Design and simulation of solar pumping system using PVsyst, case study: TSABIT - ADRAR in Algeria

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Abstract: *In isolated sites, the extension of the electricity network requires a very high capital cost. For agriculture work, irrigation is a necessity. A possible solution is using renewable energy sources like solar power, which is environmentally friendly and available for free. This paper presents the design and simulation of a photovoltaic water pumping system for irrigation of a farm located at a place named Tsabit in Adrar southwest Algeria. A detailed approach for the design of an optimized PV water pumping system based on real water usage data is proposed. Besides, system design work and performance assessment were carried out based on hourly climatic conditions. PV SYST software is used to carry out this work. A comparison was also made between two water pumping systems with and without use of a sun tracker. From the obtained results, the use of this kind of system could have an important contribution in the social and economic development of a country, especially in the presence of a sun tracker device, where we recorded more efficiency.*

Keywords: Solar pumping, *PV SYST Software, PV system, sun tracker device, storage power.*

1. INTRODUCTION

Pumping water for irrigation, domestic or animal use is a vital need for rural populations and farmers. Generally, the pumping of water is done by means of electric or mechanical motor pumps. In sites not connected to the electricity grid, farmers often have no other choice than diesel engines or, failing that, traditional methods: manually or by animal traction.

In agricultural applications, photovoltaic pumping is by far the most widely used. Now, photovoltaic solar power provides the electrical energy needed to operate a motor pump to draw water from depths of up to 350 meters.

Given the solar energy potential of the city of Adrar (radiation which can reach 7.34 [kWh/m2/d] in the summer), In addition to being an agricultural area par excellence. For these reasons we chose the city of Adrar to do this study.

The main objective of this article is to present in detail the solar pumping system, and its sizing. Then, we will do a comparative study by evaluating the performance between a pumping system without a solar tracker and another with a solar tracker, pumping water necessary to irrigate 10 hectares as well as domestic and animal uses in this farm.

The dimensioning will be carried out using the PVsyst software. PVsyst is software used for the study and simulation of photovoltaic systems initially developed by the Applied Physics Group (GPA) of the University of Geneva by Andre Mermoud. This software is considered a standard for the design and simulation of PV systems worldwide.

2. CONSTITUTION OF THE SOLAR PUMPING SYSTEM

The solar pumping system is generally composed of:

1. The photovoltaic generator;
2. The electric pump unit;
3. Command and control electronics;
4. The storage part if necessary.

PV Generator

The PV generator is a complete system ensuring the production and management of the electricity supplied by the photovoltaic collectors. The current generated by the panel is:

$$I_P = N_{sh} I_{ph} - N_{sh} I_0 \left[exp\left(\frac{q\left(V_P + \frac{N_s R_S}{N_{sh}} I_P\right)}{n N_S k T} \right) - 1 \right] - \frac{\left(V_P + \frac{R_S N_s}{N_{sh}} I_P\right)}{\frac{R_{Sh} N_s}{N_{sh}}} \quad (1)$$

$$I_0 = \frac{I_{sc}}{\left[exp\left(\frac{q.V_{oc}}{nkT}\right) - 1\right]} \quad (2)$$

Where:
V_P: Voltage of the photovoltaic panel [V];
I_P: Output current of the photovoltaic panel [A];
I_0: Reverse saturation current of the diode [A];
I_{ph} : Photocurrent [A];
q: Electric charge of the electron
$q = 1.602177 \times 10^{-19}$ [Coulomb];
k: Boltzmann constant, $k = 1.38 \times 10^{-23}$[J/°K];
n :Quality factor of the diode 1≤ n ≤ 2 [unitless];
R_{sh}: Parallel (shunt) resistance [Ω];
R_S: Series resistance [Ω];
V_{oc} : Open circuit voltage [V];
I_{sc} : Short-circuit current (At 25°C-1000W/m²) [A];
T: Operating temperature of the cell [°C];
N_S: Number of cells in series
N_{sh}: Number of cells in parallel.

The electric pump unit

A. Pump: A pump is a device for vacuuming and ejecting fluid. Water pumps are generally classified according to the principle of operation, either by positive displacement or centrifugation. In addition to those two classifications, there are also two other types of pumps according to the physical location of the pump relative to the pumped water: aspiration pump and discharge pump [1].

B. Engine: The motor of an electric pump unit converts electrical energy into mechanical energy. This can be continuous or alternating current. If the motor is alternating current, an electronic converter called an inverter is needed to convert the direct current coming from the photovoltaic generator into alternating current.

C. Command and control electronics: *The command and control device is ensured by an inverter or chopper.*

D. Storage: *Energy storage can be done in two ways: water storage (without battery) or electrical storage (with battery).*

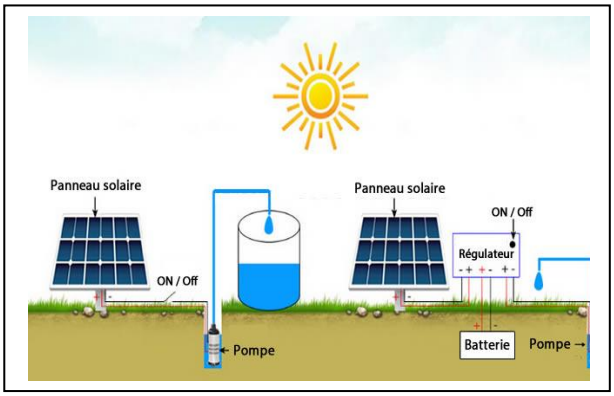


Fig. 1 Solar pumping without batteries and with batteries.

Sizing and modelling of the pumping system

The different stages of sizing up a pumping system are:
- ✓ *Estimation of daily water needs;*
- ✓ *Sizing and choice of the pump;*
- ✓ *Available solar energy and dimensioning of the photovoltaic field;*
- ✓ *Choice of components.*

A. Evaluation of daily water needs: For agricultural perimeters with large areas, the estimation of water needs must be carefully carried out.

Table 1 Specific consumption given by the OMS.

Human	Survival	5 l/day
	Minimum allowable	10 l/ day
	Normal living condition in Africa	30 l/ day
Animals	Beef	40 l/ day
	sheep-goat	51 l/ day
	Horse	40 l/ day
	Donkey	20 l/ day
	Camel	20 l/day (Reserve of 8 days)
Irrigation	Rice	100 m³/ day /ha
	Seeds	45 m³/ day /ha
	Sugar cane	65 m³/ day /ha
	Cotton	55 m³/ day /ha

There are several software and decision support tools that can be used. For example: "CROPWAT 8.0" and "the water needs assessment tool".
For small agricultural areas, water consumption can be estimated based on local practice and experience (socio-economic surveys) or based on consumption ratios established by international organizations such as the OMS “Tab.1”.

B. Pump sizing and selection:

- Determine the required flow and the HMT;
- Stop system configuration (type of pump, motor, etc.).
- Choose the nominal voltage at the output of the generator.
- Choose the type of electrical power conditioning needed and estimate the efficiency.
- Adjust the load to optimize efficiency and convert it to amp-hours per day.

Hourly pump flow Q_p en [m^3/h]

Is the amount of water that the pump can supply during a given time interval. In pumping, the flow rate is usually given in [l/h]. During solar pumping, the flow (or the water requirement) in [m^3/Day].

Storage capacity

The tank is not only used to store water, but it is also a flow regulator. Thus, the usable capacity of the reservoir will be determined so that it can store excess pumping during hours of low consumption and compensate for the deficit between pumping and consumption.

Static Level

It is defined by the level of static fluid in the well, distance from the ground to the water mirror. To find out this distance, you must do the following *[4]*:

a. About one hour before the measurements, stop the water intake from the well to restore its natural level;
b. Take a string of sufficient length and tie a small load to its end;
c. Lower the string into the hole until you hear a snap. The sound will indicate that the weight has reached the water;
d. Next, make a mark on the chain and remove it;
e. Lay the string on the floor and measure the distance from the end of the weight to the mark using a tape measure. The result will be the static water level value.

Dynamic level

This parameter is measured after a certain time of using the device and determines the distance from the water mirror to the surface of the ground. Measurements are made as follows:

- ✓ Turn on the pump and let it run for a few minutes. If you do not have this equipment, you will have to borrow it to take measurements;
- ✓ Tie a plastic bottle to the end of the rope with a little water. The bottle must serve as a float and not sink;
- ✓ Lower the bottle into the well (possible with the hydraulic machine running) and observe the cable. When the water decreases and stops at the same level, mark the string and remove it;
- ✓ Measure the distance to the mark. The result indicates the amount of water that falls when the pump is running. That is, you will know its dynamic level.

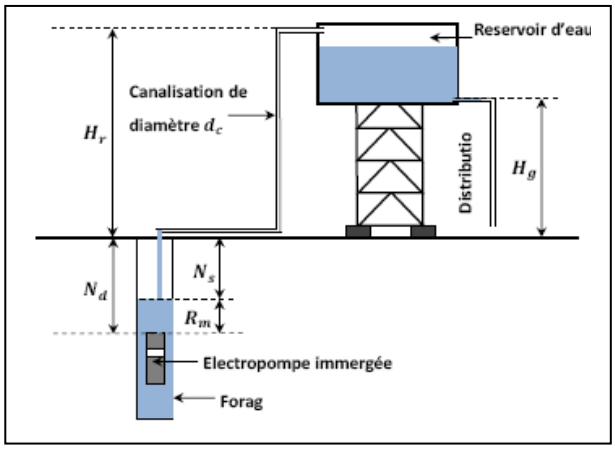


Fig. 2 Block diagram of the pumping system with water storage.

Where:
H_{hr} : Geometric height from the ground to the top plane of the tank [m];
H_{br} : Geometric height from the ground to the bottom plane of the tank [m];
N_s : The static level of the water table [m];
N_d : The dynamic level of the water table [m];
R_m : Maximum drawdown before stopping the pump (drawdown is the difference between the dynamic level and the static level [m].

Determination of the volume flow of the pump

$$Q_v = \frac{D_d}{H} \quad (3)$$

D_d : Peak daily demand
H : Number of hours of sunshine.
1 [kWh/m²] = 1 [hour]

Total manometric head HMT

The HMT of a pump is the pressure difference in meters of water column between the suction and discharge ports.

It is calculated using the formula:

$$HMT = H_a + H_r + P_c + P_u \quad (4)$$

H_a : Suction height corresponds to the height between the surface of the water and the axis of the pump and, it is a physical law, can never be greater than 8 meters. In the case of a submerged well or borehole pump $H_a = 0$.
H_r : Delivery height corresponds to the height between the axis of the pump and the highest point of delivery (for example, the highest tap);

$$H_r = H_{hr} + N_s \quad (5)$$

P_c : Average pressure drops in the pipes, which depend on the section and nature of the pipe (linear pressure drops), but also on the number and type of fittings (elbows, tees, junctions) present along the pipeline; they are commonly called "singular head losses". This is the resistance encountered by the water in the pipes. It is calculated according to the length, diameter, quality of the pipes, their shape and the number of accessories;

$$P_c = P_l + P_S \quad (6)$$

P_l:Linear load losses. It calculates in [Pa] (1bar=10^5 Pa, 1l=10^{-3} m³), the formula (pressure loss) of Darcy-Weibach (1857) can be used:

$$P_l = \chi \cdot \frac{L}{D} \cdot \rho \cdot \frac{{V_{ecol}}^2}{2} \quad (7)$$

P_S:Singular load losses.
P_{res} Residual pressure, the pressure at the outlet of the delivery pipe or the desired working pressure when the tap is opened. It is chosen on average around 1 bar, or 10.33 m at 2.5 bars, or 25.825 m of pressure. When the discharge is carried out directly in a tank $P_{res} = 0$.

Load losses expressed in [mCF]

$$P_l = \chi \cdot \frac{L}{D.g} \cdot \frac{{V_{ecol}}^2}{2} \quad (8)$$

$$V_{ecol} = \frac{Q}{S} \quad (9)$$

$$S = \frac{\pi D^2}{4} \quad (10)$$

χ: The pressure drop coefficient is a dimensionless coefficient. It depends on the Reynolds number. (Re) [unitless] [17; 115].

$$Re = \frac{V_{ecol}.D_{cond}}{\upsilon} = \frac{\varpi.V_{ecol}.D_{cond}}{\mu} \quad (11)$$

The calculation of head losses is based entirely on the determination of λ:

$$Re < 2000 \Rightarrow \text{laminar regime} \Rightarrow \chi = 64/Re$$

$$Re > 2000 \Rightarrow \text{turbulent regime} \Rightarrow \chi = 0.316.Re^{-0.25}$$

L : Length of the pressure line in [m].
V_{ecol}: Flow velocity in [m/s];
D_{cond} : Pipe diameter in [m].
υ : Kinematic viscosity; in [Pa.s]=[kg.m^{-1}.s^{-1}]
μ : Dynamic viscosity [kg/m.s];
ϖ : Density [kg/ m³];
S_{cond}: Pipe section [m²];
The singular head losses are calculated by the following formula:

$$P_s = \zeta \frac{{V_{ecol}}^2}{2g} \quad (12)$$

ζ: The sum of the singularity coefficients.

It is also possible to calculate the HMT, quite simply by taking the head losses of 10% to 15% of the geometric height H_g.

$$H_g = H_r - H_a \quad (13)$$

From where:

$$HMT = H_g + (10\% - 15\%)H_g + P_{res} \quad (14)$$

Calculation of the hydraulic power of a pump

$$P_h = Q.\Gamma.g.HMT \quad (15)$$

$$\Delta P = \Gamma.g.HMT \quad (16)$$

$$\Delta P = P_2 - P_1(1) \quad (17)$$

P_h : Hydraulic power of the pump [W];
P_1 : Suction pressure [Pa];
P_2: Discharge pressure [Pa];
Q: The daily water flow [m³/h];
Γ: Water density [1000 kg/ m³];
g: Acceleration due to gravity (9.81 m/ s^2).

Motor sizing

The useful power of the motor P_{uM} in [W] which will drive a pump is equal to:

$$P_{uM} = \frac{P_h}{\eta_P} \quad (18)$$

η_P : The efficiency of the pump ($0.4 \leq \eta_P \leq 0.8$).

C.Sizing of the photovoltaic field:

- ✓ Choose the optimum slope of the field.
- ✓ Determine the energy produced by the field at this inclination during the period of operation. Choose the least sunny moment (1 kWh/m^2 = 1 hour).
- ✓ Determine the approximate field effectiveness (losses due to temperature, cables, dust, optimal point imbalance, etc.).
- ✓ Estimate the capacity, in watts-peak, that the field must have.
- ✓ Determine field configuration, readjust according to module specifications.
- ✓ The operating point of the PV field is fixed by the choice of the motor pump unit and the inverter (converter).
- ✓ Determine the operating voltage of the field and choose the number of modules in series.
- ✓ Calculate the operating field strength and determine the number of modules in parallel required.
- ✓ Recalculate the power of the PV field, according to the type of module chosen and the configuration stopped.

Calculation of the power required for a solar installation

$$E = \frac{E_{day}}{\eta . \varepsilon} \quad (19)$$

E : Energy produced by solar [kWh/day];
E_{day} : Hydraulic energy required per day;
η : The efficiency of the hydraulic pumping system;
ε : Electrical efficiency.

Consideration of system efficiencies

Example:

A pumping system is designed for a water production of 60 m^3/day at a total head of 10 meters. The hydraulic energy required E/day is therefore :

60 * 9.81 * 10/3600 = 1.635 kWh per day.

If the hydraulic efficiency of the pump is 60%, this means that the input energy is:

1.635 / 60% = 2.725 kWh / day.

If the overall electrical efficiency is 40%, the network must produce:

2.725 / 40% = 6.8125 kWh/day.

A list of hydraulic and electrical efficiencies is shown in the following table:

Table 2 Hydraulic and electrical efficiency.

Element	Efficiency	Observation
Pump, hydraulic part	60%	Depends on type, curve and load
pump motor	70%	Take average pump load
Cables	98%	Depends on cable diameter, length and material
Converter	90%	Depends on type

Orientation and tilt of the solar modules

I: the tilt is the angle between the plane of the solar panel and the ground.
O: Orientation is the angle between the solar panel and the due south axis.

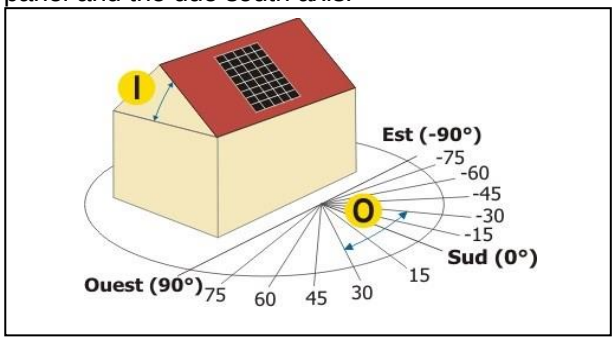
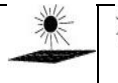


Fig. 3 Representation of inclination and orientation.

Table 3 Summary of efficiencies according to the azimuth of a solar panel.

Tilt / Orientation				
	0°	**30°**	**60°**	**90°**
East	93%	90%	78%	55%
South East	93%	96%	88%	66%
South	93%	100%	91%	68%
South West	93%	96%	88%	66%
West	93%	90%	78%	55%

Sunshine available and sunshine used

Table 4 Efficiency related to sunshine and the solar panel.

Element	Efficiency	Observation
Tilt	105%	Calculate
Morning-evening effect	80%	Only for centrifugal pumps, depends on HMT
dust and reflection	90-100%	Depends on their cleaning
Age of panels	80-100%	Decreases with age

With these efficiencies, one can calculate what proportion of the sunshine is actually used. For example, if the insolation during the most critical month is 5.58 kWh/m²/day, and the combined effects of morning and afternoon, dust and reflection, and age panels show 71% efficiency, this means the available sunshine is:

5.58 * 71% = 3.96 kW/m² day.

Temperature correction

Table 5 Temperature losses.

Element	Efficiency	Observation
Temperature losses	85%	Calculate

Example:

If the network must produce 6.8125 kWh/day, and the efficiencies are as presented in the tables (inclination 105%; morning-evening 80%; dust and reflection 95%; the age of the panels 80%; temperature 85%), the total network efficiency is 54.3%. The power to be installed is therefore:

6.8125 / 54.3% = 12.554 kWh/day.

Calculation of number of solar panels

The calculation of the number of panels to be placed in series and in parallel is given by:

$$N_{Ps} = \frac{U_{umod}}{U_{mod}} \quad (20)$$

$$N_{Psh} = \frac{P_{cmod}}{P_{mod} * N_{Ps}} \quad (21)$$

The number of solar panels to be installed is then:

$$N_{PT} = N_{Ps}.N_{Psh} \quad (22)$$

The efficiency of a solar panel is given by:

$$\eta = \frac{P_{mod}}{G_{PV} * S_{mod}} \quad (23)$$

The power of a panel is:

$$P_P = \eta G_{PV} S_{mod} N_{PT} \quad (24)$$

G_{PV}: The global radiation in the plane of the PV generator [W / m²];
S_{mod}: Surface of a single module [m²];
U_{umod}: Useful module voltage [V];
U_{mod}: Module voltage [V];
P_{mod}: Module power [W].

D.Reservoir sizing: *The tank volume is calculated by the following formula:*

$$V = \pi.\frac{d^2}{4}.l \quad (25)$$

V: The volume of the tank [m³];
d: The diameter of the tank [m];
l: The height of the tank [m].

Pipe sizing

Using Bresse formula:

$$D = K_{\text{tuy}} \sqrt{Q_{\text{crête}}} \quad (26)$$

D: Pipe diameter [m];
K_{tuy}: Coefficient which varies from 0.75 to 1.4;
$Q_{\text{crête}}$: Peak flow of the pump [m³/h].

$$Q_{\text{crête}} = \frac{\pi\, D^2}{4}\, v \quad (27)$$

v : Mean fluid velocity.

E.Choice of components:

Pump type selection criteria:

- HMT <25 m³/day: hand pumps may be more interesting.
- For heights of less than 7 meters, the use of suction pumps will be preferred.
- For low flows and variable available power (for example, wind coupling), the use of a cavity pump (volumetric) allows a more constant flow.
- For an average HMT, between 10 and 50 meters, the centrifugal submersible pump is generally the most efficient. But its performance is very closely linked to HMT and its sizing is critical.
- For HMT greater than 35 meters and low daily flows (< 20 m³), the volumetric pump will be used the most, especially if a strong variation in the drawdown of the water table (therefore of the HMT) is observed.
- For higher flow rates, the use of a centrifugal pump is often the only possible choice.

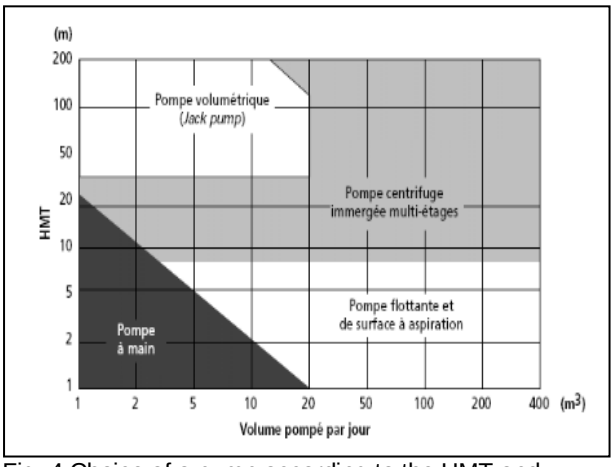


Fig. 4 Choice of a pump according to the HMT and the flow requested.

3. SIMULATION AND RESULTS

The comparative study was made between two cases:
Case 1: without a tracker, fixed inclined plane (the inclination is 30°);
Case 2: With a tracker, inclined axis, the Azimuth is 45°; the inclination of 10° and the limit of rotation -60°/60° (- towards the east, + towards the west).

Determination of water needs

The monthly average daily water requirement is 604 m^3/Day.
According to the survey that we carried out, the static level of the locality of Tsabit is 41 mCE. The geographical coordinates of the site studied:

Table 6 Geographical coordinates of Tsabit.

Locality	Tsabit, Adrar, Algeria.
Altitude	249 m above sea level
Latitude	28.3505° or 28° 21' 1'' North
Longitude	-0.2240 or 0° 13' 26'' West

Hydraulic pumping circuit

Water storage is carried out by means of a reservoir in order to irrigate an area of 10 hectares.

- Borehole:

Table 7 Borehole characteristics.

Static level	Drawdown [mCE]	Maximum flow [m3/h]	Minimum dynamic level [m]	Pump level [m]	Borehole diameter [cm]
41	24.2	120	65	76	100

- Tank characteristics:

Table 8 Tank characteristics.

Volume[m3]	Diameter[m]	Height [m] Injection	altitude [m]
604	12.40	5	8

Determination of hydraulic power

$$P_h = 2.725 * Q * HMT$$
$$P_h = 2.725 * 101.879 * 70.2$$
$$P_h = 19.489\ kW \quad (28)$$

Choice of pump

Characteristic of the pump:

- Model: Grundfos_SP95_7.PMP;
- Pump technology: Multi-stage centrifugal;
- Type of pump: Submerged;
- Maximum power: 30 kW;
- Flow rate: 20 m^3/h;
- Minimum MPP voltage: 400 V;
- Maximum MPP current: 45.6 A;
- Maximum height: 46-142 m;
- Efficiency: 57%.

Choice of converter (inverter)

Characteristic of the inverter:

- DC input voltage: 470 V;
- Rated output current: 75 A;
- Minimum output voltage: 400 V;
- Maximum field voltage: 926 V;
- Maximum input current: 45.6 A;
- Rated output power: 30 KW;
- Threshold power: 300 W;
- Efficiency: 97%.

PV generator

Characteristic of the PV module:

- Model:Si-mono, JKM585M-7RL4-V monocrystalline;
- Manufacturer: Jinkosolar;
- Number of cells: 156 (78 in series, 2 in parallel);
- $P_{mpp} = 585.1\ W$;
- $I_{mpp} = 13.21\ A$;
- $V_{mpp} = 44.3\ V$;
- $I_{CC} = 13.91\ A$;
- $V_{CO} = 53.4\ V$;

- Efficiency: 21.40%.

The simulations were made with the same pumping system with a power equal to 35 kWp. It consists of 60 modules, 4 chains and 15 panels in series with a unit panel power of 580 Wp, the area occupied by this system is 164 m^2. The inverter chosen is the MPPT-AC type with a nominal power of 30000 W AC, with a fixed input voltage of 460V and maximum input current of 45.6 A. The maximum field voltage is 926 V.
In this work, the meteorological data used are those recorded at the Meteonorm 8.0 station (Meteonorm is a global meteorological database. It is a very complete collection of meteorological data. It also contains algorithms for creating – from the measured values – weather files from anywhere on the globe).

Without a sun tracker
With a sun tracker

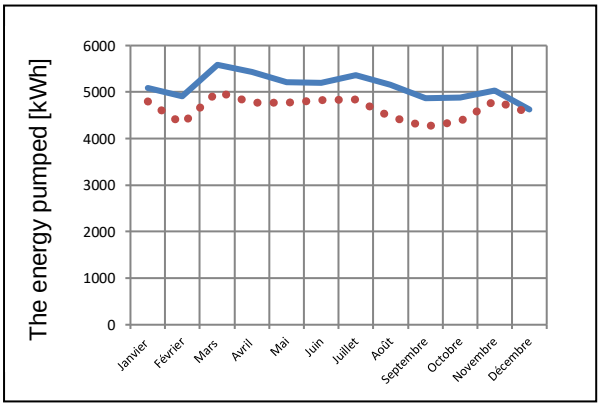


Fig. 5 The energy pumped during a year for the system without and with a sun tracker [kWh].

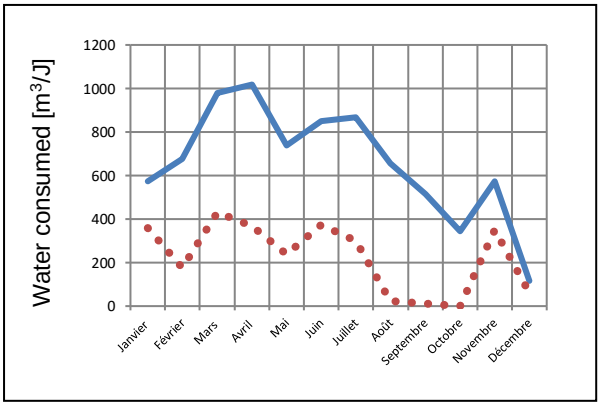


Fig. 6 Quantity of water consumed during a year for the system without and with a sun tracker [m^3/J].

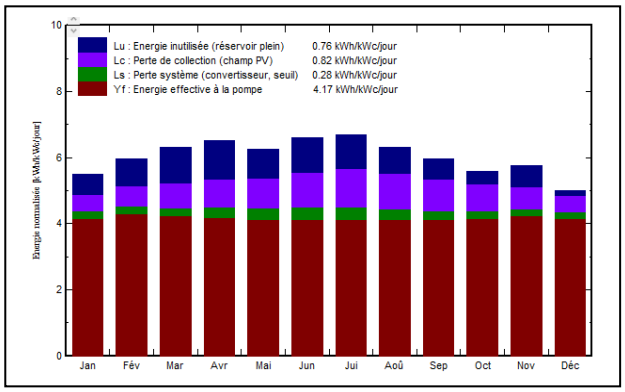


Fig. 7 Energy losses; collection losses in PV system; converter losses and efficient energy at the pump during a year for the system without a sun tracker.

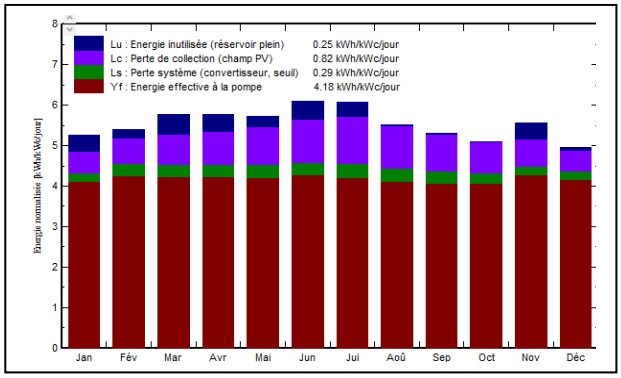


Fig. 8 Energy losses; collection losses in PV system; converter losses and efficient energy at the pump during a year for the system with a sun tracker.

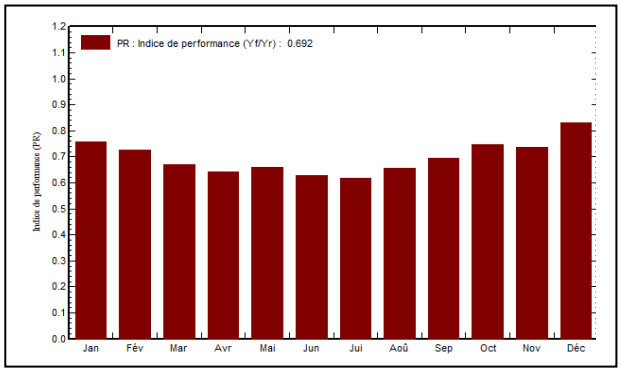


Fig. 9 Performance index during a year for the system without a sun tracker.

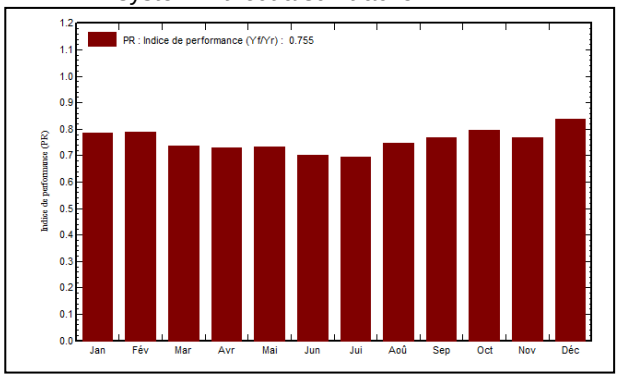


Fig. 10 *Performance index during a year for the system with a sun tracker.*

From fig.07 and fig.08, the losses *Lu, Lc, Ls* and *Yf* are respectively: the energy losses; collection losses in PV system; converter losses and the energy used by the pump.

Lu losses are the unused energy when the reservoir is full. According to the variation of *Lu* during the year,the amount of unused energy is lower in summer and higher in winter and this is due to climatic conditions (As temperature increases, the rate of evapotranspiration increases). On the average, it is a round 0.61 kWh/day for the system without a sun tracker compared to 0.25 kWh/day for the system with a sun tracker. The improvement registered is 0.36 kWh/day.

Lc losses are the irradiance losses of photovoltaic modules . *Lc* are low from November to March, and they are more important in the other months of the year, they are linked to the solar deposit of the locality. On the average, *Lc* losses are worth 0.98 kWh/day for the system without a tracker and is about 0.82 kWh/day for the system with a tracker. It has been shown that the energy lost is reduced by a round of 0.16 kWh/day in the presence of a sun tracker.

The losses *Ls* are due to the converter used. It is of the order of 0.31 kWh/day for the system without a tracker and 0.29 kWh/day for the system with a tracker. Hence, the reduction in losses is in the order of 0.02 kWh/day.

Concerning Yf , which represents the energy used by the pump, we note that the energy is reduced from 5.08 kWh/day for the case without a sun tracker to 4.18 kWh/day for the case with a sun tracker.

According to the results of simulation shown in figures 5 to 10, we can establish the following table for summarizing and comparing different parameters simulated in this paper. Where we can note that ,the good performances are registered in the presence of a sun tracker.

Table Comparison of the main parameters.

Performance	Without a tracker	With a tracker
PV system efficiency	81.9 %	89.2 %
Pump efficiency	74 %	73.7 %
Unused energy	12.9 %	4.8 %
Performance index	69 %	76 %

4. CONCLUSION

The study was made for two cases of the orientation of the solar panels, without sun tracker and with sun tracker device. The comparative study showed that both cases are well dimensioned under PVsyt. We have noticed a great improvement in productivity in the presence of a sun tracker.

Except that, sun trackers are slightly more expensive than their stationary counterparts, due to the more complex technology and moving parts required to operate them.

Even with advances in reliability, maintenance generally requires more maintenance than a traditional fixed track, although the quality of the solar tracker can play a role in the amount and frequency of this maintenance.

Through our study, we can confirm that, irrigation with solar energy has become a vital necessity that must be adopted to irrigate agricultural areas, especially in the southern region of our country.

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