representative cases: Insolation 1000w/m2, a single shaded cell, similarly, for each module. The shading percentage is 25%, 50% and 75%.

As shown in Figure (6) the PV system exhibits a single PPM (whose abscissa and ordinate are respectively V=17v, P=777w) when fully illuminated, once a single cell is shaded by 25%.

Figure (7) a single PPM appears (V=18.5v, P=678w) but at a significantly lower power of around -12% (~100w).

Subsequently, for a shading of 50%, Figure (8) presents two PPMs appear at different power levels (V_1=7.5v, P_1=343w, V_2=19.5v, $P2$=473w), the same for the case of shading at 75%.

Figure (9) presents two PPMs appear at different levels that are significantly different from the previous case (V_1=7.5, P_1=343w, V_2=16.2v, P_2=253w).

It is clear that the influence of a single shaded cell is very apparent; such, that it can reduce the power of the entire PV array by -67% if the controller response converges to a local PPM.

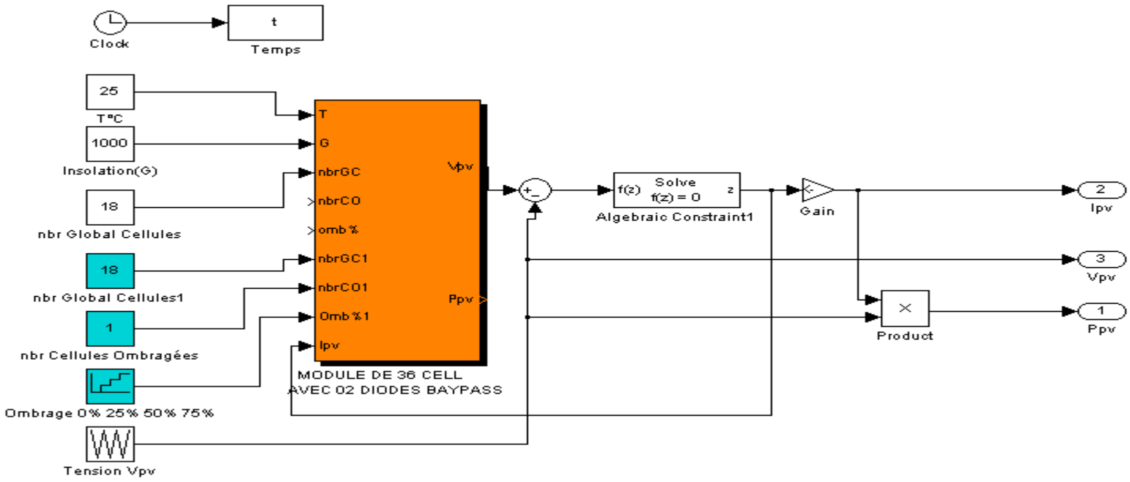

Figure 5: Block diagram of the GPV, studied under Matlab/Simulink

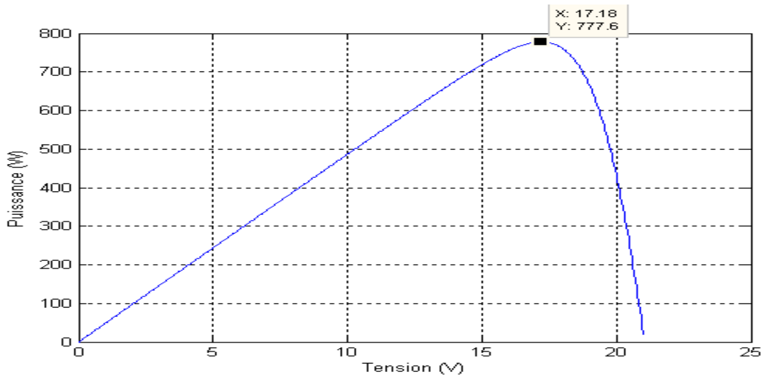

Figure 6: P-V characteristic for total illuminance (0% shading)

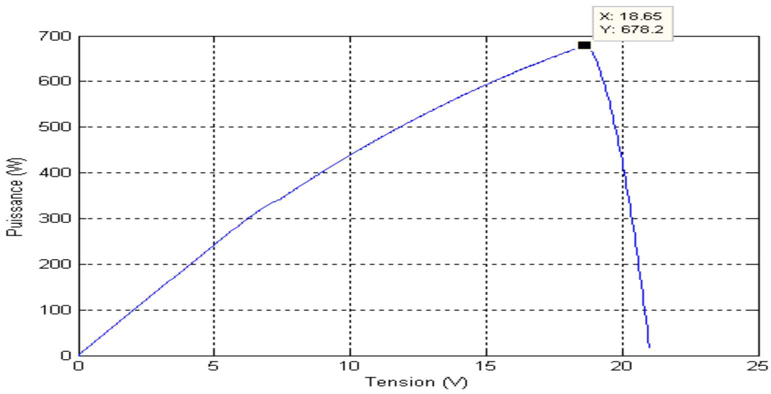

Figure 7: P-V characteristic for 25% shading

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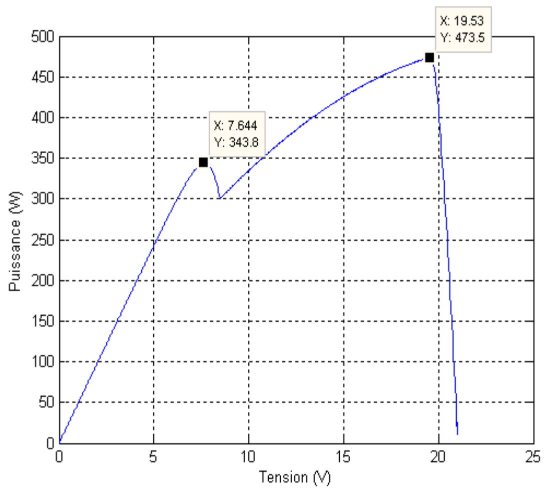

Figure 8: P-V characteristic for 50% shading

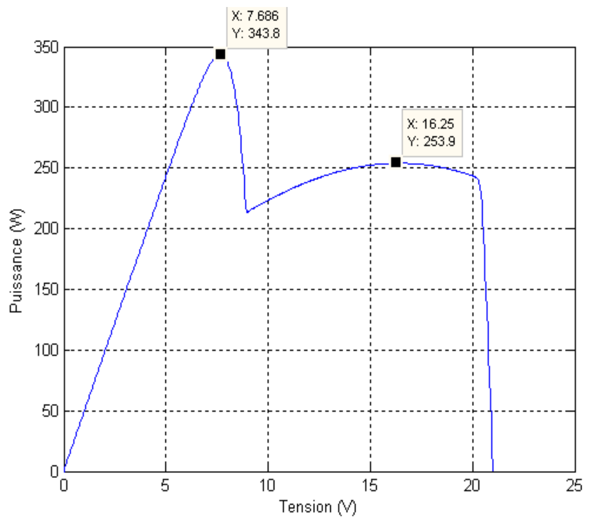

Figure 9: P-V characteristic for 75% shading

FUZZY CONTROLLER RESPONSES FOR A BOOST CHOPPER

Figure 10 presents the block diagram of the PV system with boost chopper. In the simulation of the responses of a fuzzy controller for Boost chopper we obtained different responses which are interpreted as follows:

• 1) for the case of total illumination, the response converges towards the single maximum power point (see figure (11) compared to figure (6)).

• 2) for the case of partial shading of 25% the controller also converges towards the single maximum power point (see figure (12) compared to figure (7))

• In 1) and 2) our controller can easily find and converge to the PPM

• 3) for the case of partial shading of 50%, the controller takes another attitude, it converges towards the local PPM located to the left of the characteristic. The loss of power and about 27% compared to the true PPM located on the right (see figure (13) compared to figure (8)).

• 4) for the case of partial shading of 75%, the controller converges towards the PPM still located on the left, but which this time is the real PPM, leaving the local PPM on the right. (see figure (14) compared to figure (9))

• In 3) and 4) our controller fails to find the true PPM for all cases and tends to stick to the first PPM on the left.

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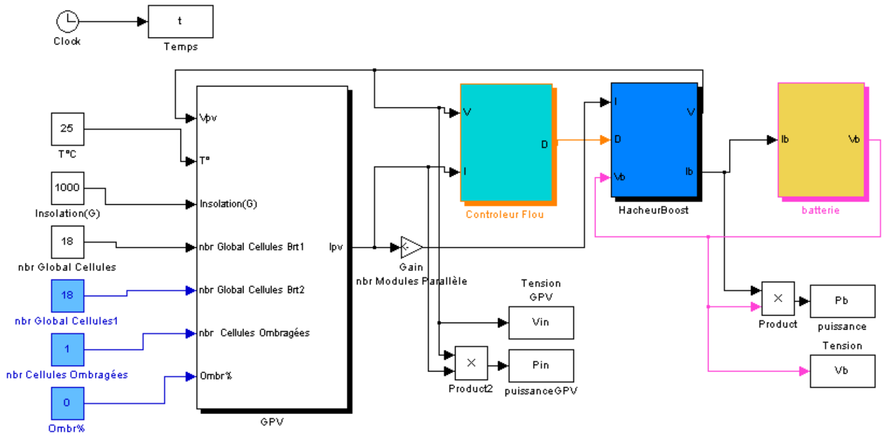

Figure 10: Block diagram of the PV system with boost chopper

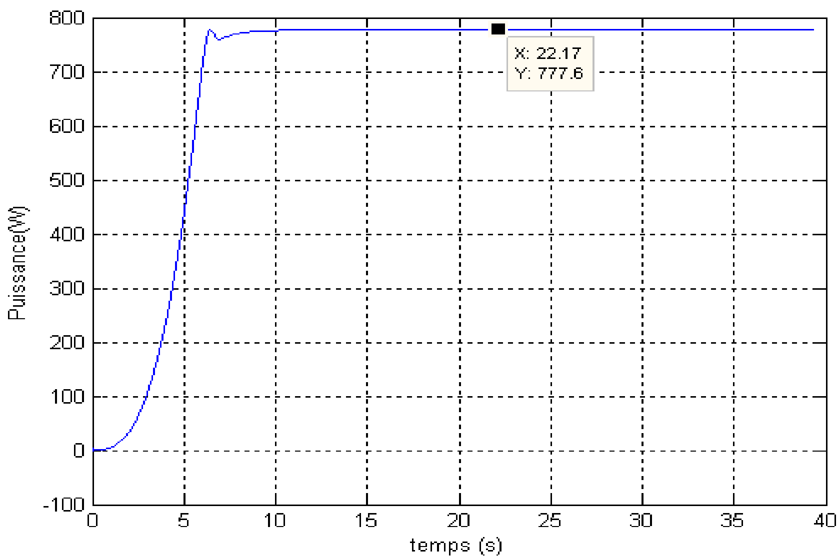

Figure 11: Fuzzy Controller response for a Boost chopper (0% shading case)

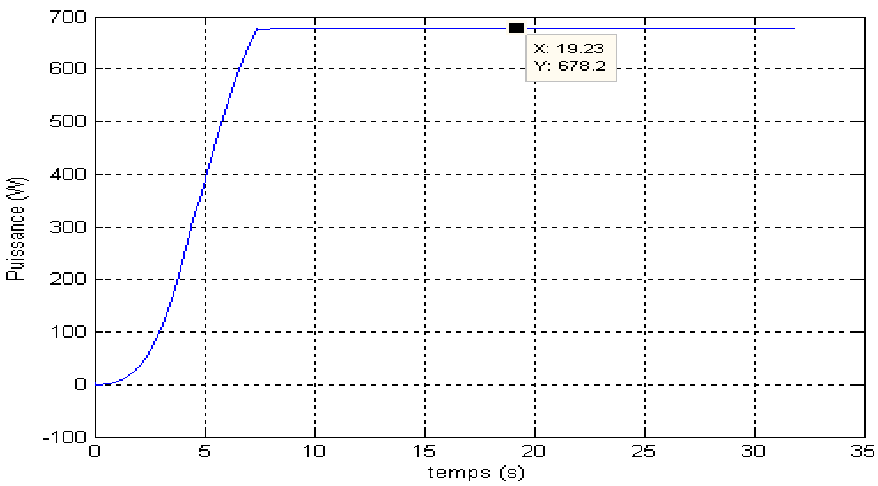

Figure (12): Response of the Fuzzy Controller for a Boost chopper (25% shading case)

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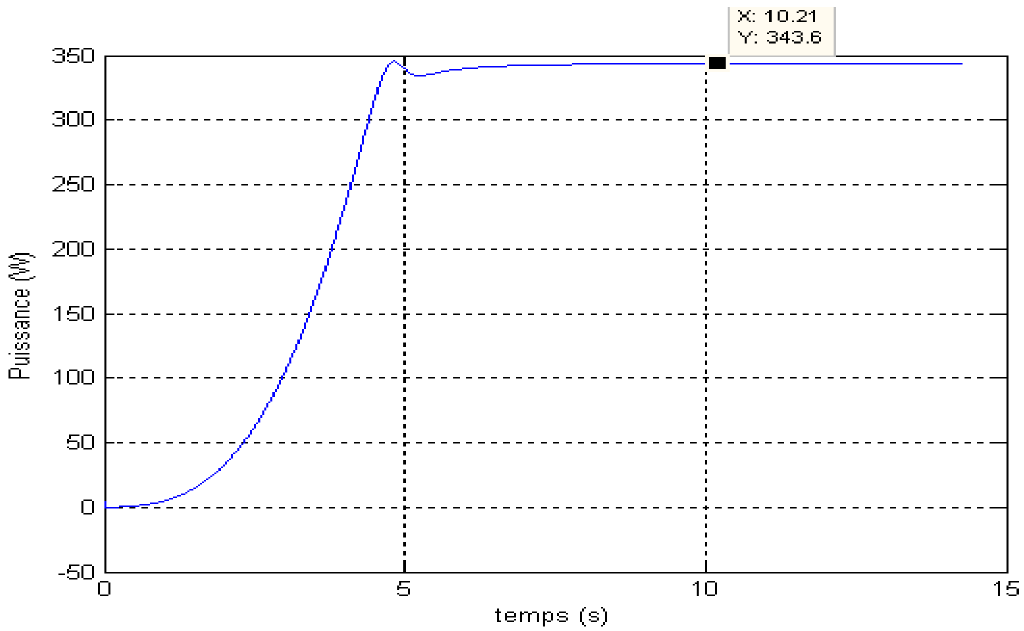

Figure (13): Response of the Fuzzy Controller for a Boost chopper (case 50% shading)

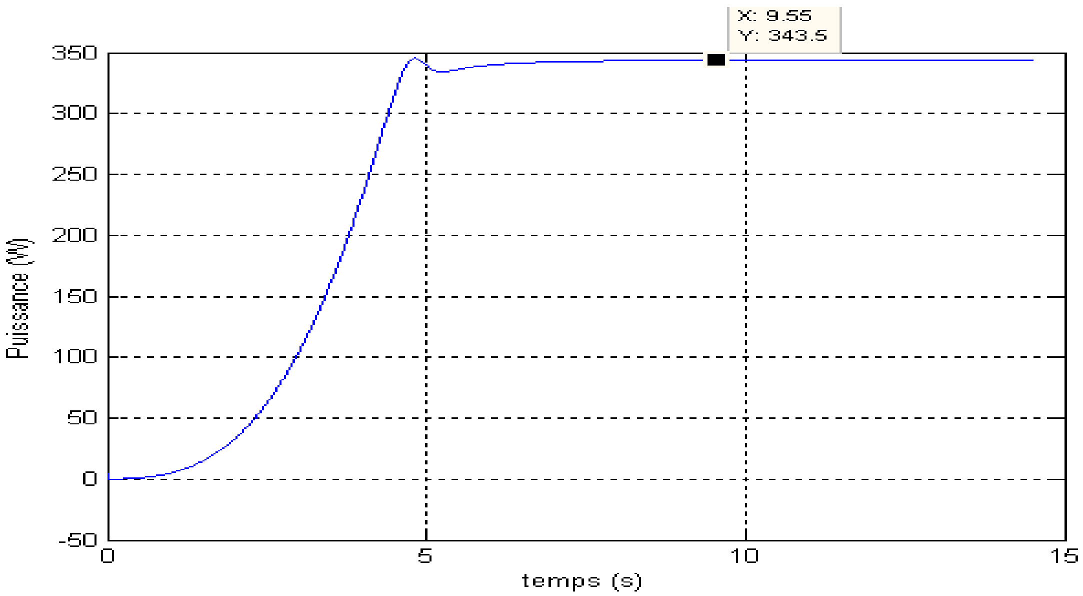

Figure (14): Response of the Fuzzy Controller for a Boost chopper (case 75% shading)

FUZZY CONTROLLER RESPONSES FOR A BUCK CHOPPER

The simulation of the responses of a fuzzy controller for Buck chopper is as interesting to analyze as the previous simulation, the different responses selected are interpreted as follows:

1) As for the boost in the case where the illumination is total, the controller easily finds the single PPM (see figure (16) compared to figure (6))

2) In the case where the partial shading is 25% the controller always finds the true PPM. (see figure (17) compared to figure (7))

From 1) and 2) the controller responses whether for a Boost chopper or for a Buck chopper always converge to the true PPM provided that the shading percentage is low enough so that the second PPM does not is not apparent.

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3) For a shading of 50% (see figure (18) compared to figure (8)), contrary to the reaction of the controller for a Boost chopper, this time for the Buck chopper, the controller finds the true PPM and leaves the local PPM on the left.

4) For a shading of 75%, the response of the controller is less good compared to the case of the Boost chopper, in fact the controller tends to stick to the first PPM located on the right thus leaving the real PPM on the left, and the power loss is about 26%. (see figure (19) compared to figure (9))

From 3) and 4) we conclude that the Fuzzy controller used with a buck chopper has a tendency to traverse the P-V characteristic on the right side.

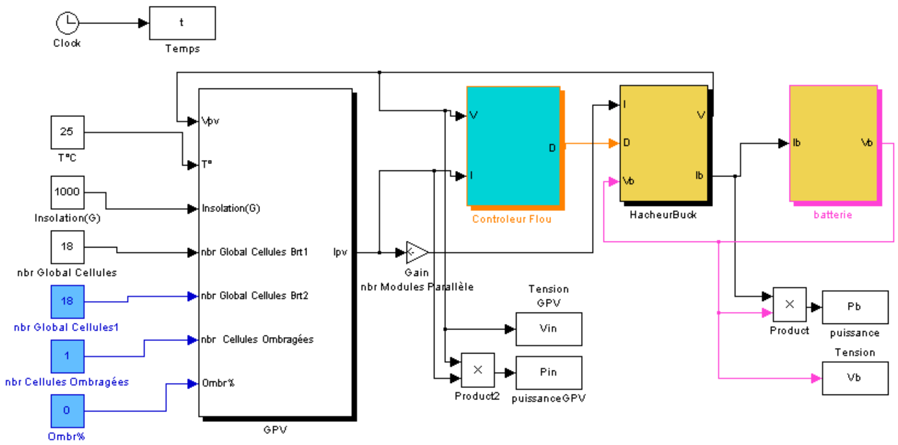

Figure 15: Block diagram of the PV system with Buck chopper

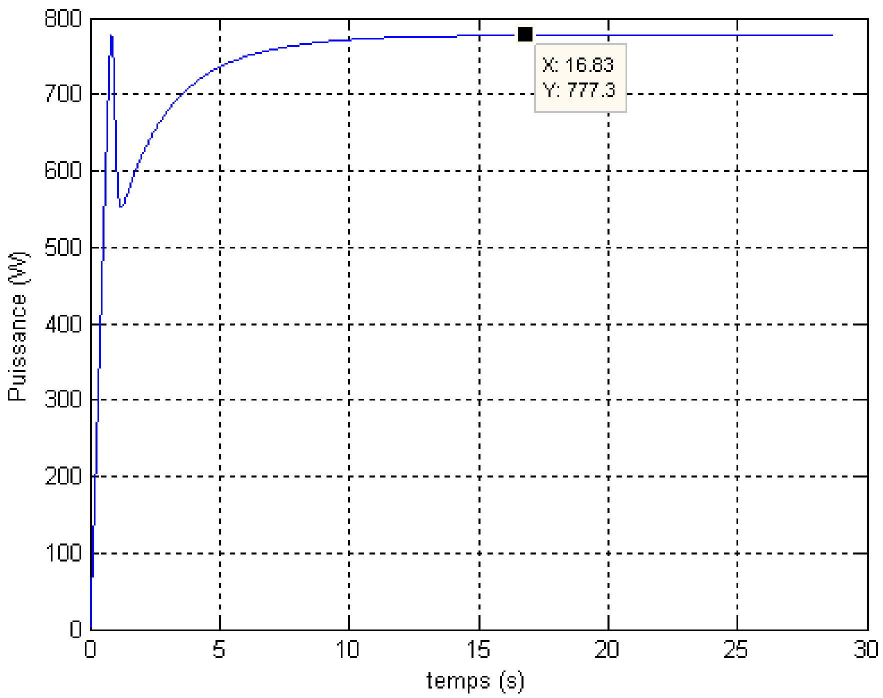

Figure (16): Response of the Fuzzy Controller for a Buck chopper (0% shading case)

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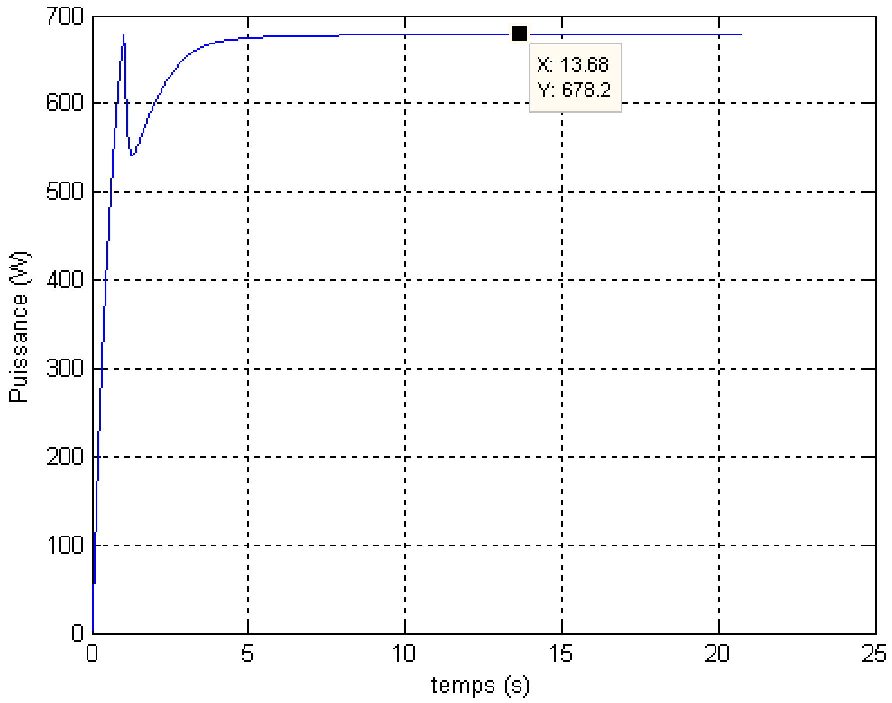

Figure (17): Fuzzy Controller response for a Buck chopper (25% shading case)

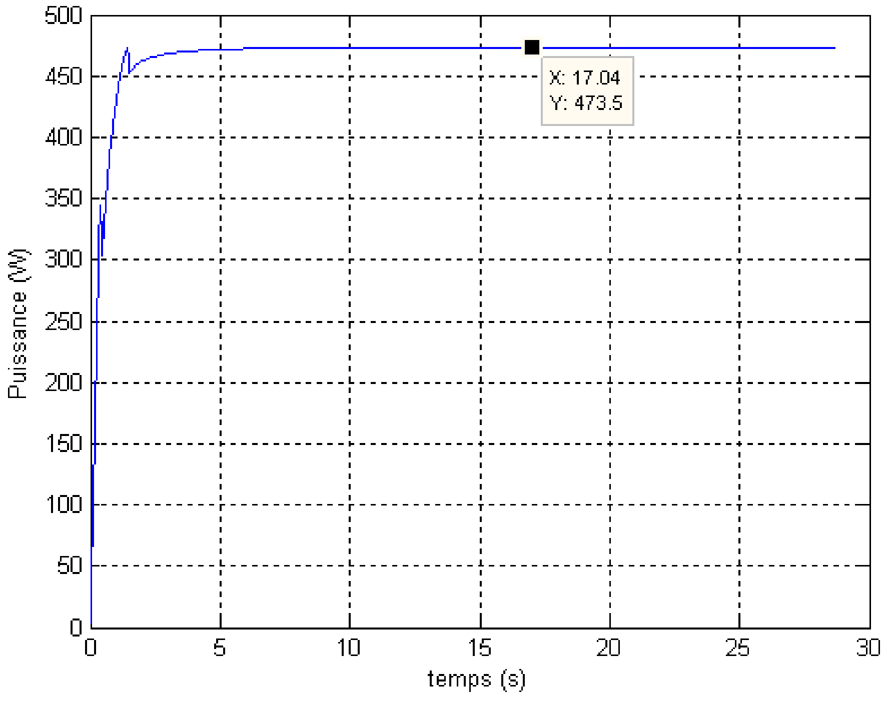

Figure (18): Fuzzy Controller response for a Buck chopper (50% shading case)

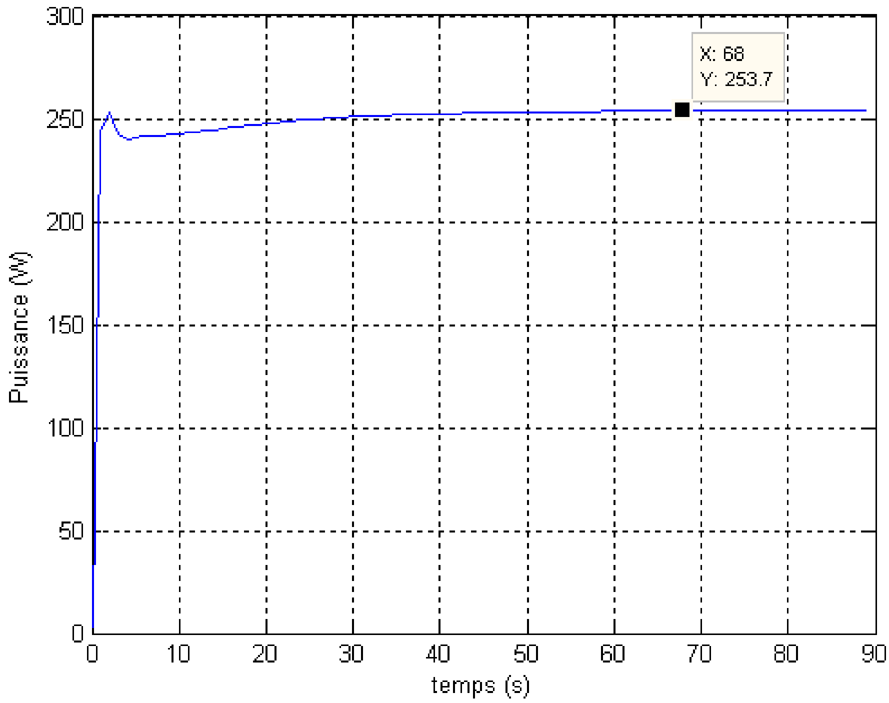

Figure (19): Fuzzy Controller response for a Buck chopper (75% shading case)

CONCLUSION

At the end of the simulation work, we will be able to conclude the following:
Set apart the quality of the controller response (response time, overshoot, ripples.), the fuzzy controller used with different topologies presents different responses; for the case of a boost, the responses of the controller mean that it begins the pursuit of the PPM from the left side (Icc) of the P-V characteristic, as soon as the convergence criteria (*E*, *CE*) are satisfied, it stopps.

For the case of a buck, the studied responses of the controller mean that it starts the continuation of the PPM from the right side (V_{oc}) of the P-V characteristic as soon as the convergence criteria are satisfied it stops.

In the two cases studied, the fuzzy controller governs by the criteria (*E* , *CE)* is incapable to detect the presence of several PPM, to then converge on the true PPM , nevertheless, the use of the buckchopper with the fuzzy controller can be more favored by starting the search where the PPM has the most probability of existing, which was verified by the simulation.

For improved tracking, it is necessary to modify the controller tracking stop criteria, so that it can scan entire firstly the P-V characteristic, then select the area where the true PPM certainly exists.
In the perspective of a future work, it is possible to combine conditions and periodicity by periodic verification of the proximity of V_{oc}.

Fuzzy logic remains the best candidate to represent the conventional algorithm.

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