Study of Two Photovoltaic Water Pumping Systems (PVPS) Upon Real Characterization Tests of Two Different pumps (Ghardaïa site/Algeria)

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Abstract— The Algerian location around the equator, favourites the solar energy exploitation in water pumping, mainly in arid and semi-arid regions. The solar radiation covering the whole south and the average sunny day which ranges between 5h until 10h hours, as well as the abundance of high quantity of underground water make the photovoltaic water pumping systems (PVPS) an appropriate solution to supply water for domestic use and irrigation in large scale, especially in remote areas. Since the installation of a complete test bench in our lab, on March 2005, for promoting study in photovoltaic pumping, at Applied Research Unit of Renewable Energies/Ghardaïa. Several tests have been carried out to characterize different submersible PV water pump models: (Grundfos with nominal voltage V= 240–300V, I= 7A, P= 900 W). On 28th February 2007, about 40 m3 of pumped water has been reached, during 8 straight hours of pumping, for a head of 25m with an average flow rate of 5 m3/h at daily average solar irradiance of more 600 Wh /m2. (Water Max WA 64 with nominal voltage V= 64V, I= 4,6 A, P= 300 W), On 27th March 2007, after about 7 hours of pumping, a daily volume of 5m3 has been registered with an average flow rate of 0.700m3/h at daily average solar irradiance of about 700Wh/m2 for a head of 15m .Two study cases have been carried out to install two PV water pumping systems for the benefit of two farms with well heads 25m and 28m, respectively and 50 m3 daily cumulative water for each system, in Sebseb village about 60 km south west of Ghardaïa. Through simulation studies, it has been found that the power required to extract such quantity of water are approximately 3.4 kW and 2.8 kW respectively.

Index Terms— PVPS (Photovoltaic water pumping systems), Test bench, Arid and semi-arid regions

I. Introduction

Supply water for drink and irrigation in remote areas of sunny regions is one of the most attractive applications of PV water pumping systems (PVPS).

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Algeria is favourable country to use and promote this soft and clean energy over its large area. Because of its position, about 90% of the Algerian total area is classified as arid and semi-arid regions and more than 80% represents the desert part, which involves a wide remote area far away from the national electric grid network. The availability of solar radiation covering the whole region in large scale as well as the abundance of high quantity of underground water reservoir covering the heart of the Sahara permits to the PV water pumping systems (PVPS) to be the adequate solution to overcome the problem of the water need supply for rural and desert regions. Ghardaïa is the appropriate site to fulfil the above mentioned conditions. Two experimental studies have been undertaken to provide a daily volume of water for the profit of two farms, through the performance data of two different solar pumps recorded during the tests of characterization.

- Stationary laboratory measurements of two PV water submersible pumps models Grundfos and WaterMax, during the spring 2007.

Study and implementation of PV water pumping systems installation to irrigate two agriculture farms with daily water volume of 50 m3 for each farm

II. DESCRIPTION OF THE SITE AND LAB

A. *Characteristics of Ghardaia site*

Location: 600 km south of the Mediterranean Sea
- Latitude: 32° 36' N
- Longitude: 3° 81'E
- Elevation: 450 m, from the sea level
- Annual daily average of global solar irradiance ranges between 5 kWh/m^2 and 8 kWh/m^2 horizontal surface.
- Rate of sunny days per year: 77%

B. Stationary (PVPS) lab/ Ghardaïa site

The stationary PV water pumping lab installed at URAER/Ghardaïa site consists of a complete test bench assembled by the following parts:

Inside the lab:

- Stainless steel tank (artificial well), type acerinox 1.4301 2B / 034DC7, completed by hydraulic system which involve two flow meters, two pressure sensors and control valve to adjust the pumped water pressure.
- MPPT (300W) for low power
- DC/AC inverter for three phases pumps.
- Electrical panel display which displays the following parameters:
  - Current I(A)
  - Voltage V(V)
  - Temperature (°C)
  - Irradiance (W/m^2)
  - Pressure P1: simulated well head ranges from 0 to 160m.
  - Pressure P2: simulated well head ranges from 0 to 10m.
  - Pressure P3: static level of the tank (artificial well) ranges from 0 to 2.50m.
- Connexion box to select the different configuration (DC pump, three phase pump or DC pump via the MPPT).
- Data acquisition connected to PC

Outside the lab:

- PV generator composed of 110 watt/24V 26 Isofoton modules, implemented about 40m away from the lab, direction full south, inclination angle of 32°.
- Earth installation.

III- CHARACTERIZATION OF TWO PUMP MODELS (Grundfos MSF Model API 0433 and Watermax WA 64)

A- Stationary PV water pumping lab characterization:

Since the irrigation requirements depend upon crop contributions and efficiency of the distribution and field application system, as well as the domestic water use which depends on sufficient quantities to meet all requirements for drinking, washing and sanitation, the stationary PV water pumping lab characterization is necessary to meet all the conditions of measurements for such PVPS installation.

To complete such task, several water source parameters should be measured, these are the static head, distance between the tank and the borehole (well), the height of the tank or water outlet point above ground level, seasonal variations in water level and the rate of refill of the water well.

B- Method:

As each PV system , the solar water pump connected to a PV array continuously changes its operating point according to the unpredictable irradiance, therefore the control pressure valve position must be adapted continuously according to the actual irradiance to keep fix the selected depth. There is relation between pressure, flow rate and the static head, so the pressure at the delivery of the pump depends mainly in the static head so it is reasonable to control the pressure according to the flow rate. The daily cumulative water is registered by the flow meter

C- Configuration of the test

- Mounting of the pump in tank with adequate volume (friction is negligible).
- Pumping in closed loop
- Flow rate measurement with flow-meter
- Pressure measurement/ fix the selected head
- Actuator pressure/ flow rate control valve
- Recording data for simulation model

IV-RESULTS AND ANALYSIS

Total static head (TMH)	Daily cumulative water	Pumpin g hours number	Average flow rate per hour	Array configuratio n
(m)	m^3	Hour	m^3/h	In Isofoton modules 110W/24V
10	5.100	6	0.8351	2 modules in serial
15	4.620	6	0.7518	2 modules in serial
20	4.528	6	0.7389	2 modules in serial
30	3.256	6	0.5038	2 modules in serial
40	2.000	6	0.3421	2 modules in serial

Table. 1 Variation of the daily cumulative water for different heads- Watermax pump

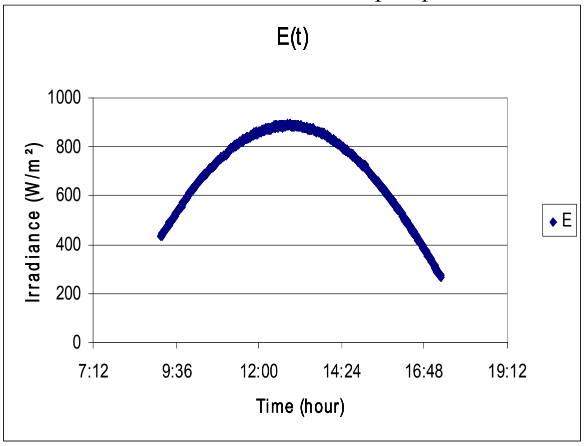

Figure 1. Variation of Irradiance– Water Max Pump--head=10 m, date: 26/03/2007

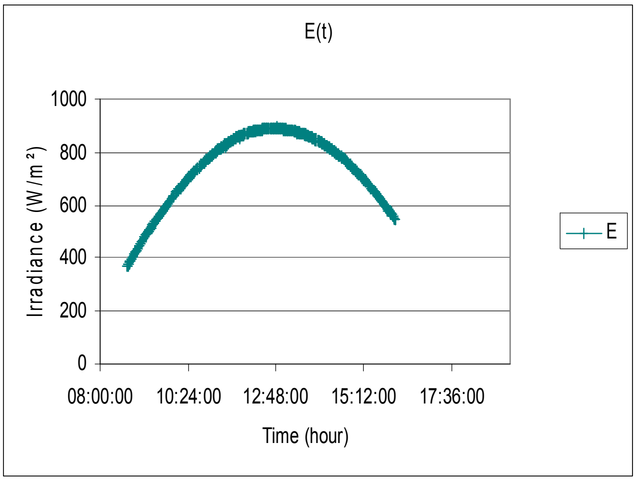

Figure 2. Variation of Irradiance– Water Max Pump- head= 40 m, date: 04/04/2007

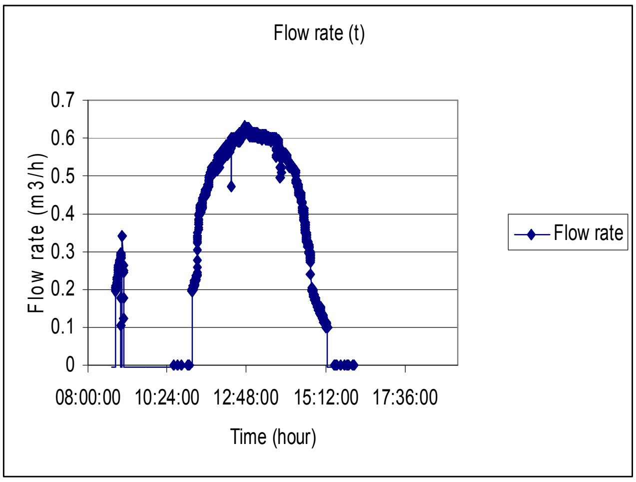

Figure 2. Variation of flow rate – Water Max Pump- head= 40 m, date: 04/04/2007

Recurrent tests carried out at different heads, for 8 straight hours of pumping, with the mentioned components (pump model, module type and array configuration) showed approximately the same results.
This model can be used in domestic water use (Drinking, washing and sanitation) according to the consumption, in region where the static heads don't exceed 40m for low power.

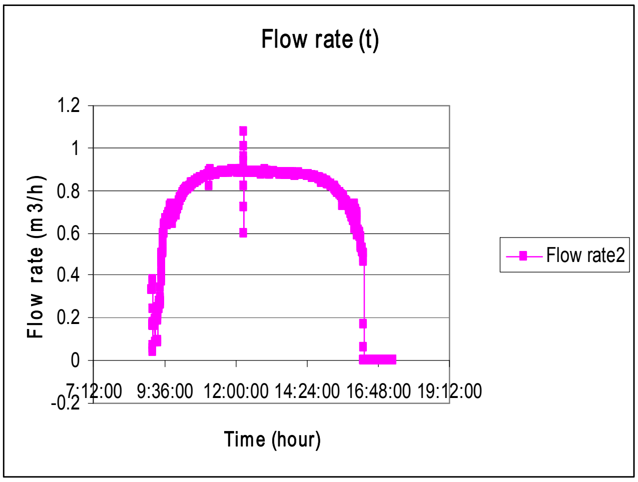

Figure 1. Variation of flow rate – Water Max Pump--head=10 m, date: 26/03/2007

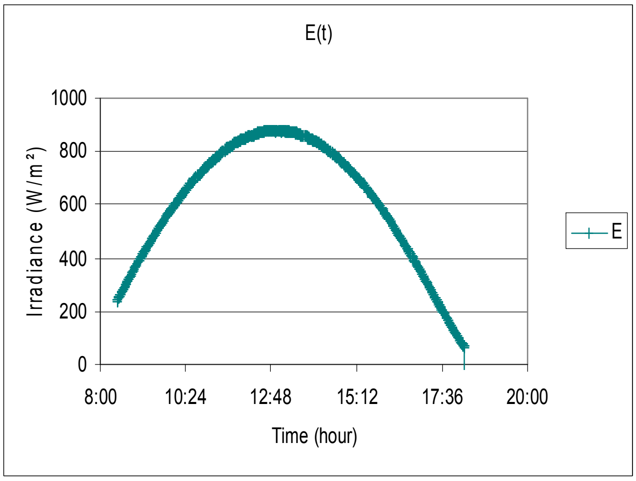

Figure 3. Variation of Irradiance– Grundfos Pump- head=25 m date: 28/02/2007

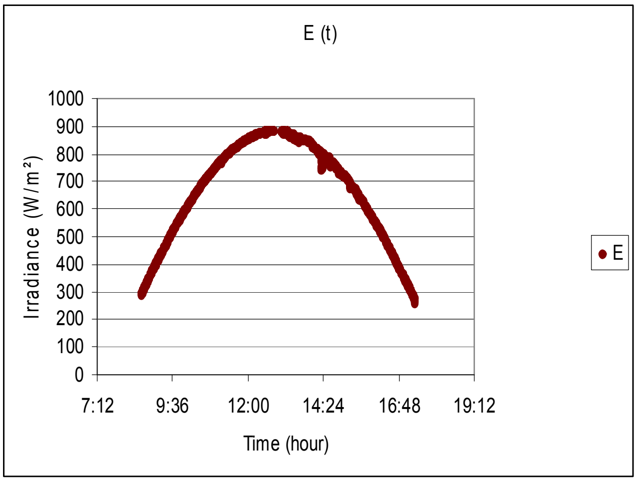

Figure 4. Variation of Irradiance– Grundfos Pump-head=25 m, date: 03/03/2007

Total static head TMH	Daily Cumulative Water	Number of Pumping hours	Average Flow rate	PV array configuration
(m)	(m^3/day)	Hours	(m^3/h)	Isofoton module 110W/24V
25	36.776	7	5.241	6x2
25	36.770	7	5.245	6x2
25	36.827	7	5.167	6x2
25	35.443	7	5.011	6x2
25	35.422	7	5.040	6x2

Table.2 Variation of the daily cumulative water for a head of 25m- Grundfos pump.

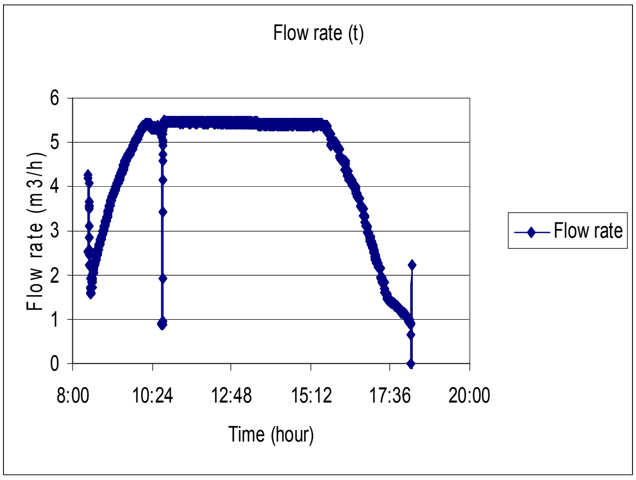

Figure 3. Variation of flow rate – Grundfos Pump- head=25 m date: 28/02/2007

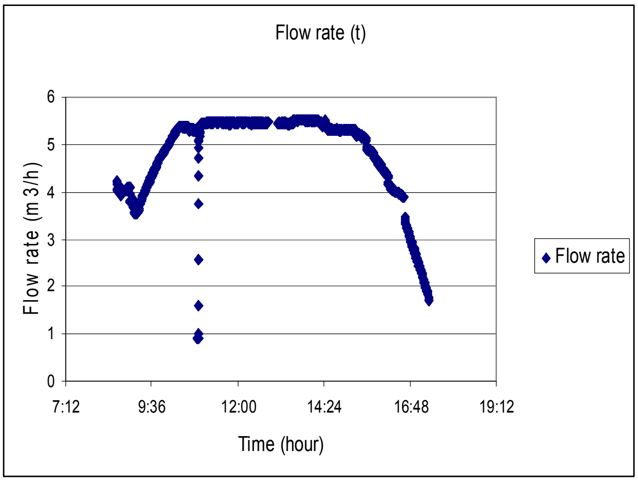

Figure 4. Variation of flow rate – Grundfos Pump-head=25 m, date: 03/03/2007

Total static head TMH	Daily Cumulative Water	Number of Pumping hours	Average Flow rate	PV array configuration
(m)	(m^3/day)	Hours	(m^3/h)	Isofoton module 110W/24V
20	39.128	7	5.871	6x2
20	40.224	7	5.935	6x2
20	41.330	7	5.966	6x2
20	39.284	7	5.769	6x2
20	40.040	7	5.987	6x2

Table.3 Variation of the daily cumulative water for a head of 20m- Grundfos pump- Spring 2007

For a fixed head of 25m, a daily cumulative water of 35m^3/day has been reached, approximately with an average flow rate of about 5m^3/h, during 7 straight hours of pumping. The delivered nominal power is assured by a PV 110W/24V Isofoton modules array with the configuration: 6x2.

For a well head of 20m, a daily cumulative water of about 40m^3/day has been reached, with an average flow rate of about 6m^3/h,during 7 straight hours of pumping

Total static head TMH	Daily Cumulative Water	Number of Pumping hours	Average Flow rate	PV array configuration
(m)	(m^3/day)	Hours	(m^3/h)	Isofoton module 110W/24V
30	25.600	6	6.140	6x2
30	27.467	7	4.092	6x2
30	29.567	7	4.167	6x2
30	27.886	7	4.043	6x2

Table.4 Variation of the daily cumulative water for a head of 30m- Grundfos pump- Spring 2007.

For a well head of 30m, we reached a minimum daily cumulative water of about 28m^3/day with Grundfos solar pump model at an average flow rate of about 4m^3/h.

V-APPLICATION

A- Study and implementation of PVPS for Driouche Farm

Technical data

Country: Algeria
Site: Driouche farm/ Sebseb: 60km south west of Ghardaïa (Ghardaïa site)
Application: Irrigation
Daily need cumulative water: 50m^3
Total Manometric Height TMH : 40m
Diameter of the borehole (diameter of the well): 1.80m
Static head: 22m
Dynamic head: 25m
Distance between the borehole (the well) and the tank: 200m
Elevation of the tank from the ground: 10m
Volume of the tank: 200m^3

The daily required hydraulic energy in (Wh/day) :

$$E = \frac{Ch.Q\ .TMH}{Rp}$$

Where:

Q : Required volume of water per day (m^3/day)
TMH : Total Manometric Height (m).
Ch : Hydraulic constant = 2.725,
Rp : Efficiency of the motor-pump group (30% - 45%), 40%

E= [2,725 x 50 x 40]/40%
E= 13625 Wh/day

Dimensioning of the field:

- Selection of the array inclination
- Estimation of the minimum monthly average solar radiation of global irradiance on a horizontal surface.
- Configuration of the field according to the available PV modules.

Yearly monthly solar radiation of Ghardaia site

Month	Average solar radiation on the Horizontal	Average solar radiation on the plan (0, 30°)	Max. Hours of solar radiation
	Wh/m^2	Wh/m^2	Hours
January	3871	5778	5.778
February	4842	6196	6.196
March	5926	6513	6.513
April	7339	7554	7.554
May	7745	7532	7.532
June	7812	7493	7.493
July	7503	7200	7.200
August	7090	7033	7.033
September	6036	6513	6.513
October	4824	5892	5.892
November	4026	5534	5.534
December	3437	**5180**	**5.180**

Table.5 Average solar radiation- Ghardaïa site –the year 2005

The lowest solar radiation average has been recorded during December

Estimation of the field power

$$Wc = \frac{E}{Nh.(1 - Losses)}$$

Nh: the lowest monthly number of sun- hours (1 sunhour = 1kWh/m²)
Losses.. estimated to 20% (dust and temperature)

Wc = 13625/5(1-20%) = 3406.25 W
Wc = 3.5 kW

Table of the field configuration

Q(m^3/day	Nh(hours)	Losses %	P(kW)	N° of Modules
50	5	20	3.4063	32
100	5	20	6.8125	62
150	5	20	10.219	94
200	5	20	13.625	124

Table.6 Ex: 110W/24V Isofoton modules for different daily cumulative water Q (m^3/day),TMH=40m).

B- Study and implementation of PVPS for Morsli Farm

With the same technical data except TMH=33m, it has been found that Wc= 2.8 kW

VI- CONCLUSION

Through the study of the results, obtained from the carried tests on the two mentioned solar pumps, during spring 2007, the energy demanded by the pump to provide the daily required volume of water can be extended for other seasons . The comparison of the recorded performances show that the Water Max solar pump model is suitable to supply water for daily domestic use , however the Grundfos solar pump model may be used to provide an important daily quantity of water to irrigate small scale fields. The study show that the optimum head is 25m , from which the pump can drawdown a daily quantity of water of about 50 m^3. The two solar pumps models are suitable to be exploited in PV pumping installations on the well of the Ghardaïa region and are efficiency for the south, about 140 km where the well heads lie between 5m and 10m.

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