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Fuzzy Logic Maximum Power Point Tracking Controller for Photovoltaic System

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***Abstract*- The paper presents a smart control strategy for photovoltaic system to obtain a DC/DC driver component which provides peak power control output. The fuzzy logic maximun power point traking method is applied to optimize the operating photovoltaic panel. The system is analyzed in different operating conditions taking under the change in temperature and solar radiation.**

The simulations are done utilizing Matlab/Simulink software. The waveform results of simulations are shown that the proposed fuzzy logic Maximum Power Point Tracking controller is capable of tracking the Maximum Power Point under the changes atmospheric conditions.

***Keywords*- Renewable energy, photovoltaic, DC/DC converter, fuzzy logic controller. Maximum Power Point Tracking.**

I. INTRODUCTION

Nowadays,the solar energy provides the opportunity to generate various power scales without emitting any greenhouse gas [1,2]. Therefore, these systems constitute an alternative to using fossil resources to protect the environment from pollution. Indeed, the use of renewable energies is needed to provide the opportunity to produce electricity that satisfies ecological requirements. Unfortunately, this issue meets economic constraints; high cost and low yield [3, 4].

The development of renewable energy sources continues to interest more and more researchers. Indeed solar energy can be used with photovoltaic solar conversion systems to convert solar radiation into electrical energy. Due to the small value of the voltage it cannot be used as a single photovoltaic (PV) cell. Therefore, the PV cells are connected in series to increase the voltage to forma PV panel. The set of PV cells are also connected in parallel to achieve higher value of output current. These sources of energy take a very important place in energy conversion systems but the performances are influenced by the climatic conditions. Indeed, photovoltaic is one of the most effective renew ble energy sources, but it is not available at night time. In this context, the PV systems require an effective control allowing to ensuring maximum efficiency of solar panels whatever the weather conditions: temperature (T) and solar irradiation (E). This consists in forcing the photovoltaic panel to operate at its maximum power point (MPP) to extract the maximum power. So, to produce the maximum power from a solar array, maximum power point tracker (MPPT) algorithms are proposed in literature. Among the most used optimization methods to extract the maximum power are: perturbation and observation techniques (P & O) [5], conductance incrementation (IncCond) [4], but these are, unfortunately, imperforming under a rapid change in weather conditions. As a result, many researchers have made modifications to these algorithms to improve their performance. In this paper, perturbation and observation method is used to find out the photovoltaic panel maximum power indented for various solar irradiation and temperature circumstances [6]. Many research teams are interested in the study of renewable energy source (RES). DC/DC converters which are mainly used for voltage regulation are fundamental components of PV systems [7-9]. So, for that the using of a boost converter is necessary to connect the output of PV to the load. Moreover, given the variable nature of the power delivered by the photovoltaic panel, a tracking command of the maximum power point developing an optimal duty cycle (Dopt) for boost control is often used adopting the functional structure of the PV system.

The paper is organized as follows. Section 2 presents the configuration of the energy conversion system studied, modelling of solar PV module and DC/DC converter. Section 3 presents the developed models, the principle and the MPPT algorithm based on P & O and fuzzy logic controller. The performance of system is shown by the numerical simulation in Section 4. Finally, the conclusion is presented in Section 5.

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II. STRUCTURE OF PV SYSTEM AND MODELING

The photovoltaic system studied is constituted by a photovoltaic array. The boost converter is used to transfers maximum power from the solar array to the DC bus, in a coordinated way and at a voltage always greater than the input magnitude. Where, we applied a smart control strategy to obtain a DC/DC driver component which provides peak power control output. , MPPT algorithm and a load. The Fig. 1 shows the system used in this work.

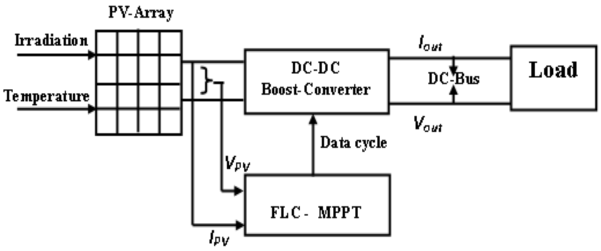


Fig.1. MPPT photovoltaic system configuration

A) *Modelling of the PV panel*

PV cells are basic units in the structure of a PV module. Based on the photoelectric phenomenon, they can transfer the energy of sunlight photons to the electrical energy. Mathematical models have been developed for the PV cell. Among which we cite: model a diode, model two diodes and the polynomial model [10-13]. In this work, we consider the single-diode model consists of a current generator that is directly dependent on the solar radiation and the temperature for modeling the incident luminous flux, an antiparallel diode for the cell polarization phenomena, a series resistor representing the various contact and connection resistances and a parallel resistor characterizing the various leakage currents due to diode. Equivalent circuit of PV cell is shown in Fig. 2.

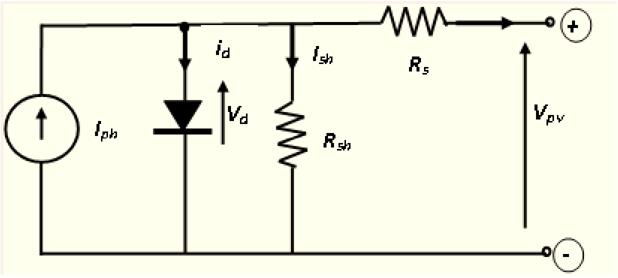


Fig.2. Equivalent circuit of the photovoltaic cell

Considering that the PV cell is ideal, this is saying considering that the series resistance is very small and the parallel resistance is sufficiently large and that the cell is illuminated, we deduce the following expression [14]. The generated current by a solar cell is obtained based on following this relation [15]:

$$Ipv = \frac{E.(I_{ph\_n} + k_i.\Delta T)}{E_n} \tag{1}$$

Where, I_{ph} is called photocurrent generated by the influence of solar radiation and cell's temperature. ΔT is the difference of temperature from the reference STC (T_0 = 25°C). E is the solar radiation and E_n is its normal rated value. k_i is the temperature coefficient of short circuit current. The main famous equation of a PV cell is as follow:

$$I_c = i_{ph} - I_0\left[\exp\left(\frac{V_c + R_s I_c}{m.V_T}\right) - 1\right] \tag{2}$$

Where, IC and VC are the output current and voltage of the cell respectively. I0 is the diode reverse saturation current and RS is the series resistor modeled for the cell. VT is called temperature voltage and it is applied 25mV and m is the diode factor which is equal to 1.5 in practice.

$$i_{pv} = i_{ph} - i_d = i_{ph} - I_s\left[\exp\left(\frac{qv_{pv}}{ak_bT}\right) - 1\right] \tag{3}$$

Since the amount of produced power generated by a solar cell is very small, almost 45 mW, they have to be organized and installed in series or parallel to produce a useful range of electrical power whether. The equation is done as following:

$$P_{pv} = N_{sh}I_{ph} - N_{sh}I_s\left[\exp\left[\left(\frac{Q}{nKT}\right)\left(\frac{V_{pv}}{N_s} + \frac{I_{pv}R_s}{N_{sh}}\right)\right](-1)\right] - \frac{N_{sh}}{R_{sh}}\left(\frac{V_{pv}}{N_s} + \frac{I_{pv}R_s}{N_{sh}}\right) \tag{4}$$

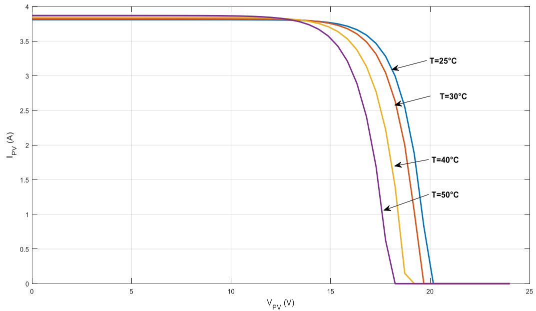
Where, I_{PV} is PV cell current, is immersion current, N_s is number of series-connected cells, N_{sh} is number of parallel connected cells, k is Boltzmann constant (1.38 * 10-19 J/K), T is Nominal temperature, q is the elementary charge of the electron 1.607*10-9 c, R_s is series resistance. The non-direct condition, for the most part, depends upon the sunlight based solar radiation, temperature, and reference values. The reference esteems typically accommodated working state of temperature is 25°C and radiation is 1000 W/m^2. So, in this work the number of series-connected cells is 36 and number of parallel connected cells are one of PV (see Table I).The $I=f(V)$characteristic of a PV cell is not linear and depends on the irradiance and temperature and also on multiple parameters. While modeling a PV cell, series resistance R_s and shunt resistance R_{sh} of the cell are considered for precise and accurate results [16].

The parameters of the PV module used in our simulation are tabulated in Table I and its different I-V and P-V characteristics under different climatic conditions are depicted in Fig. 3 and Fig. 4.

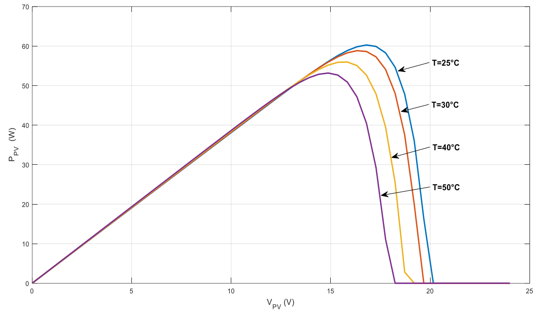
TABLE I
PARAMETERS

Q=1	E_g=1.12
T_r=298	A=1.2
K_i=0.0024	I_{rr}=5.981*10 ^ -8
K_b=1.38*10 ^ -23	I_{scr}=3.81
q=1.6*10 ^ -19	N_c=36

The resultant waveforms show the effects of weather condition in the generated current and output power. The Fig. 3.a and Fig. 3.b show, respectively, the characteristics I=f(V) and P=f(V) for different temperature values with standard irradiation E=1000W/m^2. Contrary; Fig. 4.a and Fig. 4.b are obtained by keeping the lighting constant 25°C under different values of the irradiation.

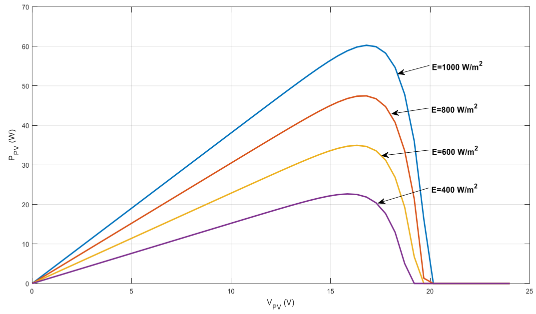


a) I=f(V) curves at *E=1000W/m^2 and T varies*

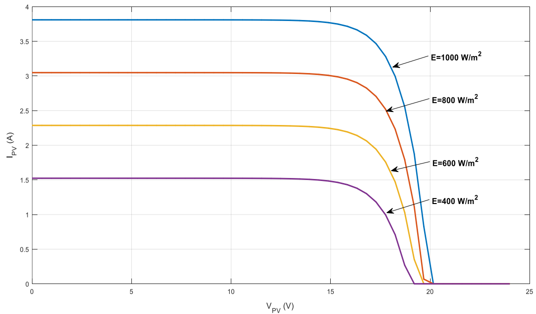


b) P=f(V) at E=1000W/m^2 and T varies

Fig.3 I=f(V) and P=f(V) characteristics under T varies



a) I=f(V) curves at T=25°C and E varies



b) P=f(V) curves at T=25°C and E varies

Fig.4 I=f(V) and P=f(V) characteristics under E varies

B) Boost converter

DC / DC converter is used as an adaptation stage. The boost converter is chosen in this study because of its simple structure and its highest voltage-to-voltage ratio compared to other topologies. After determining the structure of the converter adopted, we will present some existing MPPT techniques that allow the photovoltaic panel to operate at its maximum power. The design of an adaptation stage equipped with an MPPT method makes it possible to optimize the energy conversion and easily connect a PV panel to its load. The boost converter is essentially composed of a switch (IGBT or MOSFET) and a diode. The switch is controlled by a Pulse Width Modulated signal (PWM) fixed switching period and variable duty cycle [17]. Fig. 5 shows the block diagram of the converter.

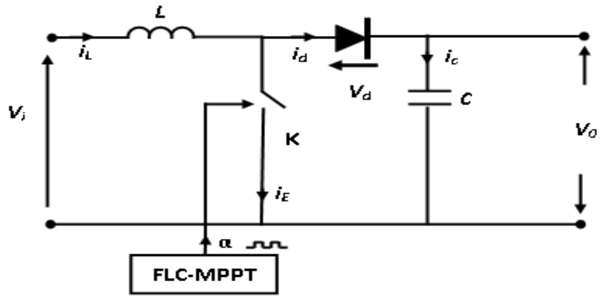


Fig.5 Boost converter circuit

During each period, the two semiconductors (switch K and diode D) operate in complement, when K is closed D is open; and when K is open, D is closed. From which, we deduce, the two following cases:

$0 < t < \alpha T_d$: Si K=1 (*Close*) et D=0 (*Open*)

$$L\frac{di_L}{dt} = V_e \tag{5}$$

$$i_L = I_{\min} + \frac{V_e}{L}t \tag{6}$$

Where I_{min} the minimum value of the current in the inductance. At time $t=\alpha T_d$, the current in the inductor reaches its maximum value I_{max}.

$$I_{\max} = I_{\min} + \frac{V_e}{L}\alpha T_d \tag{7}$$

$\alpha T_d < t < T_d$: Si K=0 (*Open*) et D=1 (*Close*)

$$L\frac{di_L}{dt} = V_e = V_s \tag{8}$$

$$i_L = I_{\max} + \frac{V_e - V_s}{L}(1-\alpha)T_d \tag{9}$$

At time $t = t_d$, the current in the inductance reaches its minimum value I_{min}.

$$I_{\min} = I_{\max} + \frac{V_e - V_s}{L}(1-\alpha)T_d \tag{10}$$

The ripple of the current in the inductor is:

$$\Delta i_L = I_{\max} - I_{\min} \tag{11}$$

$$L\frac{di_L}{dt} = V_e = V_s \tag{12}$$

$$i_L = I_{\max} + \frac{V_e - V_s}{L}(1-\alpha)T_d \tag{13}$$

Based on previous development, the DC to DC boost converter output is expressed by the follow equation:

$$V_s = \frac{1}{1-\alpha} V_e \tag{14}$$

Where , α is the duty cycle

$$\alpha = \frac{T_{on}}{T_{on} + T_{off}} \tag{15}$$

with,

$$0 \le \alpha \le 1.$$

The PV is connected to DC/DC boost converter to change duty cycle, to control the converter operation. We note that we can control the output voltage of the converter by varying its input voltage or duty cycle. The latter always being between 0 and 1, so the assembly operates as boost converter.

III. FUZZY LOGIC MPPT BY CONTROL

Controller is generally designed in the light of experience and expert knowledge [18]. The knowledge base of a Fuzzy Logic Controller (FLC) contains two components, namely, a fuzzy rule base and a data base [19], both being closely related to the concept of a linguistic variable [20]. A rule-base, i.e., a collection of fuzzy IF–THEN rules, is used to describe a particular control strategy. Fuzzy Logic (FL) is one of the most popular control methods which is known by its multi-rule-based variable’s consideration [21]. This method provides faster results compared to other Artificial Intelligent control methods such as Genetic Algorithm and Neural Networks. Being fast and robust are the main reasons of choosing FL for MPPT in the current study [21-23]. The different steps of this algorithm must be taken which are as follows.

The Fuzzy Logic Control is done in three steps: fuzzification, Inference Diagram (roles) and défuzzification.

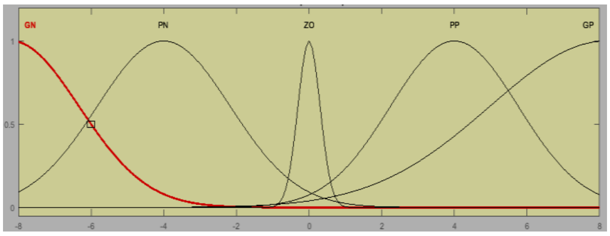
A) Fuzzification

The fuzzy controller has two (2) inputs : the error e(t) which allows to determine the position of the optimal power point of the characteristic P=f(V), the variation of the error Δe(t) which determines the direction of variation and an output corresponding to the variation of the duty cycle (dD) . For this, a MPPT control method based on fuzzy logic is applied to optimize the operation of the PV panel. The input defined in Equations (16) and (17) need to be fuzzified by some membership functions. For each inputvalue, the respective membership function returns avalue of μ. The max-min method was applied to extractthe μ from the triangle type membership function.

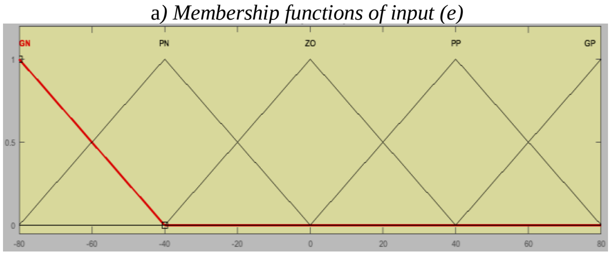
$$e(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \tag{16}$$

$$\Delta e(n) = e(n) - e(n-1) \tag{17}$$

During the fuzzification, numeric input variables are converted to linguistic variables that can take the following five values: GN (Negative Big), PN (Negative Small), Z0 (Zero), PP (Positive Small), GP (Positive Big). Figure 5 depicts the membership functions for inputs e and de and output Δα which is the variation needs to be applied to the current α value.



a) Membership functions of input (e)



b) Membership functions of input (de)

Fig. 6 Distribution of membership functions of input (e) and input (de)

B) Inference Diagram

A rule base must be applied to the obtained membership function according to Mamdani. Based on their evolutions and a truth table as shown in Table II, a value is assigned to the output parameter. The 3D input-output surface is also obtained by using MatLab FL Inference (Fig. 7).

TABLE II
RULES FOR FUZZY LOGIC CONTROLLER

	GN	PN	Z0	PP	GP
GN	Z0	Z0	PP	PN	GN
PN	Z0	Z0	Z0	PN	GN
Z0	GP	PP	Z0	PN	GN
PP	GP	PP	Z0	Z0	Z0
GP	GP	PP	PN	Z0	Z0

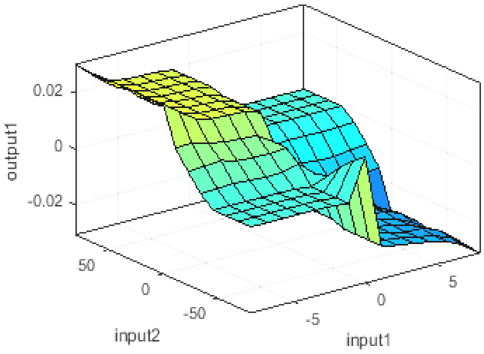


Fig. 7 Three dimensions (3-D) plot for the fuzzy rule base

C) Defuzzification

For the Defuzzification, the centroid [24] is applied to return a proper value for the duty cycle variation (Δα). The difuzzified output value of the FLC must be added to a reference value of duty cycle which is considered equal to 0.5 for the current study. Fig. 8 depicts the membership functions for outputs the result is the optimum value of α that has to be sent to the boost converter as a control signal.

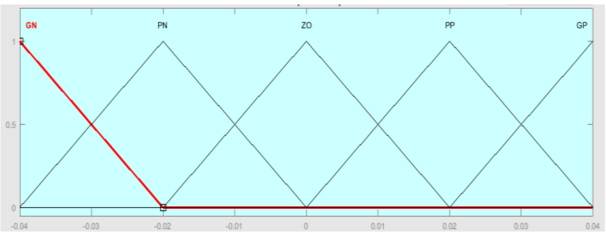


Fig. 8 Distribution of membership functions for output variable

The power is a function of the meteorological parameters (temperature and irradiance). Therefore, maximum power operation is more difficult to achieve. Then, a command for the continuation of the maximum power point based generally on the adjustment of the data cycle ratio of the converter is essential. In this structure, fuzzy logic controller (FLC) is used to determine the duty cycle (α) of the converter. The variations in the duty cycle depend on the difference in position between the PF and a PPM. Thus, as soon as the latter approaches the PPM, the increments applied to sharpen until reaching the PPM. The flow chart of the P&O algorithm is explained in Fig. 9.

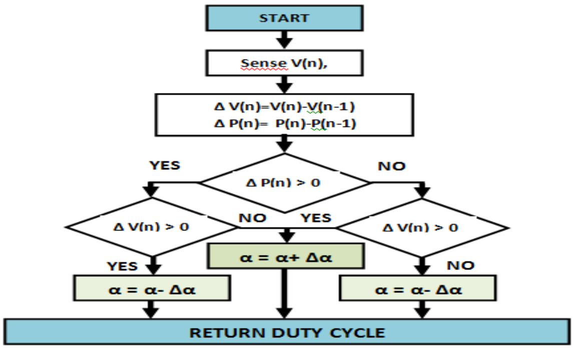
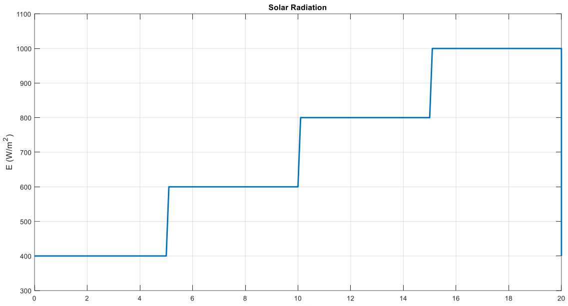


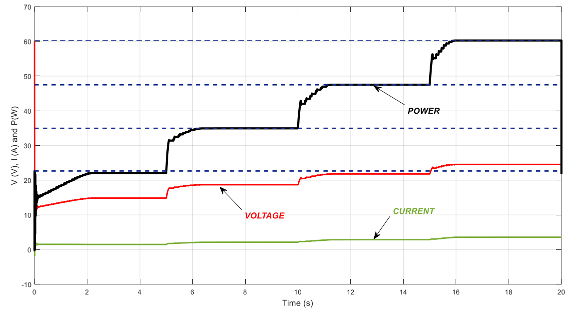
Fig.9 P&O MPPT flowchat

IV. SIMULATION RESULTS

Figures 10.a, 10.b and 11.a, 11.b present the characteristic quantities of the conversion chain. Figure 10.a shows the considered profile of solar radiance variation and Fig. 10.b shows current, voltage and power photovoltaic panel under different levels of E (1000 W/m^2, 800 W/m^2, 600 W/m^2 , 400 W/m^2) where the temperature remains constant (T=25°C). In addition, for the case where the irradiation is constant (E=1000 W/m^2) but the temperature varies according to the profile shown by the Fig 11.a, the current, voltage and power are shows in Fig. 11.b. For two (2) validation tests considered, Table III and Table IV present the maximum powers produced for the different climatic conditions, respectively, with and without MPPT application. It is noted that the powers produced correspond correctly to the values presented and it is found that good performance obtained with the control adopted.

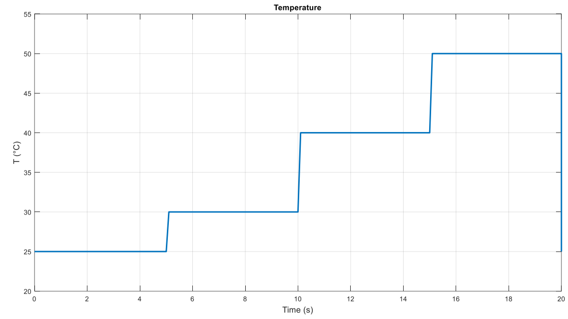


a) Profil solar radiation

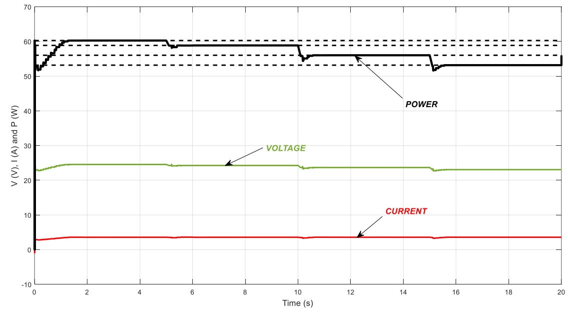


b) Voltage, current and power

Fig.10. Voltage, current and power for E variation



a) Profil of temperature



a) Voltage, current and power

Fig.11. Voltage, current and power for T variation

TABLE III
MAXIMUM POWER WITHOUT MPPT

E(W.m^{-2})/T°C	**25**	**30**	**40**	**50**
1000	60.2658	58.8320	55.9669	53.1744
800	47.4642	46.3570	44.0768	41.7175
600	34.9482	34.0764	32.2940	30.5719
400	22.6539	22.0576	20.8483	19.6896

TABLE IV
MAXIMUM POWER WITH MPPT

E(W.m^{-2})/T°C	**25**	**30**	**40**	**50**
1000	60.2722	58.8649	56.0314	53.1750
800	47.5098	46.3714	44.0803	41.7718
600	34.9472	34.0816	32.3400	30.5857
400	22.6567	21.9232	20.8842	19.6937

V. CONCLUSIONS

This work proposes a fuzzy logic MPPT controller to extract maximum power from a PV under various climatic conditions. The advantage of these fuzzy logic-based techniques is that they can operate with inaccurate input values and do not require a high precision mathematical model. The current-voltage characteristic is strongly nonlinear and has a single optimum operating point. The obtained results from simulation using MatLab/Simulik **software** confirm the validity of the designed system. Indeed, the insertion of static converters with a fuzzy logic based MPPT control, between the PV array and the load, makes it possible to optimize the transfer of energy.

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