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Photovoltaic Pumping System for Application to Sites in Mauritania

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Abstract*- In Sahelian countries, using the solar pump can be technically and economically effective. Therefore, in the aim of integrating the solar pumping in targeted communities, three locations were selected in Rosso, which is the regional capital of Trarza Province. The localities of these sites will benefit from the pumping system, once developed. It is important to note that the solar pumping is important to the targeted areas, as a simple technic that involves pumping water under the sun and works only with the sun. At night, the pump does not work, but the water can be stored in a tank at a height (H), for use as needed. In practice, two sensors are installed, one avoids dry running of the pump and the other prevents tank overflow. The proposed pilot photovoltaic pumping system for the study is the ISET of Rosso (Higher Institute for Technological Studies). Hence, two sites were created on that basis, one at Bameira village and the second at Entvachit. In this context, we are studying first, the characteristics of the photovoltaic generator through mathematical models and simulations of its parameters by MATLAB. Secondly, we offer simulations, using the software "KaleidaGraph" to confirm the electric models of the system under actual operating conditions that require different parameters which characterize the water point, as the depth of the water point, the flow rate etc.... Likewise, as our pumping system test is the one of the ISET of Rosso. It consists of an artificial lake with depths between 1 and 5 m. To keep this depth (HMT = level difference + the sum of the head losses), we proceed to winnowing using the faucet, installed at the outlet of the discharge pipe. Thus, the following winnowing, as it is long or less, has a direct impact on the pump performance (power consumption, yield.... Thus, we propose to show through this work, the influence of the control valve on the different performance of our integrated solar pump in the solar pumping system, under climatic conditions in Trarza (Mauritania).*

Keywords: *Mauritania, Photovoltaic, Pumping, Matlab, KaleidaGraph, Winnowing.*

I. INTRODUCTION

Mauritania is a country located in the northwest of Africa, which has two different climates: Saharian and Sahelian. The Sahara has a dry climate (arid) compared to the Sahel that has a semi-arid climate.

The country begins to develop some sectors; such as infrastructures, human resources, health, agronomy (agriculture and livestock), drinking water, and access to energy. etc and for this reason, Mauritania is in a process of developing renewable energy in urban and rural areas.

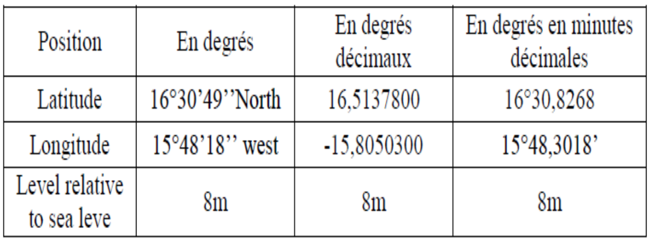
This energy is more sensitive in isolated sites where the use of conventional resources is often very expensive. That's why we chose renewable energy as a source of energy in rural areas for their difficult geographic locations (place and isolated operation).

The authors of the bibliography published in various journals [1, 2, 3, 4, 5 and 6] on the photovoltaic water pumping system and have mainly focused on modeling like other applications. Thus, applications on this large territory were not met in the scientific literature. Above all, they have a practical link with the actual weather conditions in Mauritania. Our goal in this work is to present the modeling results, experimentation and simulation and the related electrical characterization, hydraulic photovoltaic system, with implementation as pumping water in remote locations in the regions edge of the Senegal River, especially in the region of Trarza.

II. GEOGRAPHICAL LOCATION OF ROSSO

Rosso is a city located in the southern part of Mauritania, along the border with Senegal. It's the central city and the capital of the Trarza Province, which geographical coordinates are:

Table 1: Geographical coordinates Rosso



Position	En degrés	En degrés décimaux	En degrés en minutes décimales
Latitude	16°30’49’’North	16,5137800	16°30,8268
Longitude	15°48’18’’ west	-15,8050300	15°48,3018’
Level relative to sea leve	8m	8m	8m

Regarding the average of irradiation, solar measured by the meteorological station of the ISET of Rosso for 2014, is presented in Table 2 below. The average value of these measurements gives about 5,67KWh / m2 / day. This value is given in accordance with the UNEP (United Nations Environment Programme) and data registred in the laboratory (LRAER) of USTM. The table shows that the sunniest month is May andt the less sunny is January.

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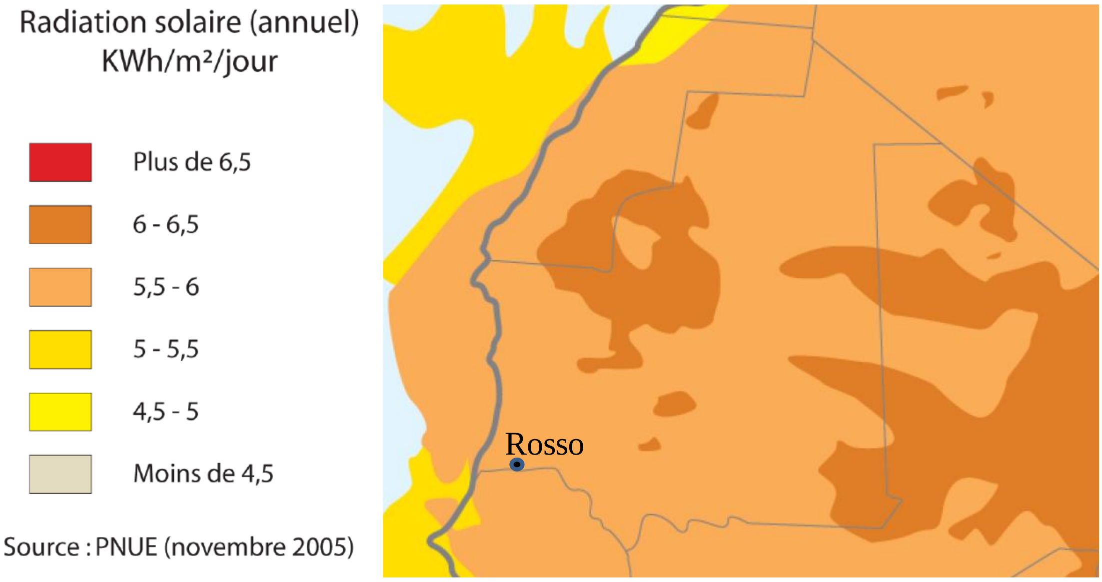
Table 2: solar irradiation in kWh / m^2 / day for 2014

N°	1	2	3	4	5	6	7	8	9	10	11	12
KWh/m^2/d	3,00	4,77	5,69	7,27	8,26	7,61	6,85	6,17	5,68	5,19	4,22	3,35



Source : PNUE (novembre 2005)

Fig. 1: annual solar irradiation in Rosso site (source PNUE)

III. EXPRERIMENTAL DEVICE FOR PUMPING AND DATA COLLECTION

The ISET Rosso's test rig is shown in Figure 2. It is composed of an artificial lake with a depth of about 1 to 4 meters with a submerged pump-type LORENTZ PS1200C SJ5 -8. The pump is powered by a photovoltaic generator via a DC / AC inverter (1.2 kW), the system is equipped with two sensors, one avoids dry running of the pump and the other prevents tank overflow.

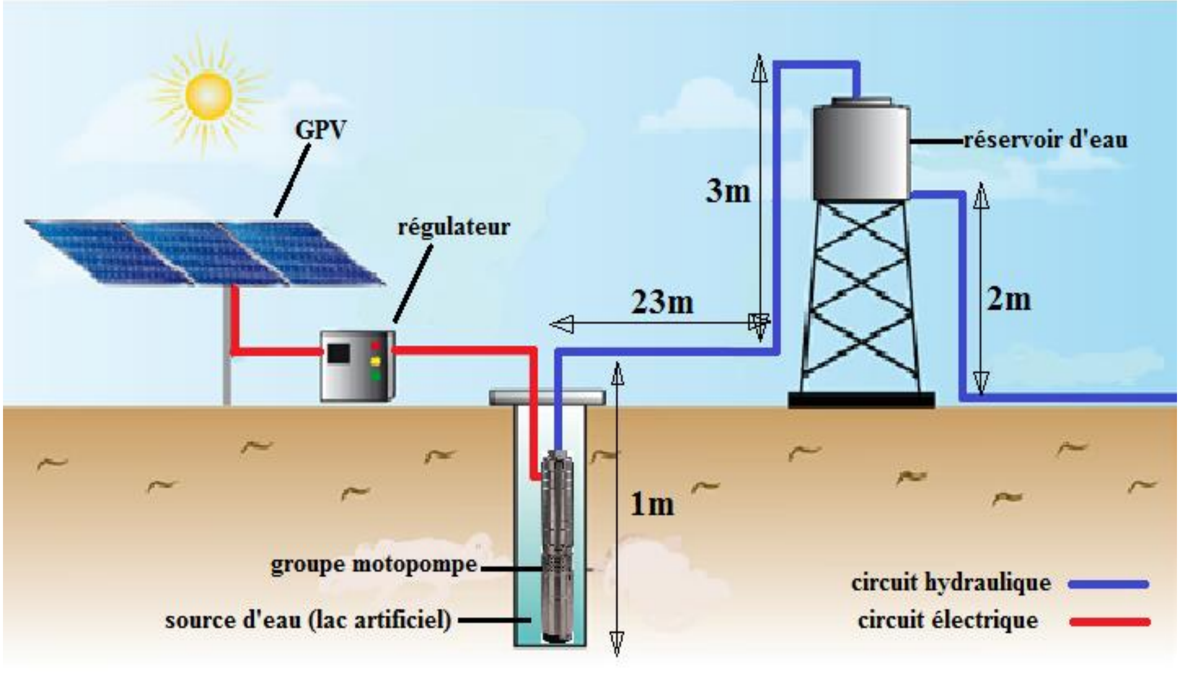


Fig. 2: Iset experimental pumping test

The table n°3 below shows the data (Power, HMT and Debits) for the three proposed cities.

Table n: 3 below shows the data (Power, HMT and Debits)

Citie	Peak power (kWc)	Number of panel	HMT (m)	Water flow (m^3)
ISET-Rosso	0.76	4 series	4	8
Bameira	1.48	8 series	10	10
Entvachitt	1.14	8 series	7	7

3.1. Panel characteristics given by manufacturers

The solar cells are generally associated in series and in parallel, and then encapsulated in glass to obtain a photovoltaic module.

A PV generator consists of modules interconnected to form a unit producing a high DC power compatible with the conventional electrical equipment. PV modules are usually connected in series-parallel to increase the voltage and current at the output of the generator.

The interconnected modules are mounted on metal supports and inclined at the desired angle depending on the place; this set is often referred to by the module field.

The table n°4 below shows the panels characteristics for the three proposed locations.

Table: 4 Characteristics for the three proposed locations

Sites	Isc	Voc	Imp	Vmp	
ISET	8.18	32.3	7.36	25.8	ASRTO Power AP190
Entvachit	5.51	44.5	5.1	35.5	ILB ENSOL model EN180
Bameira	5.35	44.5	4.8	36.4	Solterra Fotovoltaico 185

3.2. Modeling of the PV generator:

Modeling and electrical characterization of currently marketed panels are necessary to optimize the operation of photovoltaic systems [4-7] using these PV panels. This can mainly reduce the cost of the PV system and increase the efficiency of PV generators.

Thus the characteristic of I-V PV generator is based on an elementary cell modeled by the equivalent circuit of Figure 3, given by [5].

The characteristic of the I-V photovoltaic generator is based on an elementary cell modeled by the equivalent circuit well known in figure 3.

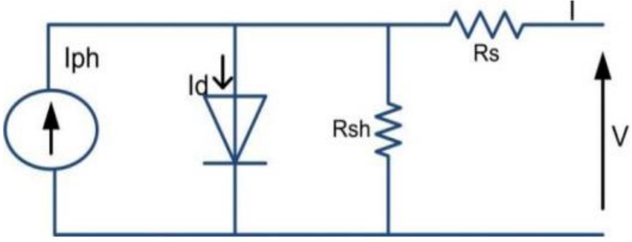


Fig. 3: Real Equivalent Circuit Diagram of a Cell

The current provided by the cell is given by the relation:

$$I = I_{ph} - Id - Ish \tag{1}$$

$$I = I_{pv} - Id\left[\exp\left(\frac{V + RsI}{Vt * a}\right) - 1\right] - \frac{V + Rs}{Rp} \tag{2}$$

The current Ipv depend directly from solar radiation G and temperature T of the cell, is given by the following relation:

$$Ipv = \left(I_{pv,n} + K_1 \Delta_T\right)\frac{G}{Gn} \tag{3}$$

The current of the diode is given by:

$$I_0 = I_{0,n}\left(\frac{Tn}{T}\right)^3 \exp\left[\frac{qE_g}{a * k}\left(\frac{1}{Tn} - \frac{1}{T}\right)\right] \tag{4}$$

With $I_{0,n}$: saturation current strongly depending of temperature, given by:

$$I_{0,n} = \frac{I_{sc,n}}{\exp\left(\frac{Voc,n}{a * Vt,n}\right) - 1} \tag{5}$$

Ish is the current of the resistor shunt, also called current shunt. It is obtained by the expression:

$$Ish = \frac{V + Rs * I}{Rsh} \tag{6}$$

$$P_{\max,m} = Vmp * \left\{ I_{pv} - I_0 * \left[\exp\left(\frac{q}{KT} * \frac{V_{mp} + R_s \operatorname{Im} p}{a * Ns}\right) - 1\right] - \frac{V_{mp} + R_s I_{mp}}{R_p} \right\} = P_{\max,e} \tag{7}$$

$$Rp = Vmp\left(V_{mp} + I_{mp}R_s\right) / \left\{ V_{mp}I_{mp} - V_{mp}I_0 \exp\left[\frac{V_{mp} + I_{mp}R_s}{Ns * a} * \frac{q}{k * T} + V_{mp}I_0 - P_{\max,e}\right] \right\} \tag{8}$$

with:
I: Current supplied by the cell (A);
Io: current of the diode (A);
Io, n: saturation current (A);
Ish: Shunt Current (A);
Isc: short-circuit current (A);
Vmp: Terminal voltage of the module (V);
Voc: open circuit voltage (V);
Imp: the current module terminals (V);
P: Module Power (W);
G: Sunning on the cell (W / m2);
Gen: Reference Irradiation 1000 W / m².
T: Temperature of the cell ° C.
Tn: Reference temperature 25 ° C.
Eg: gap Energy for crystalline silicon qv 1.12.
a: factor ideality of the junction.

Rs: serie Resistance Ω.
Rp: Parallel Resistance Ω.
Rsh: shunt resistance Ω.
q: The electron load 1.6 .10-19C.
k: Boltzmann Constant .10-23 1.38 J / K.

3.3. Simulation by MATLAB

The two main parameters affecting the operation of a photovoltaic generator are temperature and illumination. The following figures show the reaction of a photovoltaic cell according to the characteristics of the current and voltage and these parameters.

The simulation model developed can be used not only to analyze the performance of a PV system, but also to dimension the most suitable PV system, to provide different electrical charges in any specified place, if local weather data is available.

3.3.1. characteristics I (V) and P (V) and the effect of temperature on the current and power

The main objective of this part of the study is to simulate the performance of a single component of the PV system ie the PV generator. This single component is the most expensive and sensitive to weather conditions on the ground. The PV generator optimization methods are very useful for manufacturers who do not have detailed information about the future of their products implementation sites.

To achieve our goal, we have established a simple and reliable system, with reasonable accuracy, to predict the performance of a PV generator in the climatic conditions of our country. This model is validated by data obtained from a PV array installed at three sites of the ISET of Rosso, which are Bameira and Entvachit to perform the pumping of water.

The performance obtained from the data and the model is compared. We characterized the face panels (4) during a day in which the intensity of illumination measured on our site, is in the order of 701 W / m2 and temperature of around 25 ° C. In figures 4 and 5, we have shown the typical characteristics current - voltage and power - voltage obtained through MATLAB for our three respective sites, taking into account the parameters obtained from the electrical characteristics provided by the supplier.

Thus, these curves allow us to give analysis through MATLAB, electrical operation of photovoltaic modules. The photovoltaic panel is simulated to estimate weather conditions (illumination). Based on the results, we propose, then, characterization and modeling of electrical properties of the panels installed in the project the illumination ranges from 300 W / m^2 900 W / m^2 and the temperature about 22 ° C - 25 ° C. In Figure 4, we have shown the characteristics of the typical current-voltage and power-voltage obtained. On the same figures, we represented the simulated characteristics KaleidaGraph in setting the parameters of the diode (current saturation,) which makes for a good agreement between experiment and simulation.

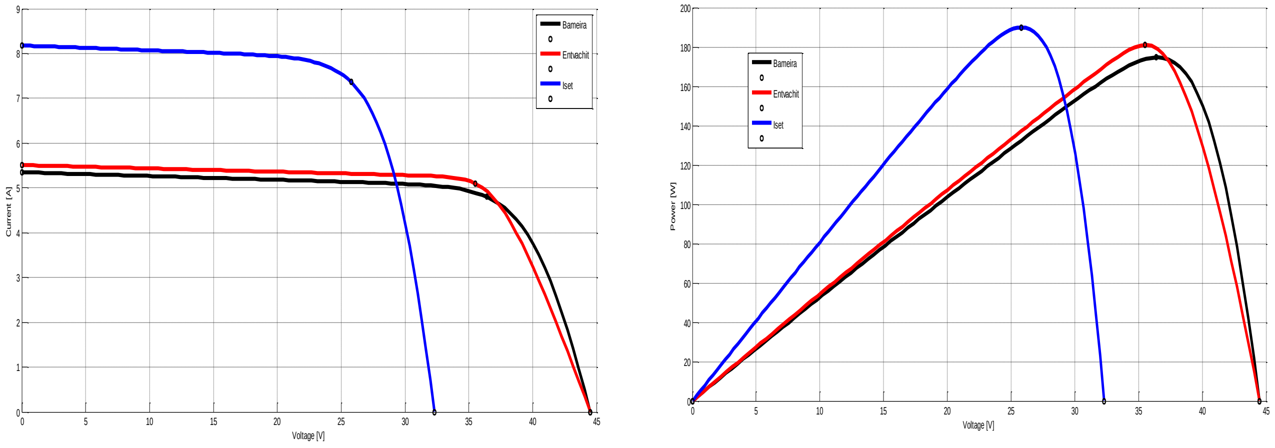
From the characteristics of figure 4, we have shown in figures 5 and 6, the variations in the saturation current (I_{SAT}) of the diode and the optimal voltage (Vopt) of the panel as a function of illumination.

It appears that for this temperature is between 20° and 25 ° C:

- Current (log (IS)) increases linearly with the illumination.
- The optimal voltage decreases linearly with the illumination.

When the illumination ranges from 300 to 900 W / m^2 the optimum voltage ranges from 14.8 V to 13.2 V (a decrease of 11%).

The comparison between these results and those previously published in the literature [5], shows both different cell parameter values to those fixed during the modeling of current-voltage characteristics provided by the manufacturer (I_S = 0- 10 A and Vopt = 17.2 V), and also the high dependence of these parameters (IS, Vopt, ...) from illumination.

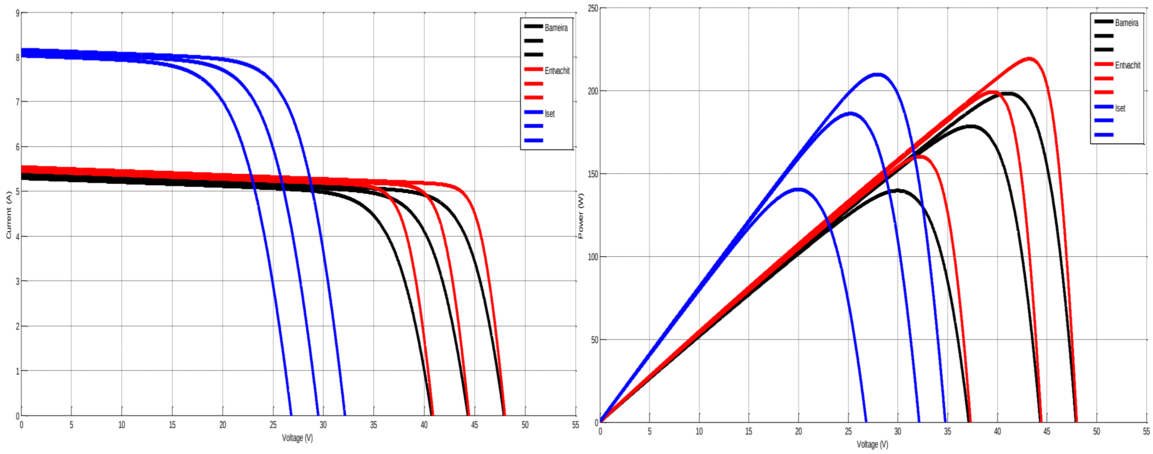


a)

b)

Fig.4, a) characteristics I (V) and b) haracteristics P (V)

In most of literature studies [1,2], it is assumed that saturation current of the diode and the voltage depend very little on illumination. Taking into account these assumptions, we showed in KaleidaGraph that this varies when the illumination of 1000 W / m^2 500 W / m^2, the voltage Vopt undergoes a slight decrease (<2%). For the evolution of the characteristic, I-V as a function of temperature (figure 5) shows that the current increases very rapidly as the temperature rises and causes, after a less pronounced decrease of the open circuit voltage.



a)

b)

Fig. 5: a) Influence temperature of I (V) and b) Influence temperature of P (V)

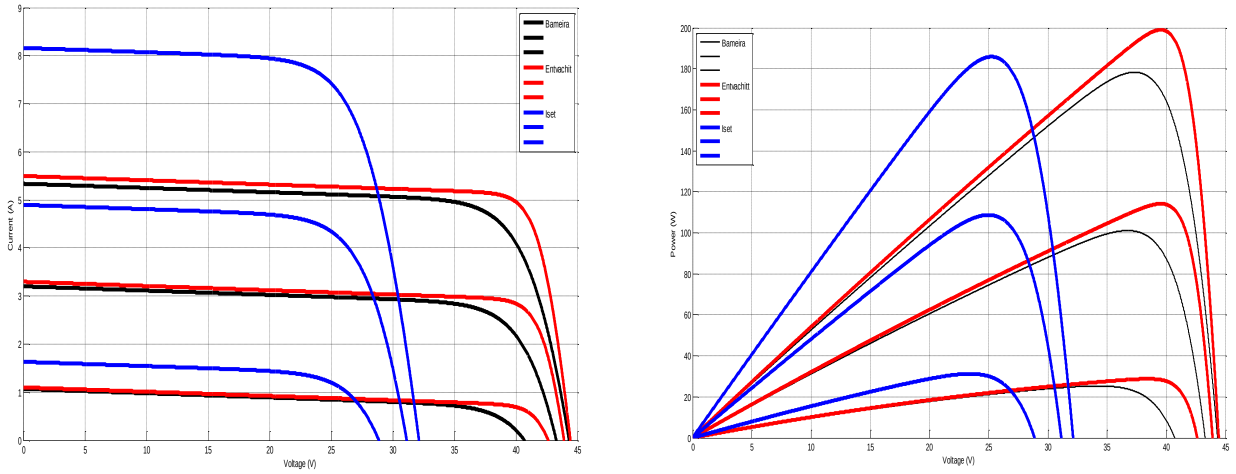
After this, we analyze the electrical parameters of solar cells and panels optimal and electrical parameters (voltage and power) depending on weather variations (temperature, light). The results obtained show that the parameters of the diode photovoltaic cells depend on illumination: the saturation current increases with illumination. This induces a reduction of the optimum voltage with illumination. When the illumination ranges from 300 W / m^2 900 W / m^2, the optimal voltage decreases to 10.2%. When the illumination is about 300 W / m2, it may decrease to 5%.

3.3.2. Effect of sunlight on the current and power

We simulated the different current - voltage and power - voltage according to illumination and charging. In figures 6, are represented the typical characteristics current - voltage and power - voltage according to illumination. This means that:

- The current of the short circuit (current when the voltage is zero) increases with the intensity of illumination,
- The open circuit voltage (voltage when the current is zero) increases slightly with illumination,
- PV panel provides maximum power (P max), which is very sensitive to light. The maximum power point (MPP) is a Vopt voltage, current Iopt and thus optimum strength Ropt (Ropt = Vopt / Iopt), the module and the PV generator.

We note (figure 6) when the sun rises, the intensity of the photovoltaic current increases, the I-V curves shift to increasing values for the module to produce a higher electric power; the maximum power points are marked with the corresponding values.



a)

b)

Fig. 6: a) the sunshine Inlfulence of I (V) and b) Inlfulence sunshine of P (V)

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In this work, and from the modeling of current-voltage characteristics, we deduced a different behavior: when illumination decreases, the Vopt voltage increases considerably. Consequently, when the regulation of power supplied by the PV panels, from the MPPT control, it is necessary to take account of this strong dependence on illumination. To validate all these achievements, we analyze, in the next paragraph, the manual regulation of the power supplied by the panel as well as the modeling of electrical performance achieved (Vopt, Iopt, Popt) depending on illumination. Considering all the modeling results, we analyzed the electrical behavior of the association of panels in series and in parallel, and the aging of a photovoltaic panel. We have shown that the connection of photovoltaic panels in series (parallel) improves (deteriorates) the optimum performance of a panel, and a photovoltaic panel undergoes aging from 4 to 5 W per year.

IV. SIMULATION WITH KALEIDA GRAPH SOFTWARE

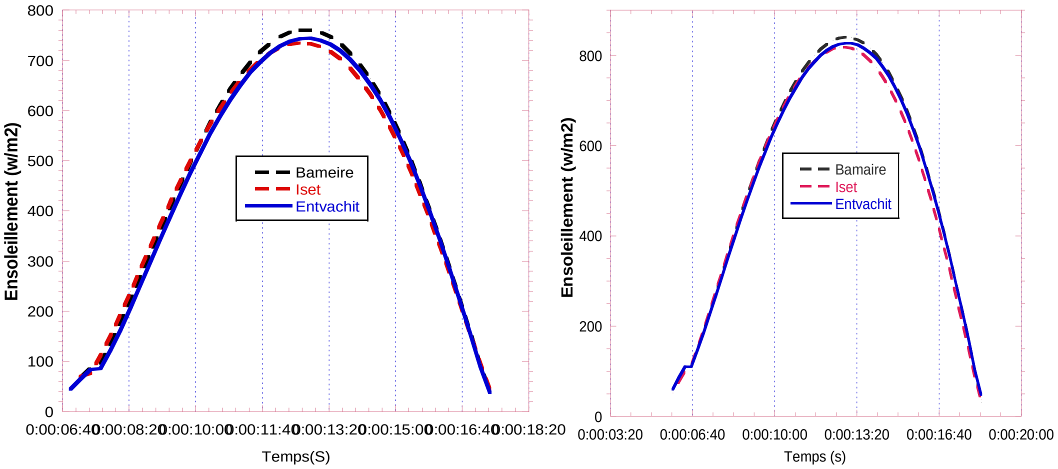
The choice of software, among many ones, existing in the market is dictated by the fact that the KaleidaGraph simulation is scientific software. Similarly, it allows entering data in a spreadsheet-like interface and it also allows direct import of files (Excel, ASCII). We give above some performances of the software, such as: Menu on-camera features: sorting, transposition, statistical analysis, library of varied and customizable graphical models, numerous setting options for complete control of graphics layout (legends , limits, axes).

4.1. Achievements

The results show that the simulation tool "KaleidaGraph" provides the ability to model an effective and timely photovoltaic pump system and also allows validating electrical models of the pumping system. Thus, we compared our simulation results sunshine data for the three sites compared with the measured values (figure 7), and we find a good deal for a normal sunshine day, and so a differences, more or less is clearly observed between sites. These differences may be explained by a error in estimating value of the cell temperature by the model or by a shift towards the East. Indeed, one can even notice that for the day, the maximum temperature point for the three sites is at the point of maximum solar irradiation generally occur at noon (midday sun).

4.2. Global sunning

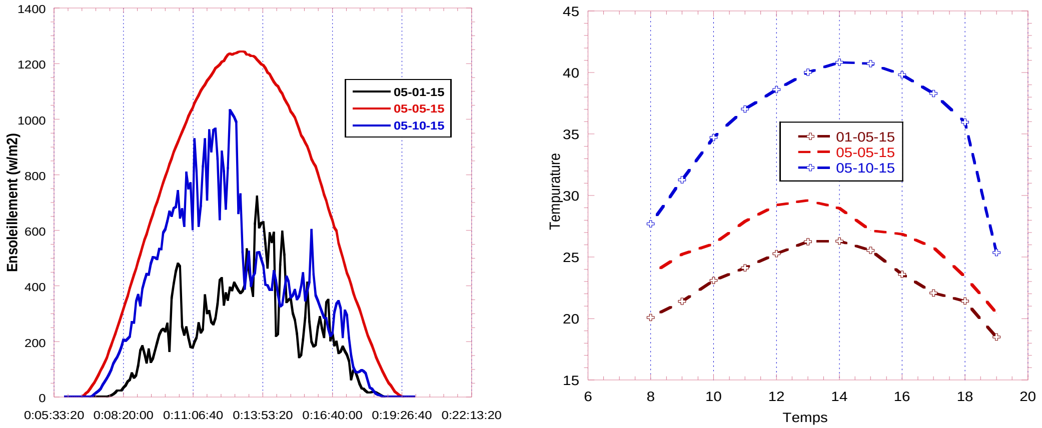
The data collected allow drawing the characteristic curves of the pump (power consumption, power output, efficiency ...). We proceeded at first to calculate the average sunshine during January and May for the three sites (Bamaire, ISET, Rosso and Entvachit) see figure 7.



a) b)

Fig.7: (a and b) the variation of sunlight for the three sites

For every hour of the day, we get what we call typical day 'sunshine, that's peaked between 12h30mn and 13 h (figure. 7). The sunshine and temperature per hour, these days are represented in the following figure over time. The figure shows that the sunshine curve is symmetrical about its maximum at 13h00 with a peak that is greater than 1 kw / m^2. The temperature of October 05 is very high compared to May 5 and June 5, 2015.



a) b)

Fig. 8: Sunning (a) and (b) the temperature of typical days (ISET)

4.3. *Sunshine change and flow rate according to the time:*

This is to install a submersible pump type Lorentz PS1200 (1.2 kW) to test the artificial lake during the day. The fixed depths are from 1 to 5 m. To keep this fixed depth (HMT = difference in level + the sum of lost charges), we proceed to winnowing using the tap installed at the outlet of the discharge pipe. The evolution of the flow rate for every hour in the day follows the evolution of the sunshine in the next figure, for every hour of the day, then we get what we call a typical day 'sunshine, which maximum is at solar noon.

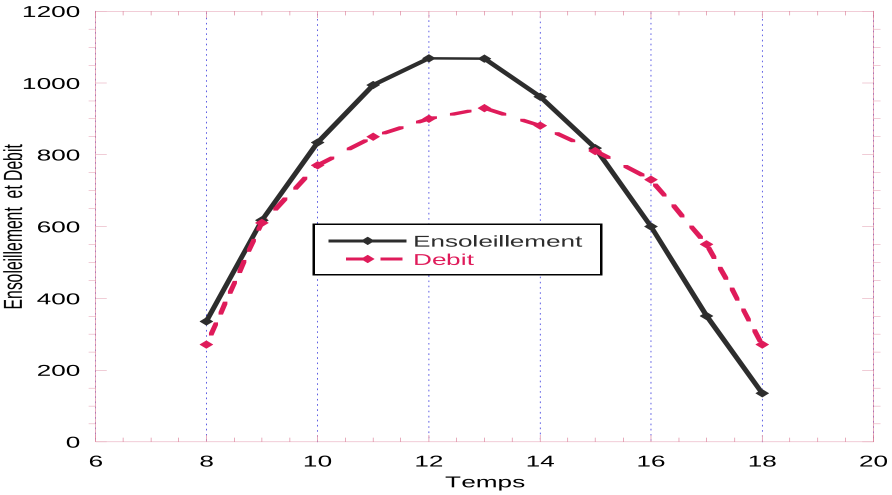


Fig.9: sunshine variation and flow rate

The solar pumping is a technic that involves pumping water under the sun, ie only when the sun is present. The genius of the solar pumping is in its simplicity. One can hardly imagine a simpler system: a solar panel and pump enough. No need for batteries, solar pump speed varies depending on the power of the panel.

At night, the pump does not work, but the water can be stored in a tank to be used as needed. In practice, it is recommended to use a controller suitable for the solar pump to protect and boost its operation in the morning and evening. Figure 7 shows the evolution of the global solar irradiance measured on the PV array during the day.

For practical purposes of comparison, the graph is carried out only during the pumping period. It is noted that the two curves are similar.

To find the amount of water pumped during the day, just do full flow on time, giving 97,13m3 / day to 2m and 87,27m^3 / day to 4m. The data collected allow to draw the pump characteristic curves (speed, power consumption, power output, efficiency,..) and the characteristics of the photovoltaic generator (current, voltage, sunshine).

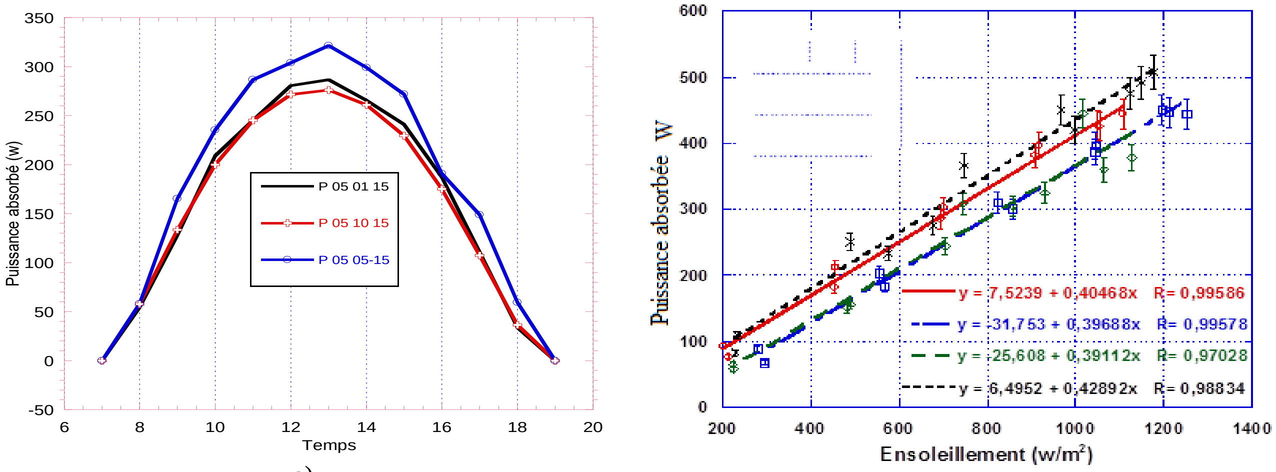
IV.1.3 power consumption and power delivered by the pump:

- Absorbed power

current and voltage data used to calculate the power consumption of the pump. It is given by the following formula:

$$P_{ab} = U \bullet I \qquad (9)$$

Pab is the power absorbed by the pump, the supply voltage U, I, current.



a) b)

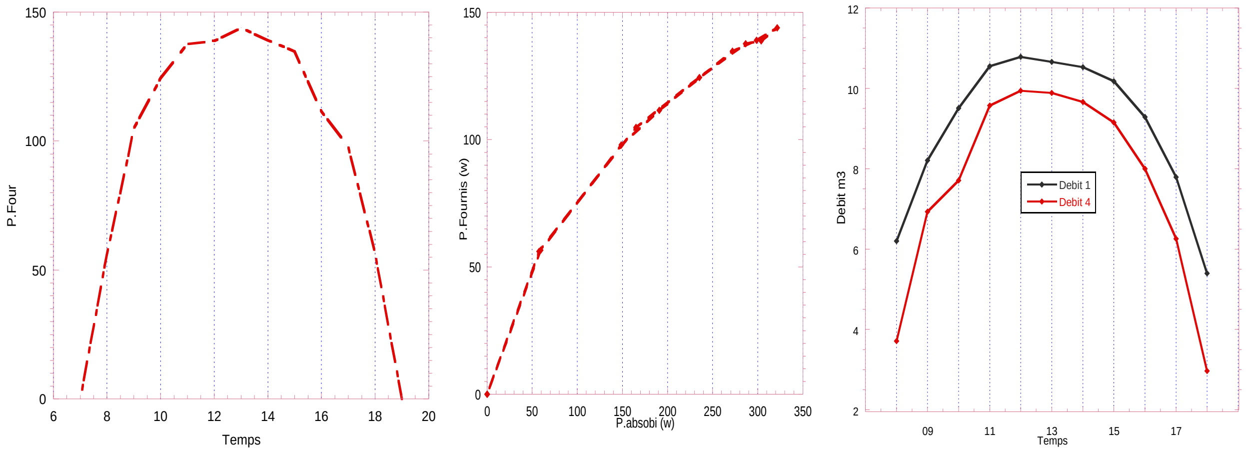
Fig. 10 a): Power consumption (pump) in the days and (b) is the variation of power consumption depending on sunshine.

From the curve of figure 10, we can see that the power absorbed by the pump increases proportionally with sunshine, reaching the maximum at solar noon, it takes the form of sunlight (figure. 10). Power supplied by the pump

To raise a certain amount of water from one point to another, the pump must pass the energy liquid. This amount of energy will be the same, regardless of the pump technology. HMT flow and data used to calculate the power delivered by the pump which is given by the following formula:

$$P_{four} = (Q \bullet H) \bullet h \qquad (10)$$

P_{four} is the power supplied (W); H is total head height, Q is the flow rate (m^3 / h) and h is the operating time.



a) b) c)

Fig. 11 (a, b and c): Power input (w), power variation (w) supplied according to the absorbed power (w) and the flow rate e, versus time for two values (HMT = 1 and 4 m)

From the curve of figure 11, we see that the power supplied by the pump increases in proportion to the power absorbed by the latter in accordance with the sunshine curve (figure. 11).

We gave the rates for two values of HMT and we notice that the most important is the one of HMT.

V. DISCUSSION

After calculating the power consumption and the power supplied by the pump, we proceed to calculate the yield which is the step centerpiece of our study. The yield is given by the following equation:

$$\eta = \frac{P_{four}}{P_{ab}} = \frac{(Q \bullet H) \bullet h}{U \bullet I} \qquad (11)$$

Figure 11 clearly shows that the maximum efficiency of the pump does not always correspond to the maximum point of the power absorbed or supplied by the pump.

To better understand the physical phenomena generated in this part, back on the process of operation, as follows:

- Early

The gate valve is fully opened (relevant section of the pipeline is maximum), the pump starts delivering from a certain power supplied by the solar modules, the pump head is almost zero in that power. To achieve the desired HMT (pumping depth), we proceed to the reduction of the liquid streams passing section. This results in an increase in pressure losses (losses of individual pressure at valve tap), which translates an increase in pressure in the pump outlet and a flow decrease and the HMT reached the desired height. This process causes a drop in the yield of the pump, a power dissipation in the fluid and an increase in the power to be developed (fig. 11).

● **During the day " sunshine** "

The speed and height increase proportionately with the sunshine to reach the maximum between 12 and 13h h30mn (Figure 7). They increase differently depending on the rated motor speed. To return to the desired HMT, we proceed to the opening of the gate valve, this causes an increase in the flow area, although the latter is maximum, the flow still reaches high values (high flow rate).

This increases the linear pressure losses and consequently power consumption increases (Figure 11) the process. The following can be summarized:

- The winnowing is gradually varied, with direct consequences for the slow performance of the pump start and stop of the latter,
- Winnowing abrupt with direct consequences on lowering pump performance during handling (Fig. 11).

The data collected allow to draw the characteristic curves of the photovoltaic generator (current, voltage, sunshine) and that of the pump (power consumption, power output, efficiency, .).

In this paper, it was presented the experimental study of a photovoltaic pumping system.

The performance of a PV system is highly dependent on weather conditions, such as solar radiation, temperature and wind speed. To provide energy continuously throughout the year, a PV system should be properly sized.

This requires a fairly rigorous study in order to make the best choice, the most efficient and cost. But the information provided by the manufacturers of photovoltaic equipment only allow approximately sizing the PV system.

VI. CONCLUSION

During our research, we noticed:

- The performance of a generator: The performances of a PV generator are strongly influenced by climatic conditions, particularly solar irradiation and temperature of PV module. In this study, we used the empirical model to a diode to simulate the operation of the PV modules for different conditions of sunlight and temperature. The main advantage of this model lies in its simplicity and ease of implementation from the specifications to the manufacturer.
- We compared our simulation results with data from three sunshine websites:
- Flow: the flow and power absorbs and provide consequences for the declining efficiency of the pump and increase the power consumption of the motor.
- The frequency and winnowing mode: During our research, we found that the frequency and mode of the control valve to impact the decline in pump efficiency and increased power consumption motor of the latter.

He moves the operating point to the risk of out of the range of use of the pump. The solar pump reaches its maximum performance or nominal operating point that depends on the sunshine, flow and pumping head. Winnowing is not the best solution for varying the flow rate and achieve the desired HMT. Other solutions exist such as variation in flow rate by varying the pump speed. But this solution remains unproven for submersible solar pumps.

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