TECHNO-ECNOMIC STUDY OF PHOTOVOLTAIC PUMPING SYSTEM FOR A REMOTE AREA IN ALGERIA

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ABSTRACT. In Algeria, diesel generation power technology offers the possibility of supplying water to remote regions for irrigation. The exploitation of solar energy through photovoltaic (PV) systems is an attractive solution to substitute fossil fuel for pumping water needed in these remote areas. The design of a photovoltaic water pumping system depends on the estimation of the crop water requirements and the solar irradiation.

This study is based on modeling, simulation and optimization of pumping system by using solar and conventional energy source in the form of standalone and hybrid system to supply irrigating water. For that reason, an Algerian farm cultivated with thousands of trees is investigated as a reference case study. The simulations, performed by HOMER, provide the best system configuration based on hour-by-hour data for energy availability and demands. It has been found that a diesel generator system remains the most suitable solution in terms of economic performance to supply irrigating water at remote and distant locations in Algeria.

KEYWORDS: Photovoltaic water pumping; Hybrid Diesel/PV system; Techno economic optimization; HOMER

1. Introduction

Water is the primary source of life for mankind and one of the most basic necessities for rural development. The remote and rural demand of water for crop irrigation, watering sheep and domestic water supplies is increasing each year. Diesel generator engines have traditionally been used to pump water. However, photovoltaic array and wind turbine pumps are now becoming more attractive than the traditional power sources, because the noisy of the diesel generator, rising of fuel prices, pollution and green house gasses.

Several studies show that some of renewable energy can be economically favorable compared to diesel generators for pumping systems. In Bushland-Texas, off-grid wind turbine and solar photovoltaic array for water pumping systems were analyzed individually and combined as a hybrid system. The objectives were to determine advantages or disadvantages of using a hybrid system over using a Wind or a solar PV array alone and find which system was the most efficient for the location [1].

A stand-alone and a grid connected systems were tested in Portugal [2]. The stand alone was compared with the cost of extending the national electric grid. In the grid-connected system two solutions were analyzed, one with a water turbine and another without. For the case analyzed the system without a water turbine proved to be more cost-effective.

Remote locations have switched to photovoltaic (PV) technology for pumping water. The results of an economic analysis show that the cost of the water unit pumped by PV systems is much less than that pumped using diesel systems for irrigation at remote area [3, 4]. Similar results have been shown in [5-7], as well as the economic favorability of PV systems over diesel.

Many studies in an isolated site of Algeria (Ghardaia, Timimoun, Adrar,…) of a techno-economic analysis are carried out in order to assess the feasibility of pumping water supplied with photovoltaic solar energy, which is compared with diesel powered pumping [8, 11].

Bouzidi [12] has studied and compared the two options for solar and wind water pumping applications in the Adrar region. He founded that the cost per cubic meter of water produced by the wind pump system is cheaper than that produced by the PV system.

In this study a cultivated remote farm situated in Algeria is taken as an example. This study allows us to size a PV pumping installation in order to satisfy the water needs of a determined consumption. It is based essentially on the water needs evaluation, the calculation of the necessary electric energy, the determination of the available solar energy and the choice of the components. HOMER ((Hybrid Optimization Model for Electric Renewable)) [13] developed by National Renewable Energy Laboratory (NREL) is used for designing and modeling the system and to determine the optimal water pumping system.

2. Design of the system

In this study the irrigation of a cultivated farm is taken as an example. The farm is located in Tkout, in the province of Batna, 500 km from Algiers. It has an area of 6 acres, and it is cultivated with 2200 trees (apple, apricot …). A diesel generator is used at present for pumping water, operating for 14 hours per day and it consumes around 60 to 70 liter of diesel. The farm has a water storage tank of 240 m^3 and well depth in the range of 100 m. The irrigation system runs from May through October.

The different steps for the design of the pumping system are based on:

- Estimation of water needs for crop irrigation ;
- Estimation of solar potential ;
- Selection of components.

2.1. Estimation of water

The first step for the design of pumping system is estimation of the water needed and the amount of water that can be supplied by the source (flow rate). The water needs for irrigation depends on the crop type, weather factors such as temperature, humidity, wind speed, evapotranspiration, soil, season of the year and the method irrigation.

The average daily water consumption over the irrigation period is about 30m^3/day/acre. To accomplish this, a pump type PANELLI of 7.5 kW is installed. It pumps around 5 to 6 l/s (18 to 21m^3/h) of water from the well. The pumped water can be used directly or stored in a tank for later use. The tank capacity is determined by the daily water needs of the system. In this study the water tank capacity is about 230 m^3 to 240m^3, and it would take the pump 13.5 hours at full power to fill the tank, so the storage capacity is 101.25kWh**.**

The electric power load demand represents the energy need to pump the required volume of water demanded by the farm. The average monthly deferrable load for irrigation is depicted in this Figure:

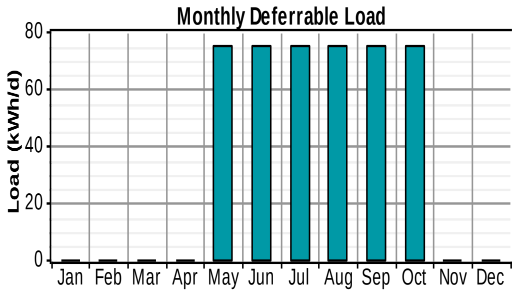

Figure 1. Monthly energy consumption for water pumping

2.2. Solar potential assessment

To design a photovoltaic water pumping system, we need to quantify the available solar energy. Solar radiation (kW/m^2) is the energy from the sun that reaches the earth. The intensity of solar radiation varies with geographic location and with the season and time of the day. In Batna, the solar radiation at the earth's surface is very important. We can see from Figure 2 that solar radiation of the region in summer is higher than winter season and the most productive hours of sunlight are from 9:00 a.m. to 4:00 p.m.

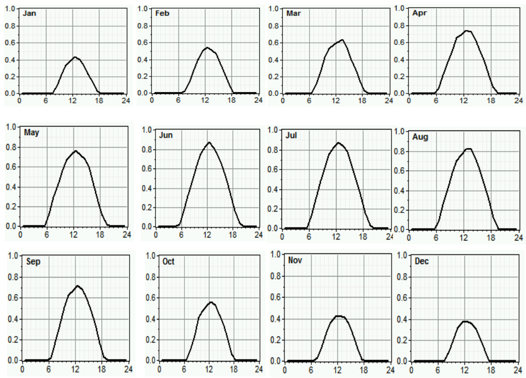

Figure 2. Monthly average sunshine hour

The solar radiation of Batna has an annual average of about 4.8kWh/m^2/day where the minimum (2.3kWh/m^2/day) is in December and the maximum value was in June and July which is 7.2kWh/m^2/day.

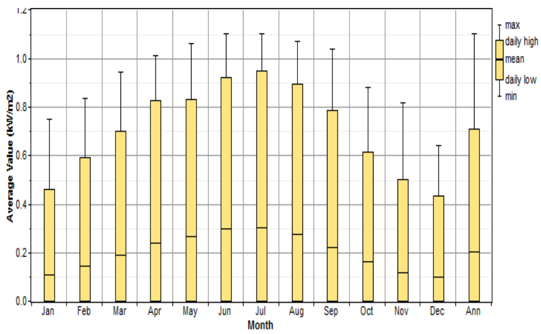

Figure 3. Solar radiation monthly average

2.3. Components and sizing of water pumping systems

The HOMER system configuration is shown in Figure 4. According to this architecture, there are four main components to the system; PV panels, diesel generator, a converter and the load. There is no need of Batteries. Indeed, water pumping is considered as deferrable load because it can be satisfied during any time of the day and not in specific hours. This type of water storage is the most widely adopted solution than the battery storage.

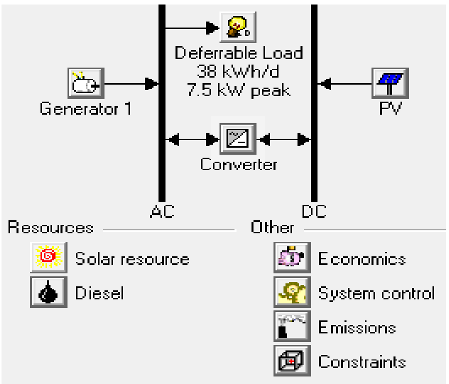

Figure 4. Scheme of the system

The system costs consist of capital, replacement, and operation and maintenance (O&M) costs.
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For this study the installed capital cost of the 25 kW Diesel generator would be about 370000DA, with replacement fixed at 360000DA, and the operating/maintenance costs is at 0.01 DA/hour. Delivered fuel cost in Algeria costs about 15.2DA per liter (0.2$/Liter).
The capital cost of the 0.25kW PV is 4800DA, with the replacement cost is at 2400DA, and the operation/maintenance cost is at 200DA/year. The PV system has a lifetime of 25 years.
For DC/AC or AC/DC conversion, a converter of a 1.2kW is used. Its capital cost and replacement price are fixed at 100409 DA, and the operating /maintenance cost is at 1000 DA/year. The converter has 25-year lifetime and 90% efficiency.
The results are derived using HOMER which determines the optimized system configuration and associated costs.

3. Simulation results and discussion

In the simulation process, after entering the necessary inputs, HOMER runs repeatedly by varying parameters that have a controlling effect. Then HOMER determines technical feasibility of a configuration and estimates the total cost of installing and operating the system over the life time of the project, in this case, 25 years. The results are listed in order of best system configuration first, to worst system configuration last, based on the Cost of Energy (COE) and Net Present Cost (NPC).

3.1. Economic analysis

HOMER defines the levelized cost of energy (COE) as the average cost/kWh of useful electrical energy produced by the system. The COE is calculated by dividing the annualized cost of producing electricity by the total useful electric energy production, as follows [14]:

$$COE = \frac{C_{ann\ tot}}{E_{served}} \quad (1)$$

Where:

- $C_{ann,tot}$ total annualized cost of the system ($/yr)
- E_{served} is the total electrical load served (kWh/yr)

The total annualized cost is the sum of the annualized costs of each system component, plus the other annualized cost. It is an important value because HOMER uses it to calculate both the levelized cost of energy and the total net present cost.
The total net present cost (NPC) is HOMER's main economic output. All systems are ranked according to net present cost, and all other economic outputs are calculated for the purpose of finding the net present cost. The net present cost is calculated according to the following equation [14, 15]:

$$C_{NPC} = \frac{C_{ann\ tot}}{CRF(i, R_{proj})} \quad (2)$$

Where:

- $C_{ann,tot}$ total annualized cost ($/yr)
- CRF capital recovery factor
- i interest rate (%)
- R_{proj} project lifetime (yr)

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows).The equation for the capital recovery factor is

$$\mathrm{CRF}(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad (3)$$

Where: i real interest rate [%] and N is number of years.

3.2. Diesel generator system

The categorized optimization results performed by HOMER for defined parameters are summarized in Figure 5. As can be seen from this figure, the stand-alone diesel system is the most economic system compared to other configurations. The total NPC for electricity supplying over project life time is 1,076,714 DA. The low installation cost of this system plays an important role in its total NPC. Also, for this system the cost of energy (COE) is 6.148DA/kWh. Since no electric power is generated by renewable sources in this configuration, obviously the renewable fraction (RF) is equal to 0.

			PV (kW)	Label (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
				4		$ 59,200	79,597	$ 1,076,714	6.148	0.00
			0.25	4	1.2	$ 207,609	82,268	$ 1,259,275	7.167	0.03
			54.50		12.0	$ 11,468,090	80,274	$ 12,494,266	70.896	1.00

Figure 5. Scheme of the system

In this stand-alone system, the 4kW diesel generators should be operated 3425h to supply the electricity demand. As is shown in Table 1, the diesel generator uses 4521L of fuel to produce 13700kW/h in a year.

Tableau 1. Diesel generator operation results

DIESEL GENERATOR	QUANTITY
Hours of operation	3425 h/yr
Electrical production	13700KW
Min electrical output	4 KW
Min electrical output	4 KW
Fuel consumption	4521 L/yr

Consequently, this leads to the emission of 11,905kg of carbon dioxide and 320,78kg of other pollutant gases in a year as shown in Table 2.

Tableau 2. Pollutant emissions for diesel system

POLLUTANT	EMISSIONS
Carbon dioxide	11,905 kg/yr
Carbon monoxide	29,4 kg/yr
Nitrogen oxides	262 kg/yr

Unburned hydrocarbons	3,26 kg/yr
Particulate matter	2,22 kg/yr
Sulfur dioxide	23,9 kg/yr

3.3. Diesel/PV hybrid system

The PV-diesel power system, which consists of 0.25 kW PV array, 4 kW diesel generator, and a 1.2 kW power converter, is the second most cost-effective scenario where the cost of energy (COE) is of 7.167 DA/kWh, and the total NPC is of 1,259,275DA. As we can see in Figure 6 the PV can supply only 3% of demand and the rest is from diesel generator, where PV array will generate 395kWh/yr and diesel generator will generate 13500kWh/yr. The total power produced by both systems is 13895kWh/yr.

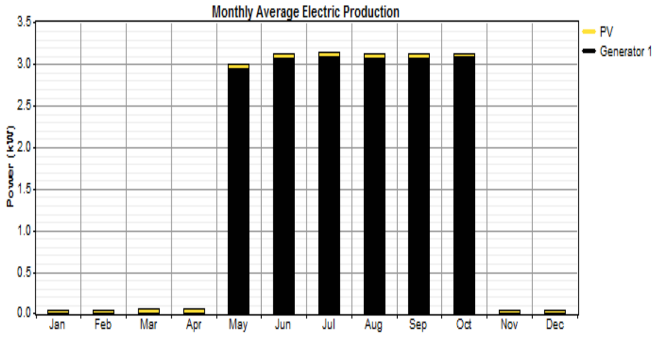

Figure 6. Monthly average electric production

The total air pollutant emission of the hybrid PV-Diesel system with only 3% renewable fraction is 327,722kg/yr which is lower than the emission generated by the diesel in the first scenario (332,685kg/yr). The percentage of reduction is related directly to penetration of renewable energy.

A stand-alone solar energy system can be designed as shown in the third scenario of Figure 5. This system consists of a 54.5kW PV module and 12 kW power converters with a COE of 70.89DA/kWh
A 54.5kWp rated capacity solar array is used in this system. As we can clearly see in Figure 7, there is generally no power generation in between 05:00 PM to 07:00 AM and there is plenty of power generation in day time of august and September. Power generation by the PV array is less in May and October.

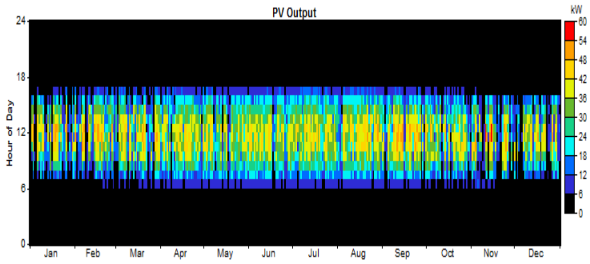

Figure 7. PV output

It can be seen from Table 3 that with the above system configuration, unmet load is 13.8 kWh/yr and excess energy of about 82,2% is generated. It should be mentioned over here, that this excess energy produced goes un-used due to lack of demand.

Tableau 1. PV operation results

QUANTITY	VALUE
PV production Deferrable load consumption	86152 kwh/yr 13786 kwh/yr

Excess electricity	70834 kwh/yr
Unmet electric load	0.1%
Capacity shortage	13,8 kwh/yr
Renewable fraction	100%

4. Conclusion

The present study investigated the ability to supplying irrigation for agricultural application in remote rural areas by PV system. A case study of an existing remote farm in Algeria was examined. The existing water pumping is based on Diesel generator. The scenario of using a PV system is developed and assessed economically by using HOMER. The results of the simulations showed that the photovoltaic Watt is much more expensive than the Diesel Watt, 71 DA/kWh against 6 DA/kWh. In the best hybrid scheme, PV/Diesel, the solar share is limited to only 3%.

The Algerian market, where the price of the fuel is very low (0.2$/Liter), is not yet favorable for the integration of photovoltaic water pumping in remote areas.

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