1. Fatima BELGACEM[1], 2. Mohamed MOSTEFAI[2], 3. Yahia MILOUD[2], 4. Aicha BELGACEM[1]

Laboratoire Génie Electrotechnique, University of Saida, Algeria (1)
Laboratoire Géométrie, Analyse, Contrôle Et Applications, University of Saida, Algeria (2)
ORCID: 1. 0000-0003-4415-600; 2. 0000-0003-3675-5854

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A Comparative Technical-Economic Study of two Water Pumping Systems for an Isolated Community in Algeria

***Abstract**. The objective of this study is to size a photovoltaic pumping system based a brushless direct current motor without storage batteries, then analyze its cost by comparing that last with a pumping system fed by diesel generator for an irrigation system in a remote site in Saida city in Algeria, relying on a method called the life cycle cost. The water pumping system is designed to irrigate an area of 8 hectares, planted with onions. Based on the results of this study, the photovoltaic pumping system is more economically viable when compared with the system running on diesel.*

Streszczenie**. Celem tego badania jest zwymiarowanie fotowoltaicznego systemu pompowego opartego na bezszczotkowym silniku prądu stałego bez akumulatorów, a następnie przeanalizowanie jego kosztów poprzez porównanie tego ostatniego z systemem pompowym zasilanym przez generator diesla dla systemu nawadniającego w odległym miejscu w mieście Saida w Algieria, opierając się na metodzie zwanej kosztem cyklu życia. System pompowania wody przeznaczony jest do nawadniania obszaru 8 hektarów obsadzonych cebulą. Na podstawie wyników tego badania, fotowoltaiczny system pompowy jest bardziej opłacalny ekonomicznie w porównaniu z systemem zasilanym olejem napędowym.* (Porównawcze studium techniczno-ekonomiczne dwóch systemów pompowania wody dla odizolowanej społeczności w Algierii***)

Keywords: Economic Analysis; Photovoltaic Pumping System; Diesel generator; Life Cycle Cost.
Słowa kluczowe: system pomp, zasilanie fotowoltaiczne.

Introduction

Demand for energy and the inevitable future depletion of conventional sources requiring research into alternative sources, such as renewable energies. Solving the problem of water in isolated sites plays a very important role in the irrigation in the vast Algerian territory [1].

Recently in Algeria, farmers are tending to use traditional diesel pumps for irrigation. However, access to electric networks is limited in remote areas. Solar irrigation pumps provide a great opportunity in that areas where have a shortage in electric networks without relying on conventional diesel or traditional electrical pumps, because Algeria has the most significant solar irradiation, with an average of 5 kWh / m² / d over the whole territory [2].

Photovoltaic water irrigation pumping system is an applied technology in many countries since 1977. Due to the convenience of this technology, it has a rapid development in order to suffice water demands discharged out of wells into far flung areas in Africa, Asia and South America [3].

Numerous researchers have detailed a comparative economic analysis of water pumping by diverse methods.
In India, Purohit et al [4] made an effort to improve a simple structure for techno-economic evaluation of systems for irrigation water pumping, and Shiv et al [5] presents a Techno-Economic study of solar photovoltaic based submersible water pumping system for Rural Areas of an Indian State Rajasthan, where they present a fuel replacement and reduction of carbon dioxide on an annual basis and economic analysis of photovoltaic based water pumping system.

The main objective of the work of Elham Mahmoud et al [6] is to prove that PV with battery systems can be utilized efficiently and effectively for water pumping, the price of the PV water unit pumped is much lower than that system using diesel and the water charge is more sensitive to PV cells' prices than their life-time periods.

According to [7-8], the operation of a generator set can degrade the quality of water and soil, has countless consequences for our health, our environment and our economy, and that the pumping by photovoltaic solar energy does not necessarily allow the flow to be instantly adapted according to the needs which vary according to the seasons and which may change over time, they found that the Photovoltaic Pumping (PVP) systems has in its favor many advantages, it is more reliable than Diesel Pumping (DP), no fuel supply.

Users prefer to use the traditional and conventional means, such as diesel. However, the support of the price of the fuel by the state makes the use of the water pumping by the diesel genset more attractive and then limiting the emergence of the solar energy even in favorable zones. [9]

The aim of this paper is to present an economic study and sizing of PVP system in a remote site in Saida city in Algeria.

Saida is not considered a desert or a hill in terms of climate, what sets it apart is the lower temperature compared to the desert and this property has a positive effect on the efficiency of the Photovoltaic Generator (PVG). Despite this particular physical setting, the consumption of solar energy is not generalized due to the lack of sensitivity of the populations and their tendency to use conventional energy sources such as generators.

To meet the irrigation needs of onion farming, an economic analysis for using PVP systems to replace diesel system takes place in this work, taking into consideration the site's physical condition and the water demand, the PVP system considers: Brushless Direct Current (BLDC) water pump fed by PV solar energy in the presence of the sun. This analysis is based on a method called the life cycle cost (LCC) where a cost analysis should include the cost of financing as well as the present value of operating costs, maintenance and replacement over the expected life of the pumping system.

Table 1. List of symbols

Symbol	Designation
Q	flow rate the of the pumping is 20 m^3 per hour
T_{pum}	daily functioning time is 6 h
H_{mt}	Manomeric height is 110 mca.
P_e	Electric power required by the pump (*W).*
C_h	Hydraulic constant
η	efficiency of moto-pump
g	Earth's gravity is 9.81 m/s²
ρ	Water density is 1000 Kg/m^3
V_{bass}	The volume tank is 40m^3

Notation

The notations used throughout the paper are resumed in table 1.

Site characteristics

Saida is geographically located in the northwest of Algeria with the coordinates latitude 34.87 N and longitude 0.15'E.

Saida benefit from a very significant irradiation greater than 6000 Wh/m^2 per year for which the use of PV water pumping system can be considered with strong chances of success [10].

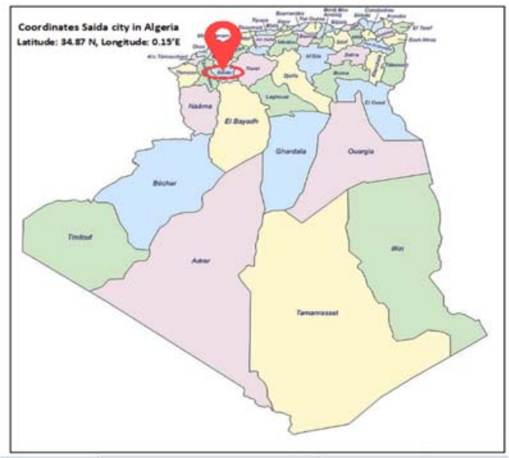

Fig.1.Location of Saida city in Algeria

Fig.2. shows the monthly solar radiations in the horizontal surface of Saida city. These measurements of solar radiation are mainly carried out in our laboratory. In this figure the maximum monthly of global radiations observed is 4.98kWh/m² per month in summer. In autumn and winter it is found respectively 3.99kWh/m² per month and 2.9kWh/m² per month [10].

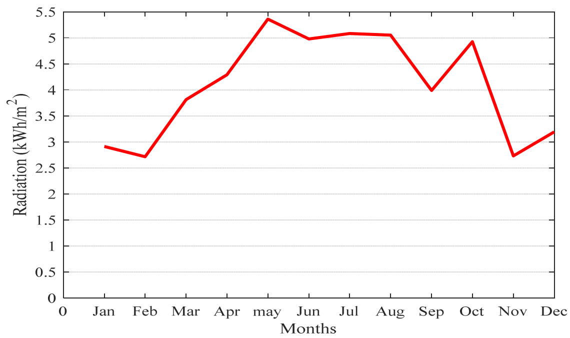

Fig.2. Example of solar radiations in Saida city during the year 2016

Case study

The water pumping system is designed to irrigate an area of 8 hectares of onion farming during 4 months from Mai to August, this area was divided into five parts, each of them being irrigated for 6 hours per five days from 10am to 4pm which is an opportunity not to use an energy storage (Pumping over sun).

A schematic representation of the pumping system is shown in Fig.3 and Fig.4, where they describe the components of both pumping systems.

Solar energy will be captured by means of photovoltaic panels and converted into electricity [11], which will power the BLDC motor and will turn on the water pump that will pump the water from a well with depth of 100m to the tank that has a height of 10m from the ground allowing irrigating one-fifth of the agricultural piece without a pump as it is presented in Fig. 3.

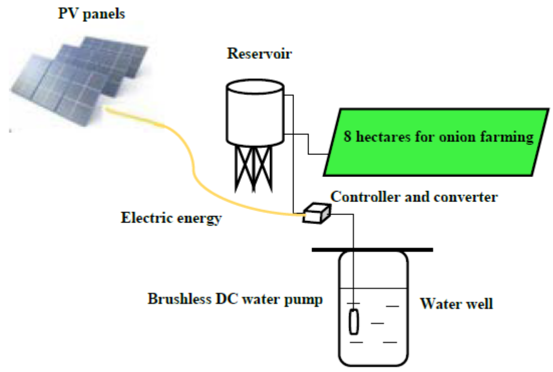

Fig.3.Schematic representation of the PVP system using BLDC motor.

The other motor is powered by diesel generator and will turn on the water pump in this same way (Fig.4.).

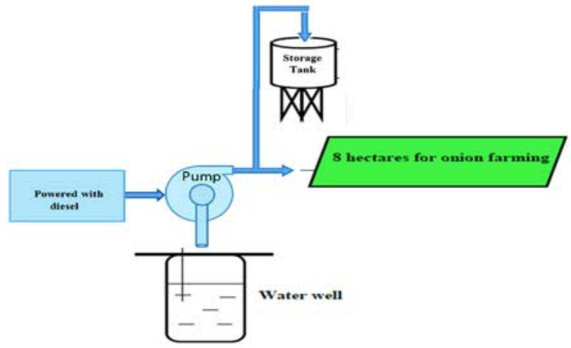

Fig.4. Schematic representation of the pumping system using diesel generator

Dimensioning the system

The electric power required by the pump was determined by [12]:

(1) $$P_e = \frac{C_h.Q.H_{mt}}{\eta}$$

The hydraulic constant is calculated by the flowing equation:

(2) $$C_h = \frac{g.\rho}{3600}$$

For sizing the photovoltaic generator, it is necessary to calculate the electrical energy E_{el} consumed during pumping time in a day [13].it can be calculated by:

(3) $$E_{el} = P_e.T_{pum}$$

The pumping time T_{pum} can be calculated by:

(4) $$T_{pum} = \frac{V_{bass}}{Q}$$

The energy produced by a photovoltaic field E_p is equal to:

(5) $$E_p = \frac{E_{el}}{K}$$

with: K –the correction coefficient depending on the meteorological uncertainty, the inclination of the solar modules and the overall efficiency of the photovoltaic system. [14,15].
The peak power of the photovoltaic generator P_c is calculated as follows:

$$P_c = \frac{E_p}{G} \tag{6}$$

Where: G – the average daily irradiation.
The total number of photovoltaic modules N_{Tot} is calculated by relating the overall power of the field P_{PV} to that P_{mod} of a single module:

$$N_{Tot} = \frac{P_{PV}}{P_{\mathrm{mod}}} \tag{7}$$

The table 2 summarizes the sizing results, it is as follow:

Table 2. Dimensioning results

Efficiency of moto-pump (%)	52.25
Electric power required by the pump P_e (W)	11500
Electrical energy E_{el} (Wh/j)	23000
Energy produced by a photovoltaic field E_p (Wh/j)	38333
The peak power of the PVG Pc (W)	6389
Photovoltaic modules number N	20

Economic Analysis of the pumping system

To assess the discounted overall cost of m^2 pumped water, it is necessary to have certain data, to know [16]:

- The lifespan of each component.
- The cost of the initial investment.
- The cost of the annual maintenance relating to the photovoltaic system.
- The cost of the different subsystem replacing.

From the investor's perspective, the present cost of pumping system allows cost comparison between different options. Its importance is linked to the fact that some options require large initial investment and operating costs and relatively low maintenance, while others present the opposite situation. In these conditions, a cost analysis should include the cost of financing the capital as well as the present value of operating costs, maintenance and replacement over the expected life of the pumping system. This analysis is called the lifetime cost calculation (life cycle cost) [17, 18,19].

In this part, an economic viability comparison between the PVP system and the Diesel pumping system is presented. To evaluate the LCC of the pumping systems, the different subsystems replacing cost is ignored.

Calculation of the total initial investment costs

The initial investment lets the user know what price they will have to pay when installing their system.
The total initial investment I_{Tot} is the addition of components costs [20]:

Table 3. Total initial investment of pumping systems.

Total initial investment	Costs($)
PVP system	6039.65
Diesel pumpimg system	5515.75

Calculation of lifespan costs

The annual global cost of the present value is calculated by the following expression:

$$C_{GA} = C_{Tot} + M_{Tot} \tag{8}$$

with: C_{Tot} – the total consumption, M_{Tot} – the total maintenance.

Calculation of total consumption costs

To calculate the cost of energy taking into account the consumption over time, the component lifespan as well as the benefits realized over the entire active life of the system [20 21], the total annual consumption of the system C_{Tot} is the addition of components consumptions.

For each component, the consumption is calculated as follows:

$$C = \frac{I}{L} \tag{9}$$

with: I – the cost of the initial investment of each component, L – the lifespan of the component. Lifespan is estimated for each of the elements of the system, are given below:

Table 4. Estimates of component lifetimes.

Equipment	Lifespan (year)
PVG	20
Diesel	7
Electric pump	7
Boost converter	7
Accessories	20

The total annual cost consumption of the two pumping systems (diesel and PV) is given in table 5.

Table 5. Total annual cost consumption of pumping systems.

Total consumption	Costs($)
PVP system	519.25
Diesel pumpimg system	995.16

Calculation of the total annual maintenance costs.

Despite the reliability of solar pumps, it is essential to ensure their proper functioning through periodic maintenance. Since the initial assumptions may be different, the cost of maintenance is very difficult to assess over time. To calculate an average annual cost, the most reasonable approach is based on real experience in the field which, as theoretical as it is, would give a realistic order of magnitude [21].

The calculation of the total annual maintenance cost M_{Tot} of the system is the addition of components maintenance costs.

Knowing that the cost of maintaining each component is calculated as follows:

$$M = I \cdot R \tag{10}$$

with: I – the cost of the initial investment of each component, R – the ratio of estimation between the cost of maintenance and the initial investment of the components, it is estimated 2%.
The evaluation of the annual cost of maintenance M of diesel is determined by the following expression:

$$M = \frac{I_D \cdot NH.5}{100} \tag{11}$$

Where: I_D – Diesel cost, NH – Number of hours of operation of diesel.
The total annual maintenance of the PVP and diesel systems is shown as follow:

Table 6. Total annual maintenance of pumping systems.

Total annual maintenance	Costs($)
PVP system	120.79
Diesel pumpimg system	1394.91

Calculation of the total annual operating costs

The operating cost of diesel is assessed on the basis of the data relating of the electrical characteristics plate as well as the fuel and lubricant consumption of diesel.
The total annual operating cost C_{Fl} is calculated by the formula [20]:

(12) $$C_{Fl} = C_F + C_l$$

Where: C_F – Fuel cost, C_l – Lubricant cost.
Knowing that, on the one hand:

(13) $$C_F = (P.Cons / year) + (D.C_{Tr})$$

Where: P– Liter fuel price, $Cons/Y_{ear}$ – Annual Fuel consumption. On the other hand, the cost of lubricants C_l is calculated by:

(14) $$C_l = \frac{(P.Cons/year).20}{100}$$

The total annual operating of the two pumping systems (diesel and PV) is given in table 7.

Table 7.Total annual operating of pumping systems.

Total annual operating	Costs($)
PVP system	0
Diesel pumpimg system	5919.78

Results and Discussion

The LCC analysis allows cost comparison between different options. Its importance is linked to the fact that some options require large initial investment and operating costs and relatively low maintenance, while others present the opposite situation.

It was found on fig.5 that PV pumping system (PVP) has an important part of the cost of investing equipment relative to other costs, as maintenance, on the other hand, the operating costs are zero.

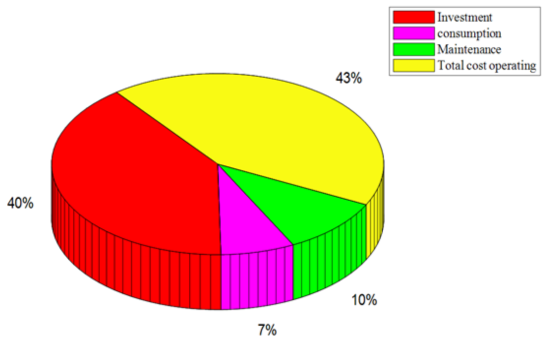

Fig. 5. Distribution of the costs of the diesel pumpimg system

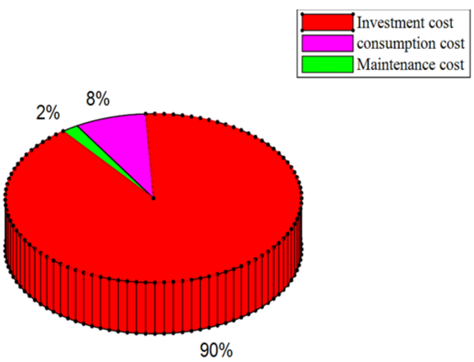

Fig 6. Distribution of the costs of the PV pumping system.

For Diesel pumping system (DP), maintenance costs are not negligible compared to the cost of the total system investment and the total operating cost (see Fig. 6).

By comparing the costs of the two pumping systems fed differently, it was noted in Fig.7 that the solar photovoltaic pumping systems constitute an important part in the cost relating to the investment of the equipment by compared to other costs, such as consumption and maintenance, on the other hand the operating cost being zero. Regarding pumping systems using a diesel generator the costs of maintenance and operation are not negligible compared to the cost of the investment.

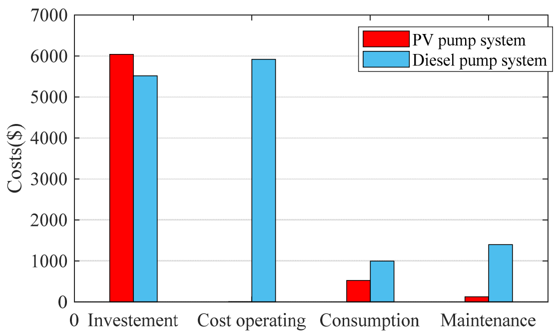

Fig 7.Comparative cash flow for the two systems using LCC analysis method

From the analyse results, it is noticed that the PV system has a much higher initial cost than that of the system with Diesel; the "weak point" of the photovoltaic pumping solution remains the initial investment.

It was found that the Diesel pumping system global cost is higher than that of the PVP global cost for irrigation in Saida, this can be explained by the fact that this system doesn't have operating cost. While the global PV pumping system cost is 6679.69 $ the DP system is 13825.60 $. (Table 8).

Table 8. Global cost of pumping systems

Global cost	Costs($)
PVP system	6679.69
Diesel pumpimg system	13825.60

On the other hand, the solar energy is a clean and renewable energy contrary to diesel generators which cause noise and produce gases.

Conclusion

The aim of this paper is to present a comparative technical-economic study of two water pumping systems (photovoltaic and diesel) in a remote site in Saida city in Algeria. The case study considers irrigation of 8 hectares of agriculture land of onion farming, the current architecture is a pumping system powered by a diesel to fill a basin from a well, where the height of this basin from the ground allows watering one-fifth of the agricultural piece without a pump.

Based on the previous system, it is taken an equivalent system but this time feeding with PV solar energy producing a power of 23 KW.

According to this analytic study, it can be concluded that the pumping system powered by a PV generator is the best solution from an economic point of view and that the configuration of pumping system without energy storage (pumping over the sun) with water storage is the favorable way to lower the price of the system and use the quantities pumped rationally.

***Authors**: Fatima BELGACEM PhD student Laboratoire Génie Electrotechnique, University of Saida, Algeria, E-mail: fatima.belgacem@univ-saida.dz*
Mostefai Mohamed: Prof.Faculty of Technology University of Moulay Tahar, Saida. Algeria, Email:mostefaimed@yahoo.fr
Miloud YAHIA: Prof.Electrical Engineering Institute of The Prof.Faculty of Technology University of Moulay Tahar, Saida. Algeria, Email: miloudyahiadz@yahoo.fr
Aicha BELGACEM PhD student Laboratoire Génie Electrotechnique, University of Saida, Algeria, E-mail: Aicha.belgacem@univ.saida

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