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Sizing Method of a Storage System for Determining the Performance of a Photovoltaic Pumping System over the Sun

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Abstract

The use of renewable energy is growing significantly in the world. In front of the growing demand for electric energy, essentially for the needs of remote, isolated and mountainous regions, photovoltaic systems, especially water pumping systems, are beginning to emerge in large applications. In this sense, the proposed study deals with the problem of the water level regulation in the photovoltaic pumping system. It is in this context that the interest in this paper is dictated by the need to use an existing energy source on the site. Still in this light, it is important to note that, often, the calculation of the size of the GPV that feeds the pumping system and the pump involves a certain degree of uncertainty, mainly due to two main reasons: the first is related to randomness of solar radiation which is often little known and the second is related to the difficulty to estimate the water needs. This is why, on the one hand, the realization of such a system has made it possible to show the possibility of determining the projected quantity for water storage. Similarly, it has shown that the prediction of this quantity of water can be calculated by a simple analytical method based on numerical computation. Thus, it was also shown for this pumping system, thanks to graphical analysis methods, developing autonomy, reliability and good performance. In this sense, this experience opens the door for a practical and economical solution to the problem of lack of water, especially in our regions. Measurements made on the studied system prove that the designed approach improves the efficiency. Finally, it is also expected to draw further conclusions for the operation of these systems in similar sites.

Keywords

Water Pumping, PV, Storage, Output

1. Introduction

Photovoltaic pumping systems are particularly suitable for water supply in deserted areas such as those in the Sahel where electricity is not available [1]. This process involves pumping water in the presence of the sun to a reservoir that regulates consumption [2]. Thus, the consumer can be powered even at night and during cloudy days. Pumped water can be used in many applications such as domestic use and irrigation [3]. The system thus widely used is the so-called "over the sun" because it is the simplest since photovoltaic energy is used directly from the panels.

The peculiarity of solar pumps is that their characteristics (flow, pressure, and yield) are in function of the time of the sunshine and the temperature which varies during the day and the seasons. This work aims to show the correlation between sunlight and flow with their influence on the performance of the PV pump, to determine the quantities of water that will be stored [4].

2. Data on the Site

The majority of PVWPS deployed in Mauritania have been installed for use in small-scale potable water as shows in **Figure 1**. Because the photovoltaic water pumping systems (PVWPS) technology is being exploited for less than 10 years, among other government policies, there are no published reports on the performance of the installed systems and the technical, economic, social and environmental evaluation. As referred, the majority of PVWPS were installed with pilot programs, which opens the window for researchers to evaluate the performance of the systems and to suggest models and methods to optimize the performance of systems installed and to be installed [5].

Our site is located in Rosso in the wilaya of Trarza 200 km south of the capital Mauritania (Nouakchott) located on the border with Senegal. The geographical coordinates of our locality are recorded in the following table. The test bench represented by **Figure 1** and **Figure 2** is composed of an artificial and approximately 2 m deep stainless steel, a pump immersed in Lorentz type well water fed by an ASTROPOWER type photovoltaic panel (AP 190) passing through DC/DC power converter, and a system equipped with two probes, one avoids the dry running of the pump and the other avoids overflow of the tank.

The two probes used in the test bench are the following (**Figure 1** and **Figure 2**):

- Probe for dry operation: The probe contains a mechanical float with a magnet inside. When the probe is immersed, the float rises, and the magnet activates a

Table 1. Coordonnées géographique de Rosso.

	En degrés	En degrés décimaux	En degrés en minutes décimales
Latitude	16˚30'49"Nord	16.5137800	16˚30.8268
Longitude	15˚48'18"Ouest	−15.8050300	15˚48.3018'
Altitude	8 m	8 m	8 m

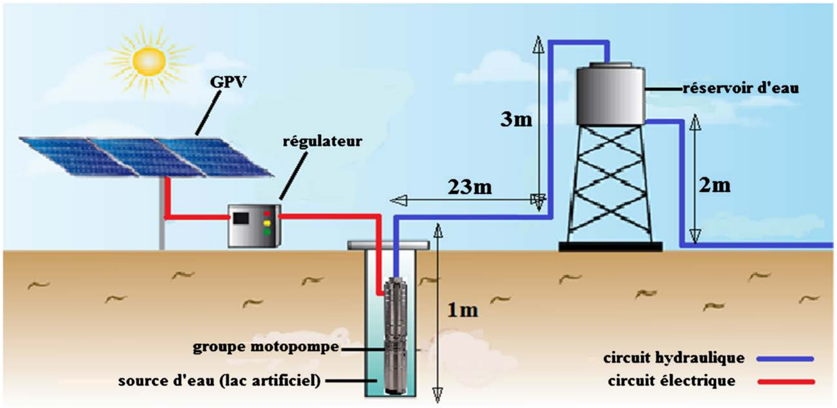

Figure 1. Water pumping stations driven by PV systems for human consumption in ISET.

Figure 2. Probe.

switch. The switch closes (closed circuit) to indicate the presence of water. The probe is waterproof, so the circuit will not touch the water.

If the water level drops below the probe, the float drops with, and the switch is open (open circuit).

- Overflow probe: using a probe against water overflow, stops the pump when the tank is full (high level) and starts it again when the water level drops (low level). This keeps the water from the source, prevents overflow, and eliminates unnecessary pump wear. The probe used in our case is an electric float.

3. Methodology

This involves installing a Lorentz type submersible pump (1200 w) for testing in the well for one day and for a depth of 5 m. to maintain this fixed depth (HMT = level difference + the sum of the head losses) [6], we proceed to the winnowing using the valve installed at the outlet of the discharge pipe. This manipulation does this:

- For a day in clear sky,

- For a day in cloudy weather.

4. Photovoltaic System: Performance-Performance

4.1. Efficiency of the Motor Pump

The Efficiency of the motor pump (1):

$$\eta = \frac{P_C}{E * S} \tag{1}$$

With:
E: Global irradiance (W/m²);
S: Panel area (m²);
P_C: Maximum power (w).

4.2. Coefficient of Performance

The overall solar water pump system efficiency is obtained by Equation (2):

$$\eta = \frac{\eta_{\text{reel}}}{\eta_{\text{theoriaue}}} \tag{2}$$

4.3. Storage Rate Optimization

Figure 7 shows two curves (hydraulic and electrical power) that are realized as a function of time. Thus, the mathematical models that give the trend approaches of the evolution as a function of time of these curves are given in the following figure. Indeed, these two equations make it possible to calculate the total quantity of the resulting flow of the intersection. Subsequently, it will be done by the integration of each of the equations according to the time in the interval where the presence of the sun is recorded [8 h, 18 h].

4.4. Design and Calculations of the Project System

4.4.1. Analyzed Method of Calculation of Stored Flow

The equations of hydraulic power P_H and electric power P_E of our system are given by the following formula:

$$\text{hydraulic power}\left(P_H\right) = -9.443t^2 + 129.95t - 72.692 \tag{3}$$

and

$$\text{electric power}\left(P_E\right) = -13.05t^2 + 180.2t - 139.87 \tag{4}$$

4.4.2. Stored Flow Calculation

To calculate the flow, it is proposed:

$$\text{Flow rate}\left(Q\right) = P_H - P_E \tag{5}$$

So:

$$\text{Flow rate}\left(Q\right) = 113.21\ \text{kWh} \tag{6}$$

Change weekly water requirements to daily water requirements.

Daily water requirement = (Weekly water requirements)/(Number of peak sun hours per day is five (5 hrs)

$$\text{Flow rate}(Q) = 22.6\ \text{m}^3/\text{h}$$

Because of the pump's design flow rate is based on the estimated daily water needs for irrigation divided by the number of peak sun hours per day [8 h, 18 h], as shown below:

Flow rate (Q) = (Total daily water requirement) * (Total daily solar insolation)

$$\text{Flow rate}(Q) = 226\ \text{m}^3/\text{day}$$

The total water storage capacity of the tank is sufficient for a minimum of two days water use.

4.4.3. Hydraulic Efficiency

Hydraulic power, P_F (W), required to supply a water flow rate (Q) at a certain TDH, considering the end use of the water and/or user requirements is given by Equation (6) [7]:

$$P_F = \frac{Q * HMT}{367} \quad (7)$$

where:

Q is water flow rate (m^3/h);

HMT is the total dynamic head (m);

The efficiency of the motor-pump system η is given as follows:

$$\eta = \frac{P_H}{P_E}$$

where:

P_E: Electric power to the input of the motor-pump unit [kW].

5. Results and Discussions

The data from the on-site acquisition system is used to plot the characteristic curves of the pump (flow, power consumption, power output, efficiency, electrical power and hydraulic power) and the characteristics of the GPV that are related to sunshine.

Thus, by a mathematical approach, it has been possible via this method to size the storage system for the performance of a photovoltaic pumping system over the sun.

For this purpose, it is concluded for the operation of these systems through this method that it is possible to adjust the capacity of the storage system with the GPV to find the performance of a system. Thus, it was calculated a quantity of water equivalent to two days of autonomy.

5.1. Variation of Global Irradiance and Temperature

The variation of the sunshine and the temperature, it represents the choice for two days characterizing the site: a day in clear sky and a cloudy day respectively

(**Figure 3** and **Figure 4**), where the sunshine and the temperature, is maximum and where it is disturbed with the development of sunshine and the minimum temperature.

Figure 3 and **Figure 4** present the behavior of the irradiance and of the temperature during these two days (cloudy day and sunny day) [5].

5.2. Flow

The data thus collected allow to show the regulation (winnowing) of flow will correspond to the sunshine during the day for a height fixed at 5 m with a day in clear sky, and a day in cloudy weather (**Figure 5** and **Figure 6**).

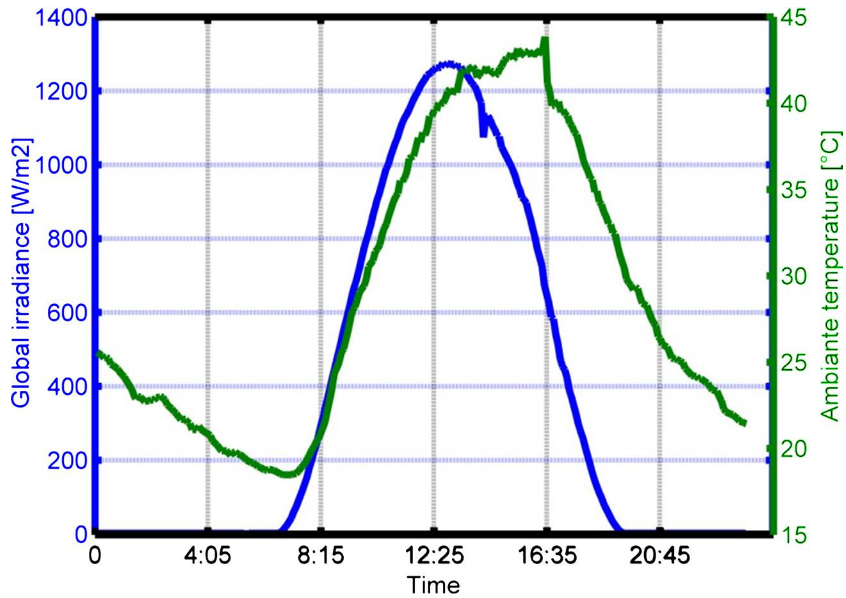

Figure 3. Variation of Solar and temperature pumping station in cloudy day.

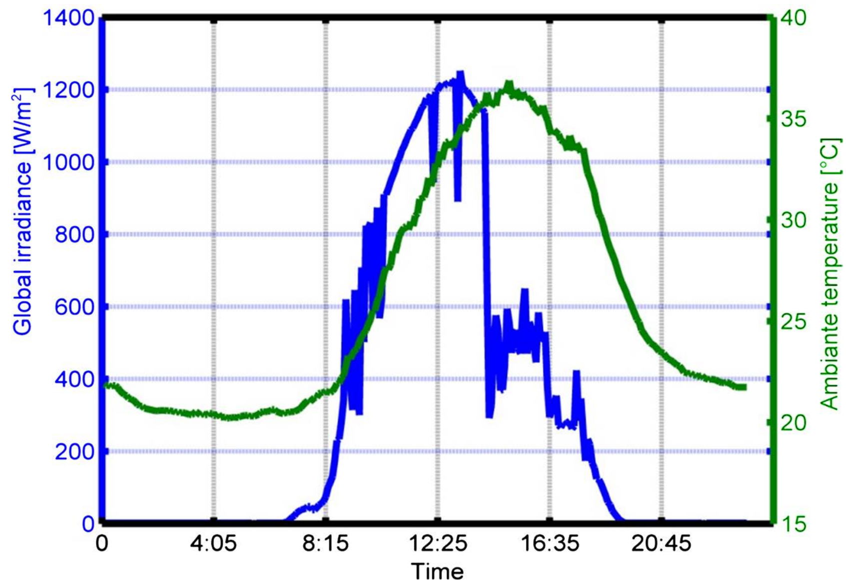

Figure 4. Variation of Solar and temperature pumping station in sunny day.

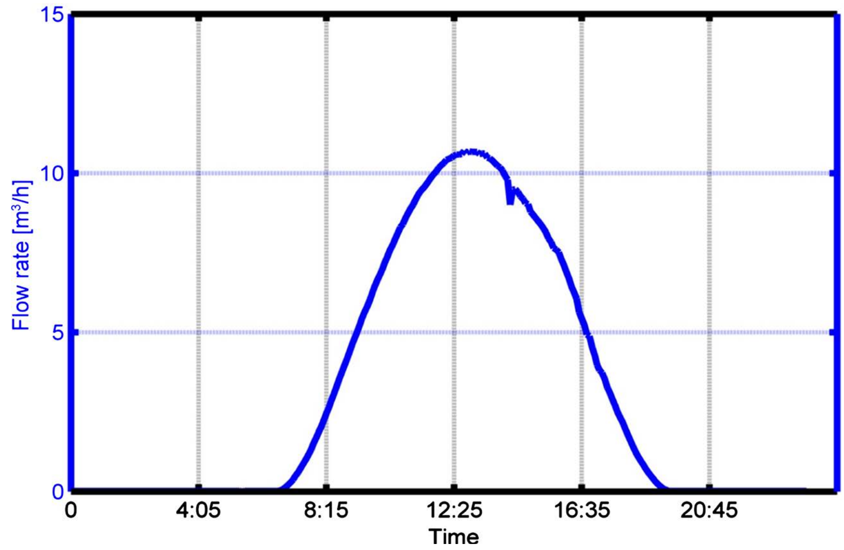

Figure 5. Variation of flow in cloudy day.

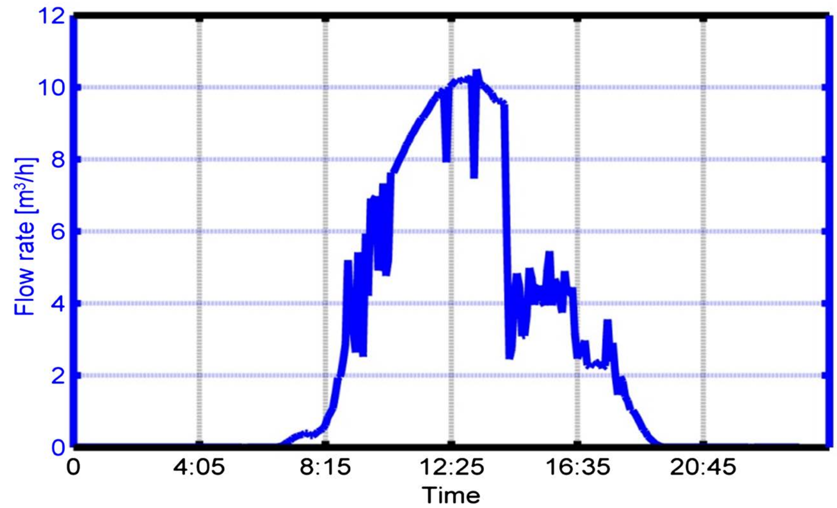

Figure 6. Variation of flow in sunny day.

5.3. Hydraulic Power

The behavior of the climatic condition have allowed us to achieve results as shown in **Figure 7** are related to the Power of each element.

5.4. Flow-Sunshine Correlation

As shown in the following figures (**Figure 8** and **Figure 9**), the flow-to-sunshine correlation for a clear day is a second-order polynomial, where the pumped flow increases with illumination, and for a cloudy day, the flow-sunshine correlation is a second-order polynomial with a significant slope, or the illumination also increases with sunshine.

5.5. Efficiency of the Pump

The plot of the overall efficiency with delivery head in **Figure 10** and **Figure 11**

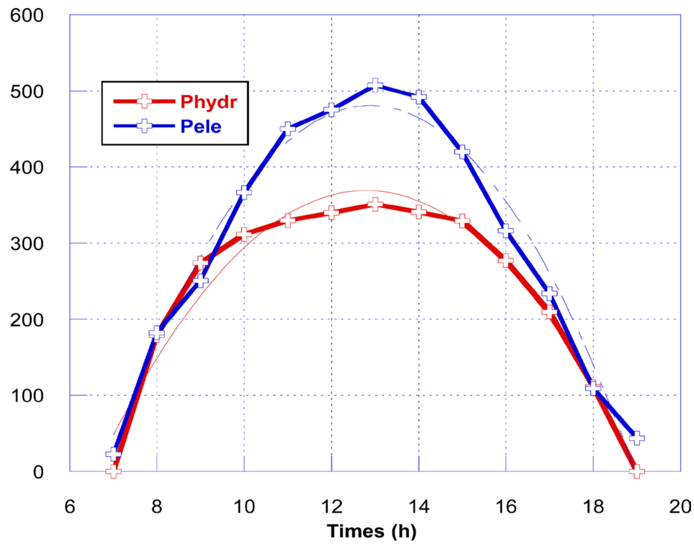

Figure 7. Graphique of power electrical hydraulic.

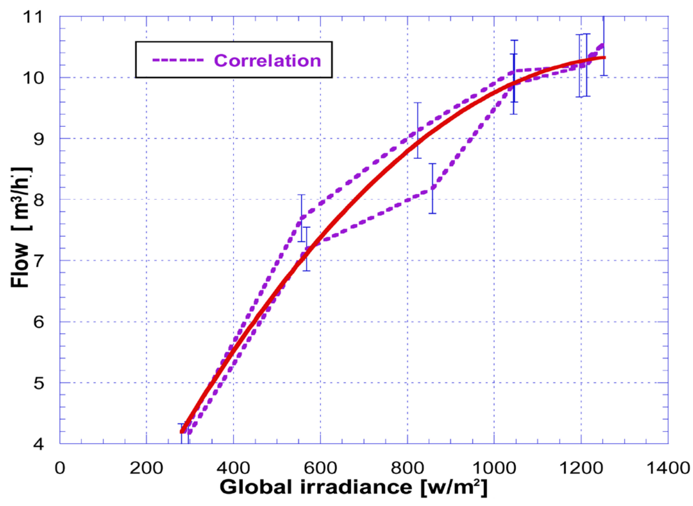

Figure 8. Correlation flow-global irradiance (cloud day).

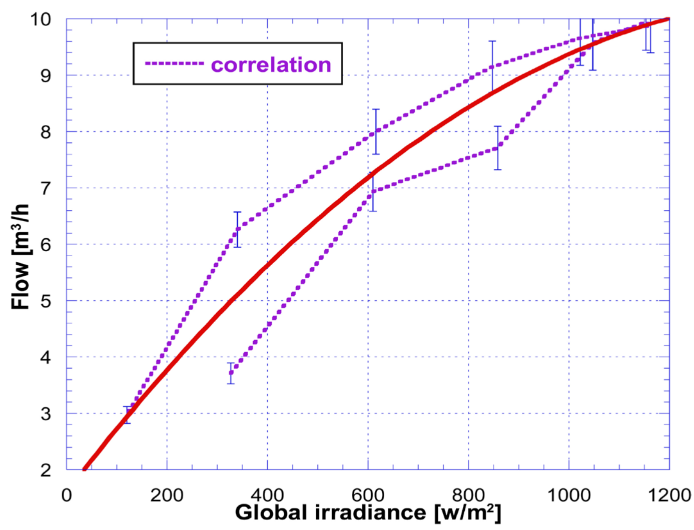

Figure 9. Correlation flow-global irradiance (sunny day).

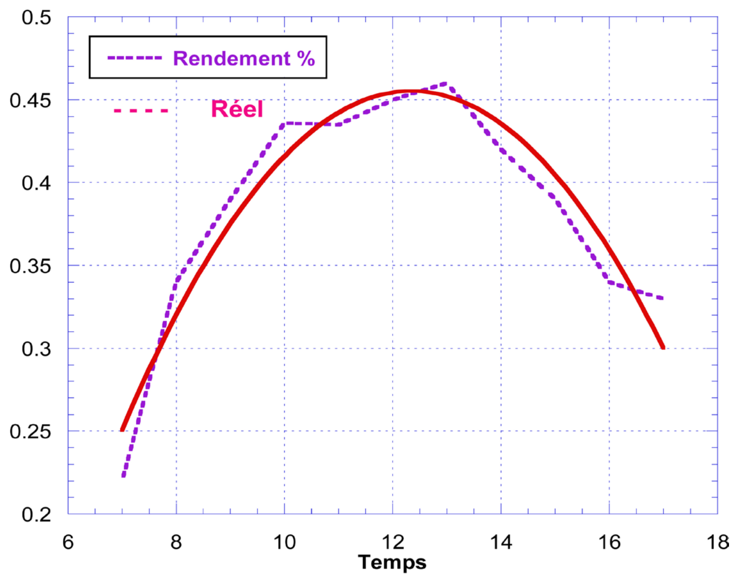

Figure 10. Efficiency of the pump (sunny day).

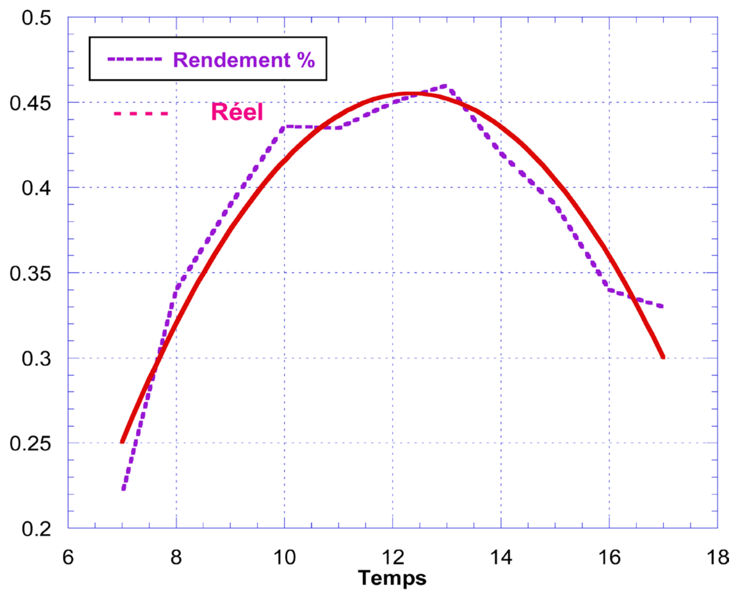

Figure 11. Pump performance (cloudy day).

indicates that this particular pump works most efficiently at 5 meter of head. After calculating the power consumption and the power supplied by the pump, we calculate the yield for a sunny day and a cloudy day [8]. Figure 10 and Figure 11 show the variation in pump performance for a sunny day and a cloudy day, respectively.

The methodology used on the real site of the Higher Institute of Technological Education (ISET-Rosso) allowed validating the numerical method. In this context, it is important to note for both figures (actual performance from recorded data and theoretical yield) are very close. Consequently, the load makes it possible to extract a power close to the maximum power of the photovoltaic generator with a theoretical flow of water that is little different from the real one and with a high conversion efficiency.

5.6. Flow-Through Correlation

From the curves obtained using the flow-yield correlation methods given for two days (sunny and cloudy) which are based on the flow data acquisition measurement system in Figure 12 and Figure 13.

Thus, in Figure 12, the flow-efficiency correlation for a sunny day is a second-order polynomial, where the pumped flow increases with illumination. In this same run, the flow-efficiency correlation is a polynomial of the same magnitude. Order than the previous one for a cloudy day, with a steep slope (Figure 13), or the illumination also increases with sunshine. To conclude, it can be said that these data provide the correct follow-up correlation since the flow-yield that is measured follows approximately the calculated ones (see Figure 12 and Figure 13).

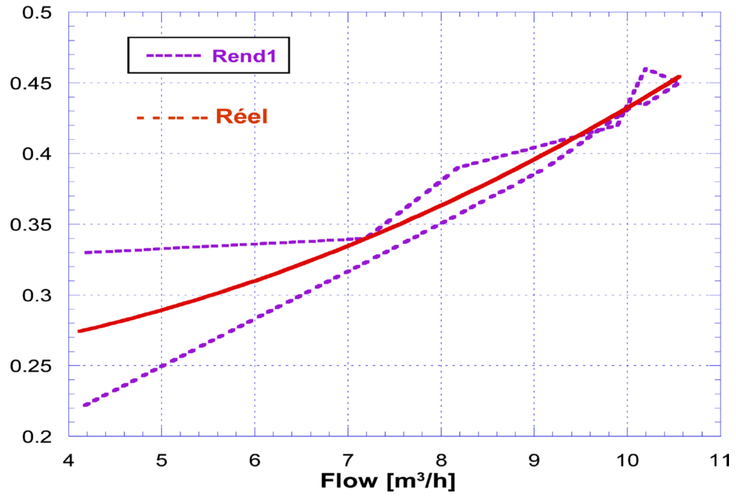

Figure 12. Flow-rate correlation (sunny day).

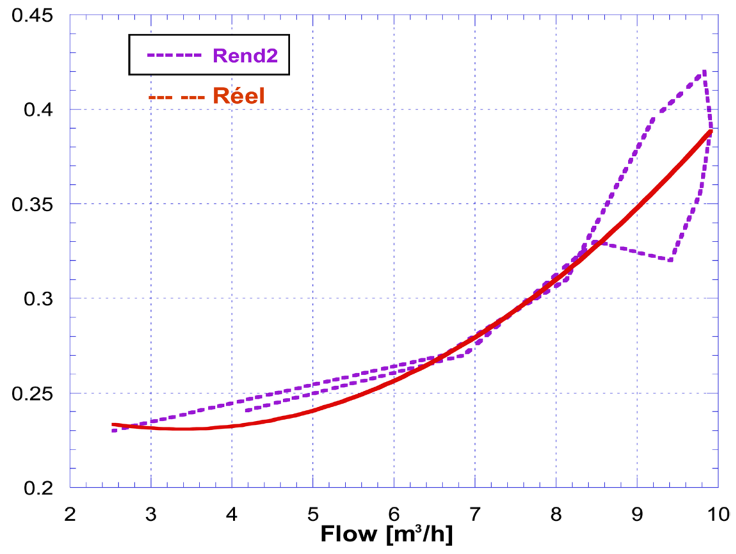

Figure 13. Correlation flow-yield (cloud day).

6. Conclusions

In the first part, it is important to point out that the meteorological data, such as solar potential, temperature, production system, have made it possible to visualize the annual global irradiation and the most economical combination variant of the pumping system (pumping over the sun) of the ISET. In a second part, it has been proposed a calculation for the size of the water storage system that is achieved through a comparative graphical study of electrical and hydraulic power.

For this purpose, it is shown for the operation of these systems through this method, that it is possible to adjust the storage system capacity with the photovoltaic generator to find the performance of a pumping system over time. Sun thus, it has been calculated a quantity of water equivalent to two days of autonomy for the storage system of our site. Another conclusion is possibly related to an impact of the analytical and graphical methods that were used.

Similarly, by the results it is shown with an effective use of the design of this type of system as pumping over the sun, that it is possible to provide water day and night in the absence of the sun, with the water storage system. Indeed, the validation of the results is obtained, thanks to a correlation between the theoretical and real data measured on site.

The methodology for calculating the monitoring of key parameters has proven to be accurate and makes it possible to predict the production of water on the site and at the same time strengthens the existing sizing tools. Finally, this methodology has come to show that this type of pumping system will have even more future in the isolated sites of the Sahel.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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