Optimal Exploitation of a Solar Power System in a Semi-Arid Zone (Case Study: Ferkène, Algeria)

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Abstract- Contribute to the development of renewable energies in rich areas of new potential energy same Algeria, was the main cause of our work in this paper. The Contribution to a study of power supply by solar energy system called a common Ferkène north of Algerian desert in the semi-arid area is our objective in this paper. The optimal exploitation of the system, goes through stages of study and essential design, the choice of the model of the photovoltaic panel, the study of behavior with all the parameters involved in simulation before fixing the trajectory tracking the maximum point the power to extract (MPPT), form the essential platform to shape the design of the solar system set up to supply the town Ferkène without considering the grid. The identification of the common Ferkène by the collection of geographical, meteorological, demographic and electrical provides a basis uniform and important data. To set provide a computing tools, modeling and control of MPPT more practical we have developed a software system PVSSS using Matlab. The results reflect a valid fictive model for any attempt to study and design a solar system to supply an arid or semi-arid zone by electrical energy from photovoltaic panels.

Keywords- Solar power, photovoltaic panel, Boost converter, PVSSS, design, electric power, Ferkène, Algeria.

1. Introduction

The renewable energy provides an opportunity to produce clean electricity and especially in a low dependence on fossil resources. Photovoltaic technology is an attractive solution as a replacement or supplement conventional sources of electricity supply due to many advantages. The operation and development of the use of solar energy in Algeria are favored because of its important geographical location, especially for the Saharan regions, semi-arid and isolated areas, where the infrastructure for the distribution of electrical energy is not very developed. Indeed, given the importance of the intensity of radiation received and the duration of sunshine that exceeds ten hours a day for several months, our country can easily cover some of its power needs through solar energy.

The purpose of this work is to supply a town of a population average solar PV, after completing all the necessary steps such as modeling of suitable solar panel on the technical and economic terms, the size of the system storage control and the MPPT control and collection of the metrological, geographic, demographic and electrical data area in question.

The area of Ferkene in this study is in Negrine town into Tebessa city and is considered the best to take it as a case of application in a semi-arid area of Algeria.

All photovoltaic systems can be composed of three parts:

- A part of energy production;
- A portion of control and regulation of the energy;
- A portion of storage and use of energy.

2. Modeling of the Solar Cell

In the literature, several studies have been developed on the model of the solar cell and solar panel which include five models that combine both the number of diodes and series resistors and shunt characterizing solar and photovoltaic effects of the circuit. By our Software PVSSS we choice the most widely used and translated in a very satisfactory so as the industrial product most commercialized in the world, namely, that a single diode and two resistors (Fig 1), [1,3].

Thereafter we simulate this model by PVSSS where the change in temperature, solar radiation, and the series resistance represent the main part of this paper.

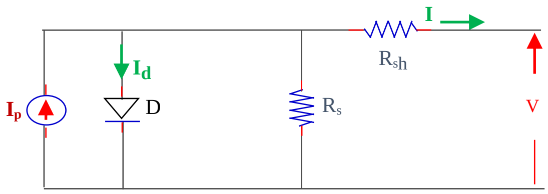


Fig. 1. Equivalent model (one diode + two resistors) of a photovoltaic cell [4]

$$I = \left(I_{ph}\text{-}I_{sat}\left[e^{\frac{q(V+I\cdot R_{SH})}{AKT_C}}\text{-}1\right]\text{-}\left(\frac{V+I\cdot R_{SH}}{R_S}\right)\right) \quad (1)$$

I, V: current and the voltage of the photovoltaic cell,

Iph: photocurrent produced,

Isat: Saturation current,

Rs et $R_{Sh:}$ serial resistor and shunt resistor

Tc: absolute temperature,

A: sensitivity coefficient of voltage to temperature, K: sensitivity coefficient of the current to temperature.

3. Influence of Various Parameters of Solar Cell

The characteristics of a PV panel represents the variation of current and power panel with the voltage of the output circuit of PV in different conditions of solar radiation and medium temperature and this for the status of short circuit (0, lsc) and open circuit (Vo, 0), [11,12].

3.1. Overview of the Simulator

The PV Solar system Software PVSSS is easily accessed through its main interface (Fig 2) where four shortcut icons are accessible to the main parts of the software simulation, calculation and necessary theoretical basis for the user.

Through the following sub-interface (Fig. 3), the user can choose the type of PV module according to the manufacturer and the electrical characteristics such as maximum power, the short circuit current, voltage and other open circuit. This choice is necessary for validate the results obtained thereafter.

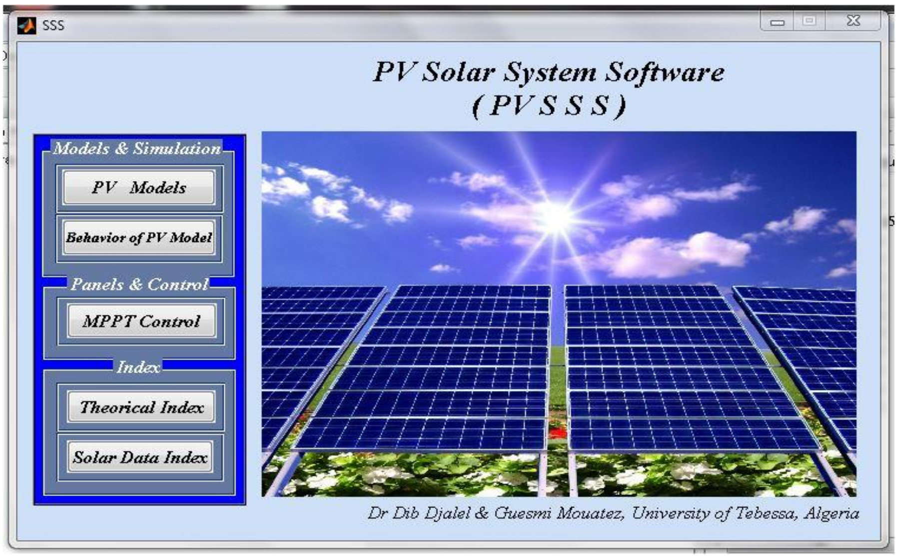
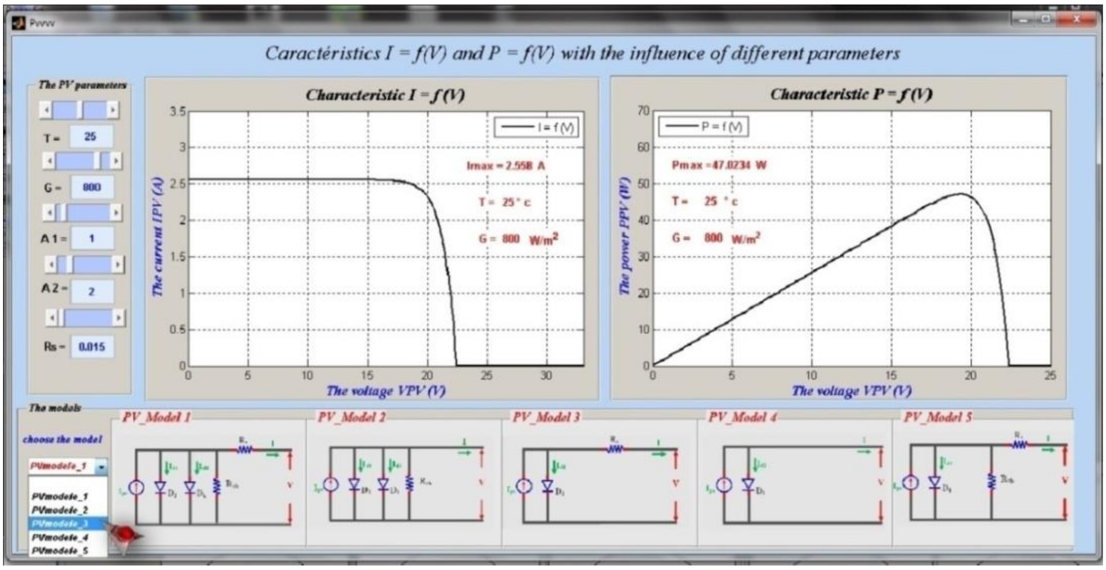


Fig. 2 . Principal interface of PVSSS

4. Variable behavior of disputes solar cell models

The display is instantaneous in this sub-interface (Fig.12& Fig.13) with graphical results of current and power generated by the PV depending on the voltage once the choice of model and parameters are set. The important advantage of this part of the simulation models available solar cells and the flexibility to vary the different internal and external parameters [15].



Caractéristics I = f(V) and P = f(V) with the influence of different parameters

The PV parameters

T = 25

G = 800

A 1 = 1

A 2 = 2

Rs = 0.015

Imax = 2.558 A

T = 25 ° c

G = 800 W/m²

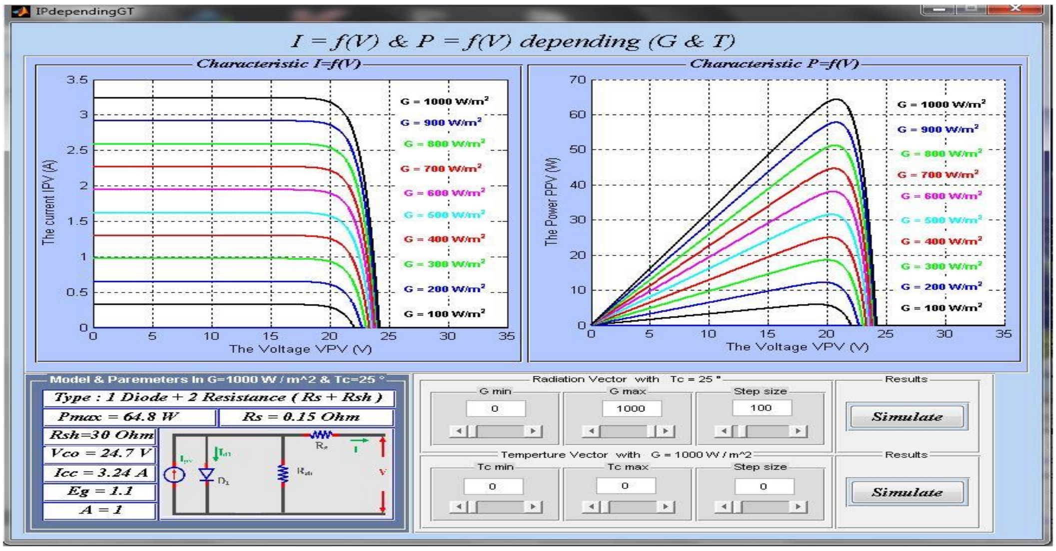
Pmax = 47.0234 W

T = 25 ° c

G = 800 W/m²

choose the model: PVmodele_1

Fig. 3. Sub-interface for the simulation of different types of solar PV with internal and external parameters in PVSSS



I = f(V) & P = f(V) depending (G & T)

Model & Paremeters In G=1000 W / m^2 & Tc=25 °

Type : 1 Diode + 2 Resistance (Rs + Rsh)

Pmax = 64.8 W

Rs = 0.15 Ohm

Rsh=30 Ohm

Vco = 24.7 V

Icc = 3.24 A

Eg = 1.1

A = 1

Radiation Vector with Tc = 25 °

G min: 0

G max: 1000

Step size: 100

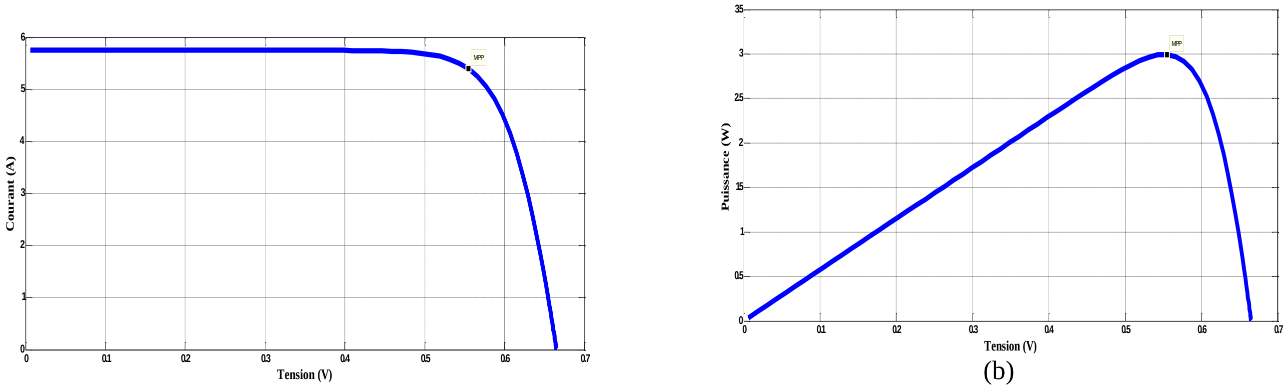
Temperture Vector with G = 1000 W / m^2

Tc min: 0

Tc max: 0

Step size: 0

Fig. 4. Another variant simulation with simultaneous variation of the conditions for a solar PV 5 parameters.



(a)

(b)

Fig. 5. Variation with voltage at a fixed solar radiation and temperature: (a) Current, (b) Power

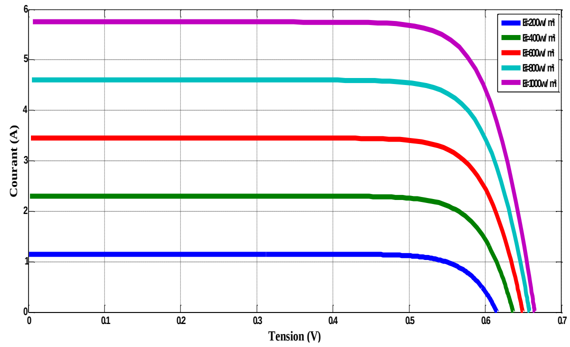


Fig. 6. Current variation with voltage at variable solar irradiance

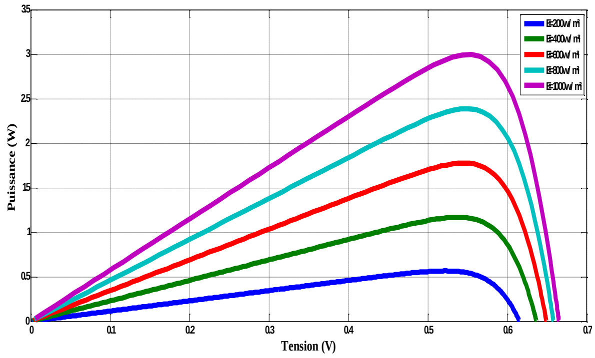


Fig. 7. Power variation with voltage at variable solar irradiance and fixed temperature

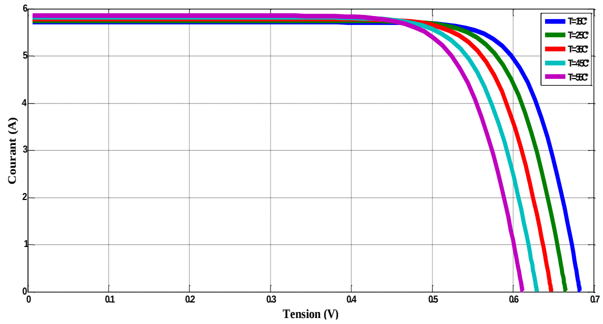


Fig. 8. Current variation with voltage at variable temperature

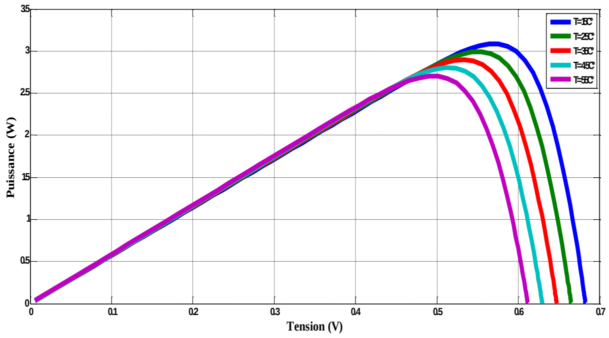
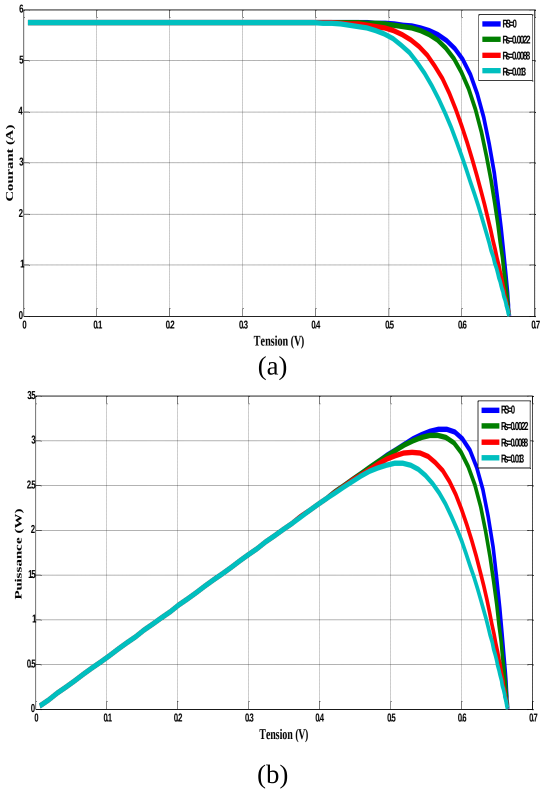


Fig. 9. Power variation with voltage at variable solar Temperature



(a)

(b)

Fig. 10. Variation with voltage at variable serial resistor: (a) Current, (b) Power

5. Maximum Power Point Tracking, MPPT

With changes in weather conditions, a control device must be integrated into the control circuit of the converter (DC / DC), as is shown in (Fig. 11). It must be able to operate the photovoltaic generator at its maximum power with the instability of conditions. This type of control is often called "Searching for Maximum Power Point" or "Maximum Power Point Tracking" (MPPT). The cell or photovoltaic panel has a maximum power point (MPP), which varies depending on sunlight and temperature and will be the target of the MPPT control analog or digital mode [7].

5.1. Finding of maximum power point tracking MPPT

With the PVSSS we can Finding of the maximum power point tracking MPPT and Behavior in the positive and negative temperature and the irradiance of the photovoltaic panel. Before to proceed to search the MPPT and the control technique to be applied, the following window (Fig.13) allows to choose by manufacturer, the industrial model of PV for the extraction of data to be entered and the validation MPPT given by algorithm.

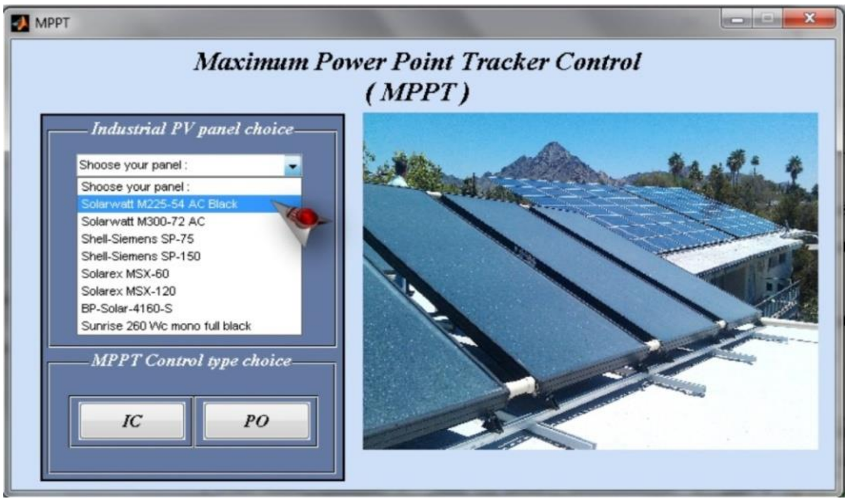
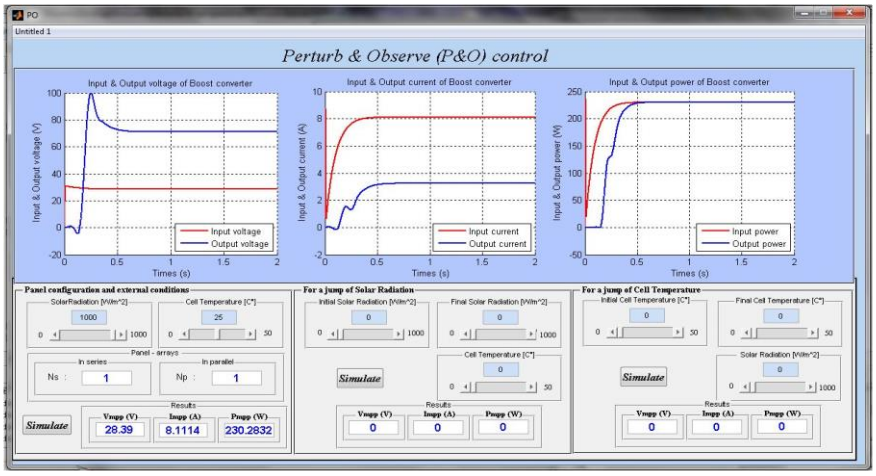


Fig. 12 . Sub-Interface2 with menu MPPT control and PV panel selection in PVSSS

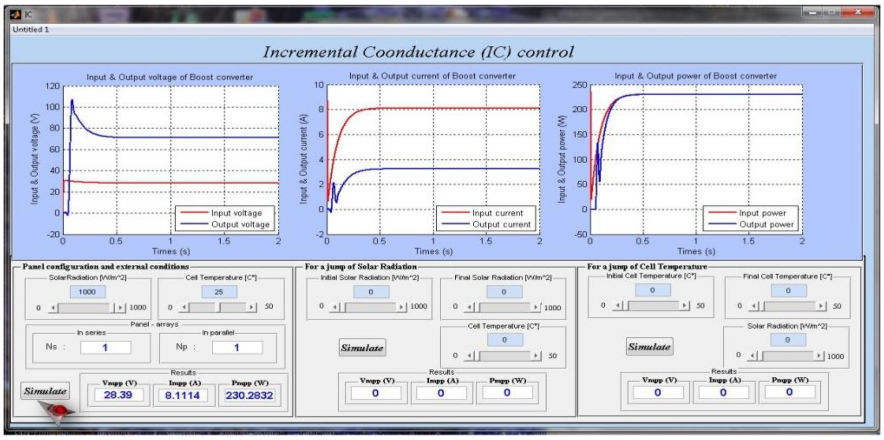
6. MPPT control sub-interface

« The MPPT control is handled via the following interface (fig15 and fig16) which displays graphical results of the system such as voltage, current and electrical power generated after introducing the various necessary parameters related to the structure of the system solar such as solar PV, the boost converter, the storage battery and the load to be supplied. In this phase of the control in our PVSSS software, we find two sub-interfaces: one for the control by P & O and the other by IC.



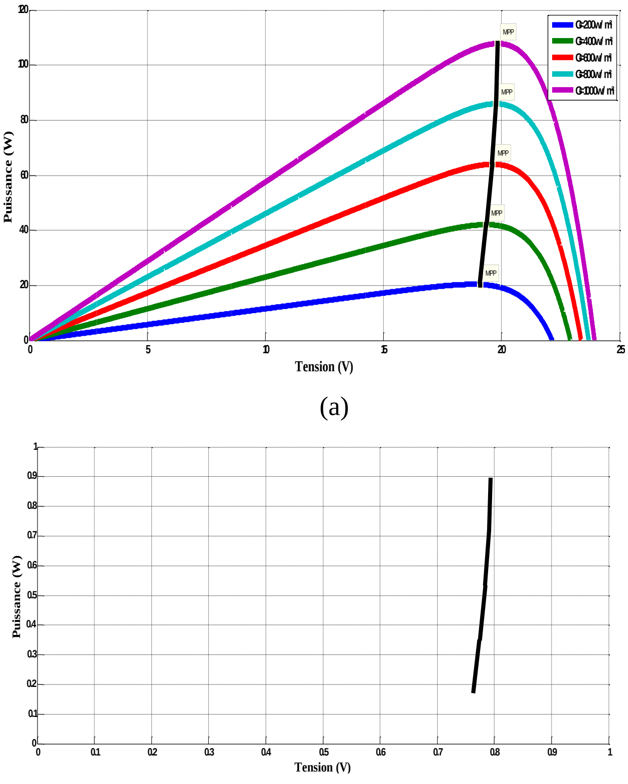
SolarRadiation [W/m^2]: 1000
Cell Temperature [C°]: 25
Panel - arrays: In series Ns : 1; In parallel Np : 1
Results: Vmpp (V) 28.39; Impp (A) 8.1114; Pmpp (W) 230.2832
Initial Solar Radiation [W/m^2]: 0; Final Solar Radiation [W/m^2]: 0; Cell Temperature [C°]: 0
Results: Vmpp (V) 0; Impp (A) 0; Pmpp (W) 0
Initial Cell Temperature [C°]: 0; Final Cell Temperature [C°]: 0; Solar Radiation [W/m^2]: 0
Results: Vmpp (V) 0; Impp (A) 0; Pmpp (W) 0

Fig. 13 . Sub-Interface of MPPT control by P&O algorithm in PVSSS



SolarRadiation [W/m^2]: 1000
Cell Temperature [C°]: 25
Panel - arrays: In series Ns : 1; In parallel Np : 1
Results: Vmpp (V) 28.39; Impp (A) 8.1114; Pmpp (W) 230.2832
Initial Solar Radiation [W/m^2]: 0; Final Solar Radiation [W/m^2]: 0; Cell Temperature [C°]: 0
Results: Vmpp (V) 0; Impp (A) 0; Pmpp (W) 0
Initial Cell Temperature [C°]: 0; Final Cell Temperature [C°]: 0; Solar Radiation [W/m^2]: 0
Results: Vmpp (V) 0; Impp (A) 0; Pmpp (W) 0

Fig. 14. Sub-Interface of MPPT control by IC algorithm in PVSSS



(a)

(b)

Fig. 15. Trajectory pursuit point MPPT for various radiations: (a) MPPT collected with variable solar irradiance, (b) Trajectory pursuit point MPPT

6.1. Pursuit Algorithm MPPT

6.1.1. Approach Conductance Increment

Several different algorithms exist to extract the maximum power from the PV array. We develop in this work, the increment technique conductance Matlab/Simulink, the operation of a photovoltaic generator linked to a follower of the maximum power point tracking (MPPT) based on this algorithm, voltages and currents panel are measured so that the controller can calculate the conductance and the incremental conductance and so decides his behavior[2,6].

We define the conductance by $G = \frac{I}{V}$ and the incrementation by:

$$dG = \frac{dI}{dV}$$

Eventually derive power from the voltage gets [10]:

$$\frac{1}{V}\cdot\frac{dP}{dV} = G + dG \qquad (2)$$

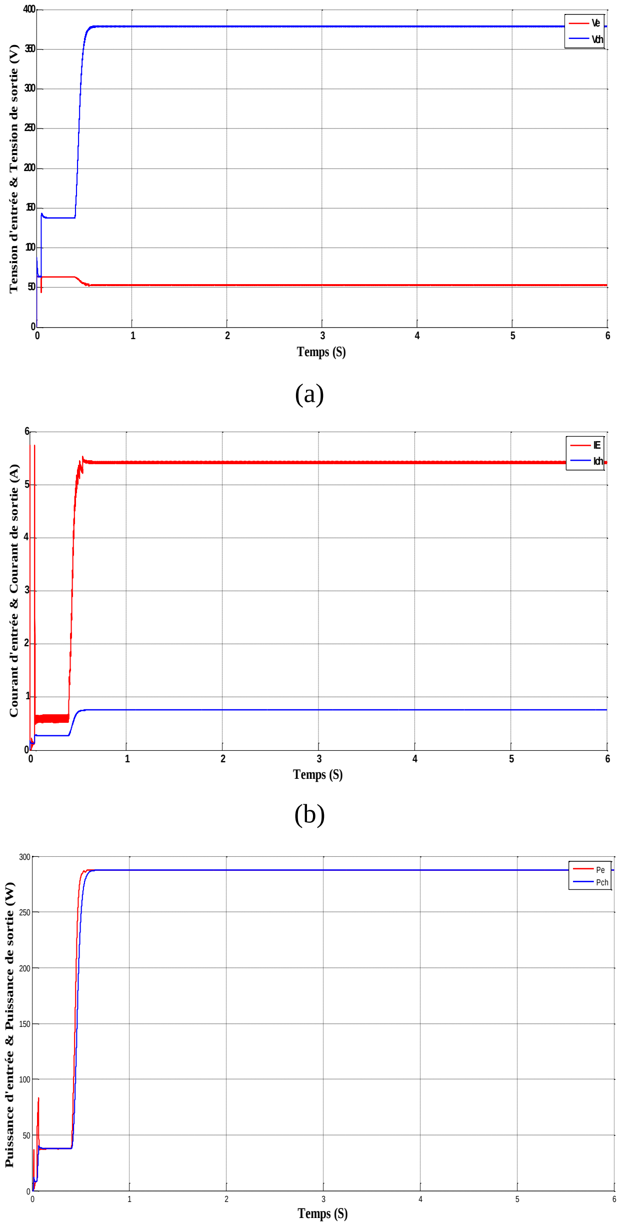
We just have to search for what the conductance G = dG, depending on the value of G three cases to consider:

$$dG = -G\ (\frac{dP}{dV} = 0)$$

$$dG > -G\ (\frac{dP}{dV} = 0) \qquad (3)$$

$$dG < -G\ (\frac{dP}{dV} = 0)$$

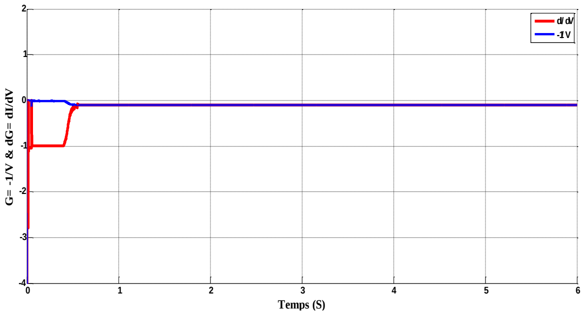
The above equations are used to determine the direction in which the disturbance is produced to move the operating point to the MPP (maximum power point). This disturbance is repeated until $\left(\frac{dP}{dV} = 0\right)$ is satisfied. The following figures show the simulation results:



(a)

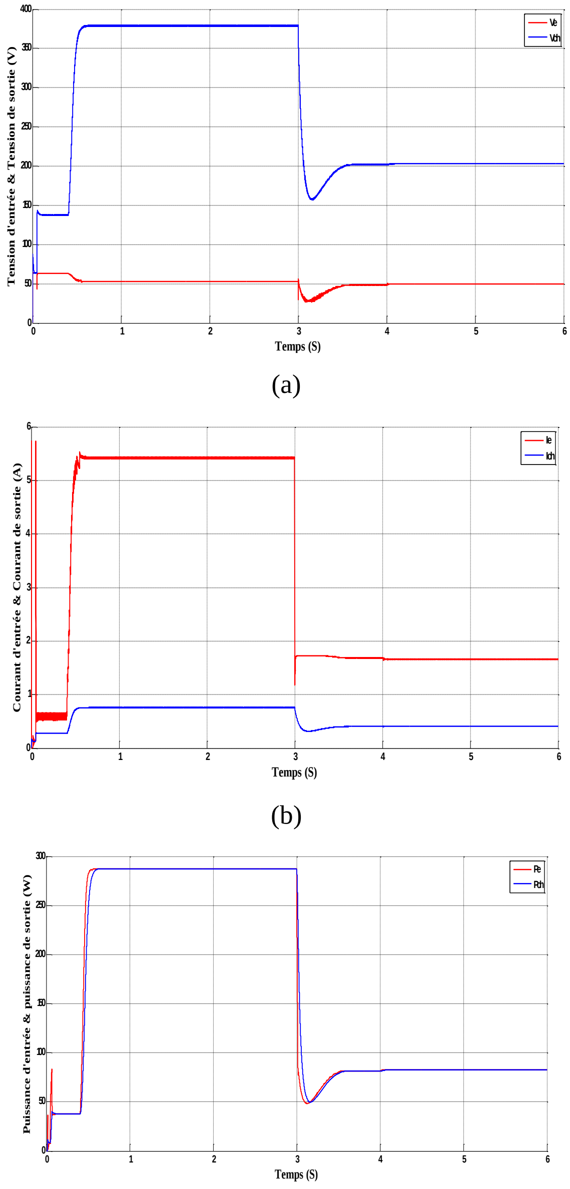
(b)

(c)



(d)

Fig. 16. Parameters behavior following algorithm of conductance incrementing on the CI at G and T fixed: (a) Voltage, (b) Current, (c) Power, (d) Conductance

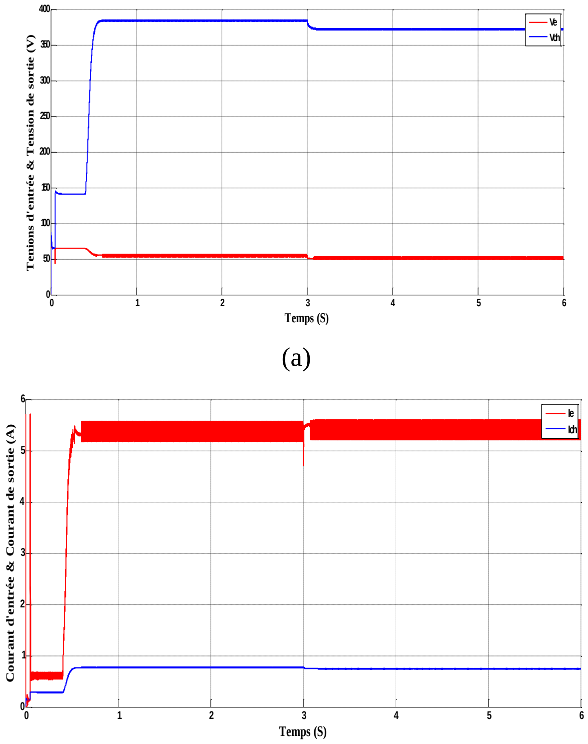


(a)

(b)

(c)

Fig. 17. Parameters behavior following the algorithm CI at negative jump of the irradiance G: (a) Voltage, (b) Current, (c) Power, (d)



(a)

(b)

Fig. 18. Parameters behavior following the algorithm CI at positive jump of the irradiance G: (a) Voltage, (b) Current

Table 1. Monthly Energy Consumed in 2012 [15,16]

Month	Energy consumed in 2012 kWh
1	
2	
3	**848118**
4	
5	
6	**873190**
7	
8	
9	**833361**
10	
11	
12	**975732**

6.2. Analysis Results

The temporal analysis makes it possible even in the first place, the difference between the value of the voltage at the input and at the output of chopper converter, where the output voltage is higher than the input voltage, which is the behavior Boost the system, after a transitional period of 0.5s, the permanent state is reached. For output power, we note that once the maximum power point (MPP) is reached, the MPPT control maintains constant. After a short transient 0.5s, the current and voltage of the generator are adjusted to their optimum values of 0.76 A and 372.13 V successively.

When the level of solar radiation changes abruptly by an upward or downward jump, for example of 1000 W/m2 to 300 W/m2, the electrical variables of the generator are adjusted to their new optimum values A and 0.41 203.67V successively.

For the variation of the power generator (Fig. 13), it behaves the same way as other electrical quantities (current and voltage), power is also changing and the average values are close to equilibrium optimal power gains are to 287.46 W 1000 W/m2 and 82.80 W/m2 to 300 W/m2, All which corresponds to the indications of the industrial manufacturer.

7. Case Study

Ferkene is a commune in the daira Negrine of the wilaya of Tebessa in Algeria (Fig. 14) is composed of two groups of dwellings; Djarech and Ferkane city, it is located 170km south of the capital of the Tébessa in northern town Ferkane is Stah-Guentis and the border of the province of Khenchela, east of the town Negrine, west border of the province of Khenchla and south of the province Eloued. Ferkane extends over 903km ² area, with a population of 5695 residents [14].

The common Ferkane is a semi-arid or desert area that is part of the daïra Nigrine in the southern province of Tebessa and has enormous resources in solar energy potential confirmed by the map of the solar reservoir established by the SOLARGIS specialized software online [17].

7.1. Geographical Characteristic

The Tebessa region is an area of transition weather, considered agro-pastoral with a presence of a large number of events (intense sunlight, frost, hail, flood, high winds). Tebessa is characterized by four climatic area [18]:

- The sub-humid (400-500mm/year), very little extended, it covers only a few subdivisions limited to the tops of some relief (and Jebel Serdies and Jebel Bouroumane)
- The semi-arid (300-400mm/year), representing in cool and cold floors and covers the entire northern part of the province
- The sub-arid (200-300mm/year) covers the steppe plateaus OumAli, Safsaf Elouesra, Tthlidjen and Bir Elater
- The arid and Saharan soft (-200mm/year), begins and extends beyond the Sahrien Atlas covers and trays Negrine and Ferkene

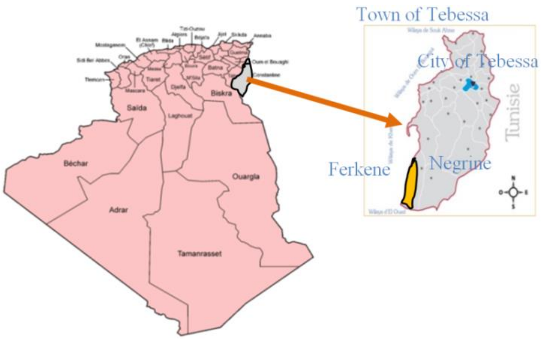


Fig. 19. Geographical location of the site

7.2. System Sizing Photovoltaic Production

Sizing and design of a specific PV system is actually relatively difficult because of the many parameters to consider surgery, some imponderable dose (meteorology) and especially interactions between multiple choices. For example the consumption of the charge controller, the inverter and the storage battery must be added to the set of receivers for total consumption of the system. However, the choice of these parameters depends on the size of the photovoltaic field, which is determined by the consumption of the load. So the design of a photovoltaic system is the result of an optimization performed by iterations.

7.2.1. Needs Assessment

The solar kWh is expensive, it must make a saving at the receptor level by low-energy technology, the overall cost of the system will be much smaller because there will be fewer solar modules and batteries in the system.

For ease of calculation, we divide the town into five Ferkene equivalent areas in consumption of electrical energy. Taking the power consumption of the last quarter when the total consumption of the town is the highest which is divided into five.

For each zone, consumption will Eczq = 195,146.4 kWh and daily consumption is Eczd = 2121.16 KWh

The consumption of the town is the highest which is divided into five. For each zone, consumption will Eczq = 195,146.4 kWh and daily consumption is Eczd = 2121.16 KWh.

7.2.2. Solar Energy Recoverable

➢ Orientation and Inclination of the Panels:

The choice to vary the angle of PV modules every month during the year to recover the maximum amount of solar energy is very difficult in our case because of the great power to install. The solution is to choose an optimal inclination angle that allows us reach our goal of optimal design.

The online software PVGIS available on the website of the European Commission allows us to obtain the value of this angle is 31° from the geographic coordinates of Ferkene municipality.

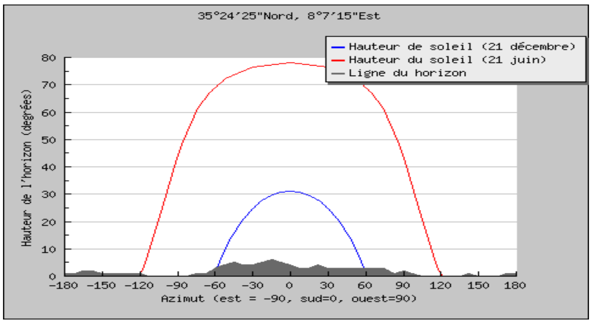


Fig. 20. Variation of the sun position in Ferkene municipality [17]

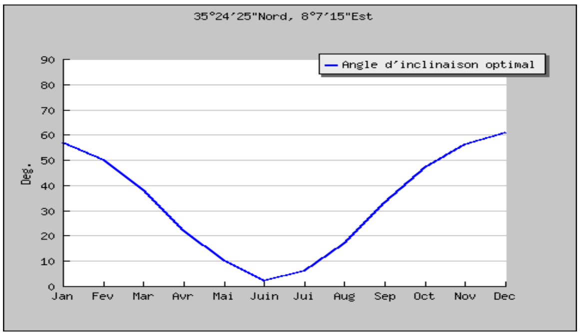


Fig. 21. Variation of the optimum angle of inclination of Ferkene municipality [17]

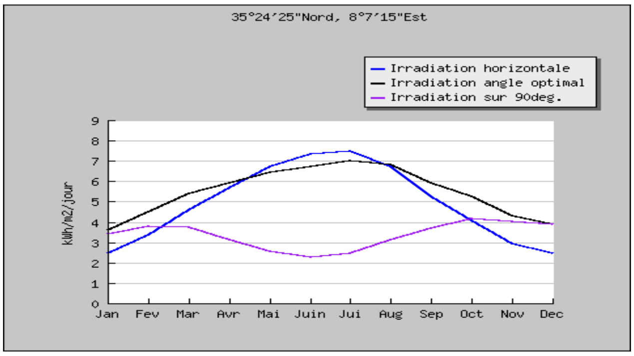


Fig. 22. The solar irradiance received on a horizontal plane at an optimum angle and 90 ° for Ferkene [17]

➢ Weather Data

We can make a fairly accurate sizing with 12 values of solar radiation received in the municipality of Ferkene given by the Photovoltaic software.

7.2.3. Definition of Photovoltaic Panels

➢ Electricity Production of a Module in a Single day:

The electrical production of PV module during one day is given by the following equation:

$$E_{prod} = N * P_c \qquad (4)$$

E_{prod}: Energy produced (Wh)

N: exhebtion Hours Number in STC conditions

P_c: peak power (W)

Table 2. Variation of Solar Irradiation at Optimum Angle [13]

Month	**1**	**2**	**3**	**4**	**5**	**6**
G	30	427	536	578	610	655
(Wh/m²)	90	0	0	0	0	0
Month	7	8	9	10	11	12
G	67	664	576	524	413	374
(Wh/m²)	40	0	0	0	0	0

G (Wh/m²) is solar irradiance at optimum angle

➢ Electrical Losses:

The inevitable current losses are introduced in the energy calculations as a known coefficient Cp: current loss coefficient. For soil loss is generally take Cp between 0.8 and 1, the "state of panels: they are cleaned regularly placed horizontally behind a glazing.

For lead storage batteries used in photovoltaic, the Ampere houre Ah efficiency between 0.8 and 0.9 depending on their characteristics.

➢ Quantification of Losses

If we combine the previous losses, the coefficient (Cp) can vary between 0.64 (= 0.8 x 0.8) and 0.9 (= 1 x 0.9) as appropriate (without glazing on modules). For our case study, dirt modules will not be a problem, users ensure their cleanliness, it will take only 5% loss on that side and the battery efficiency may be a loss of 0.8

The final calculation of the load current from the PV array, a current loss coefficient is:

$$C_p = 0.8 * 0.95 = 0.76$$

➢ Practical Calculation of Photovoltaic Power

For more accurate sizing, we will use the highest consumption period value. In our case, for annual use, the average value of the fourth quarter will be used per day which is the highest. (Eczd = 2121.16 KWh).

The timing of our study panel SOLARWATT ORANGE 60 Easy-In [19] including the following characteristics type:

$$\begin{cases} P_{max} = 220\ W \\ V_{opt} = 28.4\ V \\ I_{opt} = 7.76\ A \end{cases}$$

In consideration of the highest voltage of the devices to supply, in this case a voltage of 380 V, we need to place branches in series of 14 modules, that will deliver a voltage of Vp = 397.6 V.

To find the energy consumed (Ah), we divide the energy (kWh /d) by 380V voltage: The voltage of a panel is 28.4 x 14 equal 397.6 V.

$$Q_{cons}=\frac{E_{cons}}{V_p}=\frac{2121.16}{397.6}=5.34KAh \qquad (5)$$

Q_{cons}: Energy consumption (Ah)

V_p: The highest voltage

The optimal current for each area will be:

$$I_{opt}=\frac{Q_{cons}}{E_{sol}{}^{\times}C_p} \qquad (6)$$

$$I_{opt}=\frac{5.34}{3090\ .\ 0.76}=2273.88\ A=2.27\ KA$$

I_{opt}: Current at maximum power

Q_{cons}: Electrical energy consumed per day (Ah/j)

E_{sol} : Energie solaire journalière (kWh/m².j)

C_p: Current loss coefficient

The modules that we have chosen in our case an optimal voltage (Vopt = 28.4V), photovoltaic power (Pc) system should be minimum for each zone.

Pc,z= Vopt.Iopt . 14 panels = 904.09 KW

Pc,tot=Pc. 5= 4520.45 KW

- Photovoltaic Array (number of panels):

We recall that the module has a power of 220 W at 28.4 V. For our case study the number of modules for each zone is calculated:

$$N_M=\frac{P_c}{\widehat{P_M}} \rightarrow N_M=\frac{904094.69}{220}=4110\text{ modules} \qquad (7)$$

N_M: Nomber of modules

P_c: power system

$\widehat{P_M}$: peak power per unit module.

So for 380 V will require 14 modules in series in each branch and 294 branches → N modules, tot = 4116 modules. All results of the calculations are summarized:

$$\begin{cases} I_{opt}=2.27\text{ KA} \\ V_{opt}=28.4\text{ V} \\ N_M=4116\text{ modules},\ \ N_{M,total}=20580\text{ modules}\end{cases}$$

7.2.4. *«subcontent21»*

- Autonomy without Solar Input: It's the period of a few days during which the battery can be supplied only the installation, for our case, we take equal five days (Nd=5d), [20]-[21]
- Depth of Discharge: The proportion of the discharge capacity, we take (Pd = 0.7)
- Capacity Calculation: For our application, we get the result according to the calculation of the rated capacity (Ah) for each zone [8]-[10]:

$$C_{20}=\frac{Q_{cons}{}^{\times}N_{ja}}{P_D}$$

$$C_{20}=\frac{5340\ .\ 5}{0.7}=38142.85\ \text{Ah}=38.14\ \text{KAh} \qquad (8)$$

The total nominal capacity for the five area will:

$C_{20,tot}$= 190.7 KAh.

C_{20}: nominal capacity (Ah)

N_{ja}: autonomy days Nomber without contribution (j)

P_D: Maximum allowable depth of discharge.

- Number of Batteries

The number of batteries is defined by the ratio of the required power to be consumed on the total capacity of the battery per the nominal voltage [20]-[21].

$$N_B=\frac{E_{cons}}{C_{bat}V_{bat}}=\frac{\text{solar power consumption}}{\text{capacity of batterie*voltage batterie}}=$$

$$N_B=895\text{ battery} \qquad (9)$$

N_{Btot}= N_B.5=4475 battery

7.2.5. *Sizing Regulator*

In our system, the MPPT algorithm is given by the incrimentation conductance IC in the control chain when the sizing the regulator must consider [11].

7.2.6. *Sizing the Inverter*

Align the power of the photovoltaic field with that of the inverter is the first mission to reach. The inverter is given for its power output, so you can adjust the power of the field performance of the inverter [5,6].

7.2.7. *Wiring Diagram*

Once the system is designed, it remains to consider the practical operation of the installation wiring to ensure the coherence of the whole. The following illustration shows the wiring diagram.

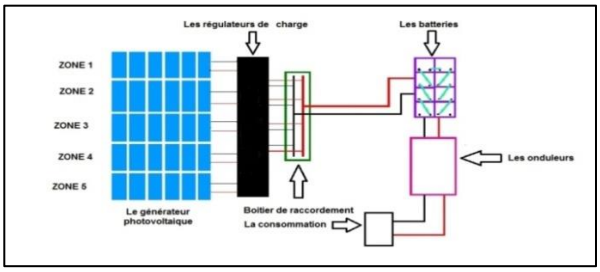


Fig. 23. Diagram of the photovoltaic array to supply Ferkene

7.3. Validation of Results

To validate our results, the Photovoltaic gives us the average values of electricity per day from the geographic location of website software is used, the angle of inclination and the installed PV power we calculated in the 3rd sizing step. Seen in the results obtained by calculating the daily consumption by area: Eczd = 2121.16KWh,

The production area: Eprod = 2200Kwh.

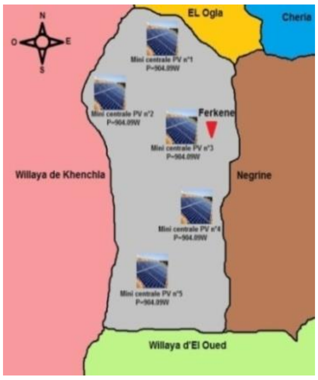


Fig. 24. Scenario of fictive distribution of mini solar power plants that feed the town Ferkène

Contribution of authors:

- Design software or a module in Matlab with interface PVSSS which deals solar panels in general (computing, modeling and simulation).
- Presentation of a model calculation need electricity to a village in a country of great solar potential as Algeria.
- Sizing of a photovoltaic system fields to meet the demand of electrical energy.

8. Conclusion

Through this work, we developed a design of a standalone photovoltaic conversion chain on a semi-arid area such as the common Ferkène in Tebessa north of the Algerian desert. To contribute to the solution of energy problems, it is of interest to develop alternative sources, renewable and decentralized energy of these. In the search for such solutions, the system of photovoltaic fields developed in this paper can be a very economical way for the electrification of this category of zones. Modeling and simulation of photovoltaic panels, research and control of the MPPT and the optimal design of the solar system using a new software PVSSS is a very important asset of this contribution and open very motivating perspectives in the field of renewable energy and sustainable development.

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