Study and implementation of a stand-alone photovoltaic water pumping system (PVPS) in desert region

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(Ghardaïa site/Algeria)

Abstract - Supply building with the safe water is necessary for domestic use that is why the Photovoltaic Pumping System (PVPS) should be integrated in such solar architectural study or urban planning. Because of its desert position and low buildings, Ghardaïa site is an appropriate location to use the (PVPS), with an easily full south inclined PV array. The availability of solar radiation covering the whole Algerian Sahara, with an average sunny day ranges between 5 h to 10 h, as well as the abundance of the underground water, with static head ranges between 5 m to 40 m help to use a stand alone (PVPS) for drink and irrigation, especially in remote regions far away from national electric grid. On March 2005, complete PV water pumping test bench has been installed at our URAER (Applied Research Unit for Renewable Energies)-Ghardaïa site in order to carry out the characterization tests on available solar water pumps. The obtained results will be used in such dimensioning study needed for (PVPS) installation. Many tests have been carried out on different submersible water pumps, namely: Grundfos with nominal power (DC 30 V – 300 V, I_{max} = 7 A, P = 900 W), Water Max WA 64 with nominal power (V = 64 V, I_{max} = 4.6 A, P = 300 W). With the Grundfos solar pump model, an average of about 40 m$^3$ per day of the pumped water volume has been achieved from fixed head of 25 m, at daily average solar irradiance (7 hours) of about 760 W/m$^2$ to about 880 W/m$^2$, during March. With the Water Max WA 64 model, an average of about 5 m$^3$ of the pumped water volume has been reached during 7 hours of pumping, from fixed head of 15 m, at daily average solar radiation (7 hours) ranges from about 880 Wh/m$^2$ to about 940 Wh/m$^2$, during April. Similar studies have been done to implement two stand alone(PVPS) for two irrigating wells of two farms ,within TMHs are 28 m and 25 m respectively, and with reservoir storage capacity of 50 m$^3$ each. It has been averred that the daily required powers are approximately 4.5 kW and 3 kW, respectively is needed to extract such quantity of water. The mentioned study is carried out upon the pumping lab PV array, which is implemented outside, on full south with an inclination angle of 32°.

Keywords: ‘PVPS’ Photovoltaic water pumping system - Test bench - Desert region - Livestock irrigation, - Hydraulic energy, - Electric energy, - Stand alone system, - Arid region.

1. INTRODUCTION

The supply of safe water for domestic use in desert regions remains the worry of the Saharan coast countries, especially those who have remote villages and farms far away from the electric grid. The PV pumping systems become the appropriate solution to overcome this problem in desert regions. There are two main advantages that help to profit from such new technology: the availability of free source of energy that is the sun and the abundance of the underground water sources.

The geographic position of Ghardaïa region (Latitude 32°N, Longitude 3°81'E and elevation from the sea level 450 m) makes it sunny region with more than 6
kWh/m²/year (recorded in 2005). The static water level of the boreholes vary from 25 m until 40 m in Sebseb region 60 km south west of Ghardaïa and from 5 m until 20 m in El - Golea region 270 km south Ghardaïa.

These static heads make the TMH (Total Manometric Height) lower or equal than 50 m involving the level of the tank above the ground. Such PV water pumping installation has been preceded by a complete study upon the following steps:

Data that should be taken at site:
- Characteristics of the site.
- Technical data of the well.
- Estimation of the daily water consumption.

Analytical study:
- Estimation of the daily required energy in Watt-Hour.
- Characterization of the selected PV generator and the load.

2. CHARACTERIZATION OF THE TWO PUMP MODELS

Methods
- The PV generator is mounted at about 40 m outside the Lab, south facing (Panel azimuth angle equal to Zero) and its tilt angle equal to the latitude of the site (L = 32°).
- G1: PV generator with configuration (2 x 6) is selected to feed the Grundfos solar pump.
- G2: PV generator with configuration (1 x 2) is selected to feed the Water Max solar pump.

3. DESCRIPTION OF THE MATERIALS

- Mounting of the pump in the artificial well of the test bench (stainless steal tank of 2 m).
- Pumping in closed loop.
- Control the fixed pressure: Due to the unpredictable irradiance, the pressure control valve must be adapted continuously according to the actual irradiance to keep the fixed water pressure which corresponding to the fixed head (the friction is negligible).
- Flow rate and the cumulative water volume are measured with flow-meter.
- The results are shown on the display panel and recorded on PC via Acquisition Data, simultaneously.

4. RESULTS AND DISCUSSION

Table 1: Variation of the monthly cumulative water for different heads during spring- Watermax pump

<table>
<thead>
<tr>
<th>Month</th>
<th>TMH (m)</th>
<th>Daily cumulative water (m³/day)</th>
<th>Number of pumping hours</th>
<th>Average Flow rate (m³/h)</th>
<th>PV Array config.</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>10</td>
<td>5.100</td>
<td>6</td>
<td>0.8351</td>
<td>1 x 2</td>
</tr>
<tr>
<td>March</td>
<td>20</td>
<td>4.528</td>
<td>6</td>
<td>0.7389</td>
<td>1 x 2</td>
</tr>
<tr>
<td>April</td>
<td>30</td>
<td>3.256</td>
<td>6</td>
<td>0.5038</td>
<td>1 x 2</td>
</tr>
<tr>
<td>April</td>
<td>40</td>
<td>2.000</td>
<td>6</td>
<td>0.3421</td>
<td>1 x 2</td>
</tr>
</tbody>
</table>
Table 2: Variation of the monthly cumulative water for A head of 25 m during Winter- Grundfos pump

<table>
<thead>
<tr>
<th>Month</th>
<th>TMH (m)</th>
<th>Daily cumulative water (m³/day)</th>
<th>Number of pumping hours (7)</th>
<th>Average Flow rate (m³/h)</th>
<th>PV Array config.</th>
</tr>
</thead>
<tbody>
<tr>
<td>December</td>
<td>25</td>
<td>28.751</td>
<td>7</td>
<td>4.218</td>
<td>2 x 6</td>
</tr>
<tr>
<td>January</td>
<td>25</td>
<td>34.921</td>
<td>7</td>
<td>4.962</td>
<td>2 x 6</td>
</tr>
<tr>
<td>March</td>
<td>25</td>
<td>35.646</td>
<td>7</td>
<td>5.053</td>
<td>2 x 6</td>
</tr>
</tbody>
</table>

The obtained results of characterization tests of the two mentioned model pumps showed that the two pumps types can be used in private domestic water supply, Water Max type can be used in private home livestock and Grundfos type can be used in private farm irrigation for TMH ranges from 10 m to 40 m. The following table shows the variation of the flow rate according to the TMH, during spring.

Table 3: Variation of the flow rate according to different Depths, during spring- Grundfos pump

<table>
<thead>
<tr>
<th>TMH (m)</th>
<th>Daily cumulative water (m³/day)</th>
<th>Daily pumping duration (7)</th>
<th>Average Flow rate (m³/h)</th>
<th>PV Array config.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>55.35</td>
<td>7</td>
<td>7.887</td>
<td>2 x 6</td>
</tr>
<tr>
<td>15</td>
<td>50.12</td>
<td>7</td>
<td>7.051</td>
<td>2 x 6</td>
</tr>
<tr>
<td>20</td>
<td>42.25</td>
<td>7</td>
<td>6.205</td>
<td>2 x 6</td>
</tr>
<tr>
<td>25</td>
<td>36.02</td>
<td>7</td>
<td>5.116</td>
<td>2 x 6</td>
</tr>
<tr>
<td>30</td>
<td>28.63</td>
<td>7</td>
<td>4.100</td>
<td>2 x 6</td>
</tr>
<tr>
<td>35</td>
<td>21.23</td>
<td>7</td>
<td>3.015</td>
<td>2 x 6</td>
</tr>
<tr>
<td>40</td>
<td>15.25</td>
<td>7</td>
<td>2.203</td>
<td>2 x 6</td>
</tr>
</tbody>
</table>

4.1 PVPS Design for Drioueche Farm/Sebseb
The purpose of this study is to reach an optimum (PVPS) installation design to provide the farm with a most daily average water capacity of 50 m³, during summer. The study of the previous consumption has showed that this quantity of water is largely enough to satisfy the farm demand in irrigation and the surplus volume can be used in emergency cases as cloudy weather or when the system is stand by in case of damage or maintenance.

The Grundfos pump model is involved in the study, by referring to the results showed on the table 3.

4.2 Meteorological and location characteristics of the site
- Location: Sebseb village, located 60 km southwest of Ghardaïa.
- Specifications: Classified as arid region
- Location from the sea: About 660 km south of the Mediterranean Sea.
- Latitude: 32°09’ Longitude:3°35’ Level / sea: 465 m.
Number of sunny days: about 80% per year, average irradiance: more than 6 kWh/m²/day.

- Temperature varies from Minimum average 26° until Maximum average 42°, in summer.
- Agricultural region: famous with palm trees, peanuts, and other vegetables.

4.3 Project specification requirements

The farm is consist of four land pieces, one piece is planted with 400 orange trees, each tree has an average consumption varies from 20 l to 25 l in hot seasons and from 15 l to 20 l in winter season. The other pieces are ready to be planted with the same number of various fruitful trees for each piece and the overall daily consumption is estimated of about 30 m³ of water.

About 15 to 17 m³ of daily demand of water, for other agriculture irrigation and usage. The farm demand in water is estimated at more 50 m³, in summer. The farm has a storage consists of a ground storage tank of 200 m³ capacity.

It is enough to substitute any deficit in water demand during the cloudy days when there is no much insolation level to provide the starting current for the motor pump, and when the system is stand by for further maintenance.

**Technical data**

- Daily needed cumulative water: 50 m³/day
- Diameter of the borehole (diameter of the well): 1.80 m
- Static head: 22 m
- Dynamic head: 25 m
- Distance between the borehole (the well) and the tank: 200 m
- Diameter of the water conduction pipe: 50/60
- Elevation of the tank from the ground: 10 m
- Total Manometric Height TMH: 40 m
- Capacity of the tank: 200 m³

4.4 PV pumping installation design

**Daily required hydraulic energy in Wh/day**

\[ E_h = \rho \times g \times Q \times TMH \]

\[ TMH = H_g + L_h \]

\[ H_g \] , geometric height between the dynamic level and the pipe outlet, \( L_h \) , losses of the hydraulic load caused by the water friction on the piping wall. These losses are in function of the piping distance (\( D \)), their diameter (\( dp \)) and of the pump flow rate.

\[ \text{Ch} , \text{hydraulic constant} \]

\[ \text{Ch} = g \times \rho = \left[ \frac{9.81 \text{m/s}^2 \times 103 \text{kg/m}^3}{3600 \text{s/h}} \right] = 2.725 \text{ kg.s.h/m}^2 \]
The daily demanded hydraulic power

\[ E = Ch \times Q \left( \frac{m^3}{day} \right) \times THM(m) = 2.725 \times Q \times TMH \]

The daily required electric energy: Assuming the overall efficiency of the couple pump – electric motor is \( R_p = 45\% \) which yields a demanded input electric power as follow:

\[ E = \frac{Ch \times Q \times THM}{R_p} \]

\[ E \left( 2.725 \times 50 \times 40 \right) / 45 \% = 12111.12 \text{ Wh} \]

**Daily required electric energy in W/day**

During the hot season the required quantity of water doesn’t exceed the nominal capacity which is 50 m\(^3\)/day. August is the month of the hot season where the maximum irradiance is the most weak (7.090 kWh/m\(^2\)/day), received on tilted PV panel with tilt angle equal to the latitude of the site.

So for a full south facing PV panel with tilt angle equal to the latitude of the site (\( L = 32^\circ \)), the average hour number of insolation reaches about (one h = 7 hours) per day. The losses caused by dust and temperature are estimated of about 20 %.

The following model estimates the maximum required power (MRP) by such load:

\[ \text{MRP} = \frac{E}{1h \times (1 - \text{Losses})} = \frac{12111.11}{(7 \times (1 - 20\%))} \]

\[ \text{MRP} = 2162.698 \text{ Watts.} \]

It can be estimated at 2400 Watts.

### 4.5 PV panel design

**Dimensioning of the field**

- Configuration of the field according to the available PV modules.
- Selection of the optimum tilt angle, optimum panel azimuth angle and avoid the shade place of installation.
- Estimation of the minimum monthly average solar radiation of global irradiance on tilted PV panel.

The farm owner selects the pump type. In our case, we can use two pumps installed in serial of Grundfos model with the characteristics (DC 300V, Isc = 7 A, P = 900 W). The mentioned Grundfos type is available in our PV pumping lab.

It may need an other a temporary livestock tank at 25m height from the dynamic level, just near the well with capacity of 25 m\(^3\), previously filled by the first pump mounted in the well, before starting the second pump which is mounted in the temporary livestock tank to fill the final tank (capacity 50 m\(^3\)) at height of about 15 m from the dynamic head of the second pump.

The water level in the temporary livestock tank is controlled by an electric sensor that cut off the current of the first pump emerged in the well, when the tank is filled. For such configuration study, refer to the table 3.

The PV generator is consists of two PV arrays of 12 Isofoton modules (110 W / 24 V each, with configuration (2 x 6)). Each pump is fed by a PV array, separately.
Table 4: Configuration of the PV generator composed of two PV arrays of twelve modules each

<table>
<thead>
<tr>
<th>E (Wh)</th>
<th>h (h)</th>
<th>Losses (%)</th>
<th>MRP (W)</th>
<th>V (V)</th>
<th>I (I)</th>
<th>Config</th>
</tr>
</thead>
<tbody>
<tr>
<td>(12111.12)/2</td>
<td>7</td>
<td>20</td>
<td>2400 / 2</td>
<td>40 x 6</td>
<td>7</td>
<td>2 x 6</td>
</tr>
<tr>
<td>(12111.12)/2</td>
<td>7</td>
<td>20</td>
<td>2400 / 2</td>
<td>40 x 6</td>
<td>7</td>
<td>2 x 6</td>
</tr>
</tbody>
</table>

5. CONCLUSION

The characterization tests of the two mentioned pump models were carried out even in summer, the results were more profitable than other seasons. In this study, the cloudy weather seasons are taken as reference. Mathematical study has been performed upon the following conditions: the maximum demand on water volume and low insulation.

The two mentioned solar pumps are very profitable for such PVPS installation in this desert region for both domestic water supply and irrigation.

To reach an optimum PVPS installation, it must be only require a livestock tank and an optimum PV array installation. Diminish the losses means reduction of the distance between the well and the tank, avoid the bad and long connection, keep clean the PV panel from dust and smokes and follow up the daily maintenance of the materials.

An evaluation of the PVPS station operation will be made for a period at least one year to determine the efficiency of the PVPS installation.

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