Photovoltaic system simulation of groundwater pump operation

Ezeddin Alshbuki[1*], Mufida Bey[2] , HafedAlmosi[3]

[1]alshbuki.ezeddin@sabu.edu.ly, [2]bey.mufida@sabu.edu.ly, [3]hafedalmosi@gmail.com

[1]Industrial Engineering Department, Faculty of Engineering, Sabratha Uuniversity, Reqdalin, Libya

*Corresponding author email:azden.hasan@gmail.com

ABSTRACT

Photovoltaic cells or solar cells. Through it, sunlight is directly converted into electricity, through the use of semiconductors, and its energies are considered a form of renewable and clean energy because it does not result in pollution of waste, noise, and radiation, not even the need for fuel. But its initial cost is high compared to other energy sources. Solar cells generate shorter-lasting electricity than regular liquid and dry batteries. The intensity of its current depends on the time of sunshine and the intensity of sunlight, as well as on the efficiency of the photovoltaic cell itself in converting solar energy into electrical energy. These solar cells can deliver hundreds of volts of direct current (DC) if these cells are connected in series. The energy produced can also be stored in lead-acid batteries or nickel-cadmium acid batteries. DC to AC can be converted by inverters for the use and management of ordinary household and industrial electrical appliances. Modeling and simulation of photovoltaic (PV) systems are critical to the task of integrating photovoltaic panels into current energy applications. Currently, measuring instruments for PV systems are available on the market, considering the proposed energy consumption, site localization, and system cost. An Advanced Specialist Program (PVSyst) was considered. In this research, a photovoltaic system was simulated in this program for the purpose of operating a submersible pump in an underground well with a depth of (30 meters) to feed the pump with a capacity of (1080 watts) from (6 panels) to provide an amount of water estimated at (30 cubic meters per day). Some important results, such as the efficiency of the system by about (81.7%), and the amount of water pumped was (10,742 cubic meters), and the area of the system was (7.7 square meters). The study is located in the Reqdalin area in the far northwest of Libya, and these areas suffer from water scarcity and frequent power outages in the network. The work was also selected to support sustainable development in that remote area.

Keywords: Simulation, Submersible Pump, Photovoltaic panels, Well depth

1. Introduction

A PVPS is a system minimally composed of a photovoltaic (PV) array and a pump, converting the solar energy into mechanical energy in order to move water from one place to another. In a more advanced setup, the system can be completed by power electronics, or a power conditioning unit, maximizing the quantity of energy used by the pump. These electronics are typical: Maximum Power Point Tracker (MPPT), a DC/DC, or DC/AC converter. Furthermore, the system often includes a method of energy storage in the form of a battery or a water tank (i.e. chemically or mechanically). This energy storage allows to access water even when the solar resource is missing [1]. PV systems have a wide range of applications and also include solar-powered, publicly owned, or private lighting systems or solar-powered water pumps. Solar pumps offer a spotless and basic choice to fuel-consuming motors and generators for homegrown water, domesticated animals, and water systems. They are best during dry and bright seasons. It doesn't need a fuel transfer and doesn't need a lot of repairs. Solar-powered lights are a useful way to implement illumination solutions in terms of technology and utilization [2]. Agriculture, in some countries, depends largely on rains and is very affected by the non-availability of water in summers. Though, the best likely irradiance is presented in summers as such more water can be pumped to meet improved water necessities. There is a huge degree to utilize PV siphoning frameworks for water supplies in rustic, metropolitan, and instructive organizations. For the most part PV systems operate over the long term at their optimum operating points due to the mismatch between the PV generator and the load characteristics, especially with the load disturbance and climatic variations [3]. In a world battling with environmental change and an Earth-wide temperature boost, inexhaustible wellsprings of power age are a vital reaction to environmental issues. In addition, they are also a key tool for developing countries, where a significant part of the population does not have access to the conventional electricity network [4]. Economists argue that agriculture is the engine of all economic growth, as a consequence, reduction of poverty throughout history [5]. However, the irrigation process in modern agriculture is still based on the exploitation of fossil fuels [6]. Since agriculture is a vital activity for the maintenance of unity, the adoption of self-sustaining agricultural production practices using renewable and endogenous energy resources becomes an essential element for the advancement of networks, either financially and socially [7]. New change strategies are investigated to limit reliance on petroleum products [8]. Consequently, the immediate connection between the accessibility of sustainable assets and water interest for water systems urges scientists and nearby partners to examine the practicality of WPS. The utilization of sunlight-based photovoltaic (PV) energy innovation for water siphoning frameworks (WPS) for water systems has been quite possibly the most well-known type of sun-powered energy application, in later decades, in remote and desert areas, as well as in some urban areas [9]. However, it is necessary to assess the availability of solar energy and water resources before installing any PV irrigation system in order to ensure good solutions [10].

2. Theory and Calculations of the System

The amount of water required per day is the basis for the design of the system, from which the pump size, the amount of energy required from the solar module cells, and the characteristics of the water source can be determined. To complete the design requirements, we calculate the total dynamic head value (TDH), which defines the minimum point in the well for the static water level to the highest point the water reaches. Figure 1 shows a schematic diagram of a PV submerged centrifugal pump system.

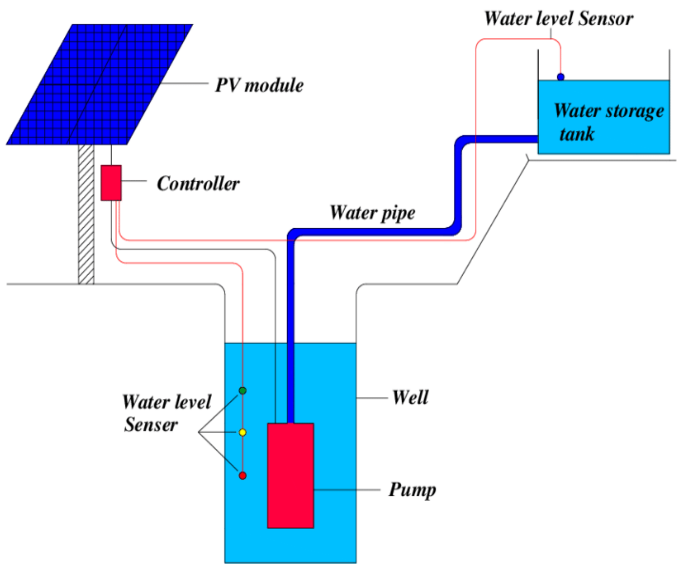

Fig.1 A schematic diagram for photovoltaic-submersible centrifugal pump system [12].

Suppose that the daily average amount of water needed for a village assumed at the south of Reqdalin area, homes about (100) people and have a cattle of about (50) Camel andcovers an area of agricultural land of (5) acres, is about (30000) liters per a day (30m 3 /day). The rate of exposure of the solar day is approximately (5) Sun hr, then the flow rate will be about (6000) L/ h.

Assume that, water static level = 15 m, drawdown level = 3 m, static dischargelevel= 2m, allowance for friction =10% *20 = 2 m,Then: the total dynamic head (TDH) equals (22) m. Matrix energies and hydraulic energies can be found by the following equations (1) and (2) [11]:

$$\text{Hydraulic energy}\left(\frac{\text{Wh}}{\text{day}}\right) = \frac{\text{Water required} \times (\text{TDH})}{\text{Conversion factor}}$$

(1)

Where the Conversion factor = 367

$$\text{Array energy} = \frac{\text{Hydraulic energy}}{\text{Pump system efficiency}}$$

(2)

The load is determined by using equation (3):

$$\text{Load}\left(\frac{\text{Ah}}{\text{day}}\right) = \frac{\text{Array energy}}{\text{Nominal voltage}}$$

(3)

Results of the pre- calculations from above equations show that the pump should have the following specifications: Static head of (30 m), flow (5.4 m^3/ h), solar panels array voltage (192Vdc), current drawn (5.0 A), and the required power output of solar panels (1080 W).

3. System Design and Simulation

In this paper, the PVsyst6.7 program [11] was used to simulate a solar photovoltaic water pump system. When designing and simulating a photovoltaic pumping system, it is assumed that the solar collectors are not shaded by a free horizon and the simulation is based on the maximum possible annual water requirement. The pump and solar modules are selected from the PVsyst program database to cover the maximum possible annual requirement. The most important design and simulation input parameters are shown in Table 1.

Table 1. Simulation input parameters

Basic simulation parameters	Simulation input values
Geographical Site	Riqdalin - Libya
Situation	Latitude 32.90° N Longitude 12.01° E
Time defined as Legal Time	Time zone UT+2
Altitude	3 m
Water requirement per day	30. 00 m³/ day, one day autonomy
Total dynamic head	84 m
Water storage tank volume	$30m^3$
Pump depth	34 m
Borehole diameter	30 cm
Pipe length	35 m
Array tilt angle	31°
Azimuth	0°
Solar panels type	Model: AD180M5-Aa Manufacturer: Aide Solar
Pump type	Model: 4GS11 Manufacturer: Lowara
Power conditioning	(MPPT-AC) inverter

The inputs for this program are the average monthly solar irradiation, the average daily water requirement, the characteristics of good depth, the selection of photovoltaic modules, and the pump. The simulation is performed on hourly values in PVsyst.

4. Results and Discussion

The main simulation results for the site are shown in Table 2.

Table 2. Simulation results for the system

Parameters	Simulation results
PV size	6.6 m^2
Total area	7.7 m^2
Pump power	1080 W
Energy at pump	1743 kWh
System efficiency	81.7 %
Pump efficiency	52.2 %
Water pumped	10742 m^3
Missing water	1.9%
Maximum loss of load within the year	207 m^3

According to the simulation result presented in Table 2, the selected photovoltaic size and pumping capacity can cover 93.0% of the water needs of the village area. From November to February there is a reduction in the water supply, during the month of January there is a significant reduction in the water supply of 207m^3/y due to the lack of solar energy falling on solar panels, but inJuly, August and Septemberthere is no reduction in the water supply. Figure 2 shows the energy balance of the proposed solar photovoltaic water that pumps the system. As can be seen in the figure, the idle power is low and the system and crop losses appear to be lower. Because the system is designed for the maximum possible amount of water produced during the year.

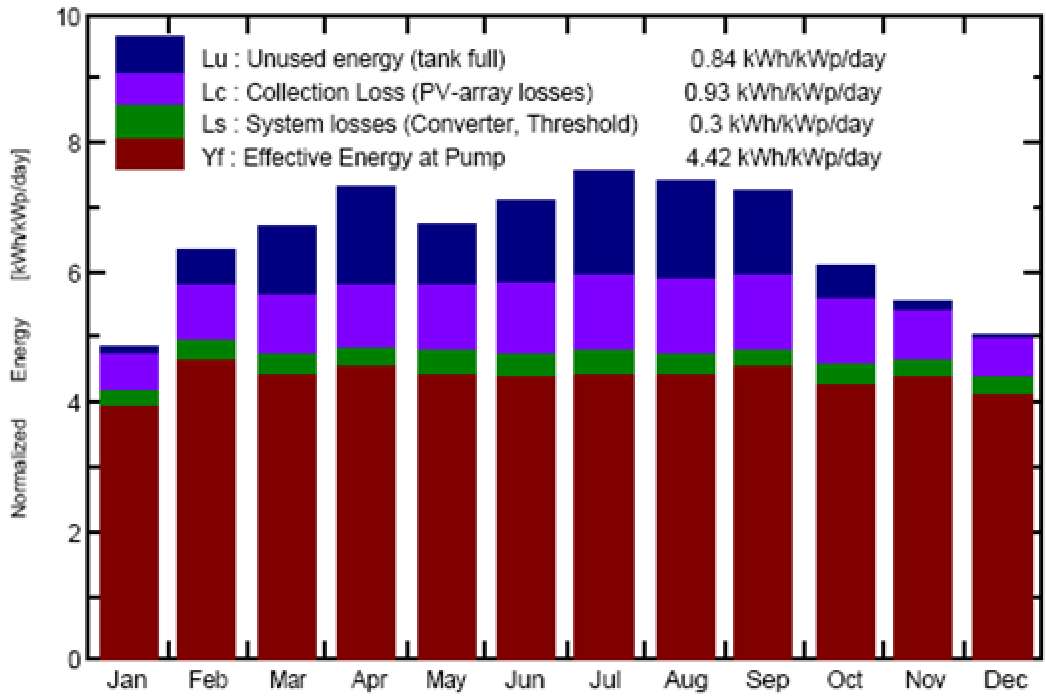

Fig. 2 Normalize productions (per installed kWp): Nominal power 1080 Wp

Figure 3 shows the linear relationship between the flow rate and the energy available to the pump. Furthermore, this figure indicates that the size of the pump depends on the available power. If the power available to the pump varies, the pump size or flow rates also vary. Therefore, the maximum power point monitoring controller (MPPT) with perturbation and observation algorithm plays an important role in adjusting the pump size according to the power available to the pump.Figure 4 shows the performance of the submersible pump in practical reality and with the same coefficients and operational conditions that were simulated in this program. By comparing Figure 3,4 we notice a clear convergence between the practical performance of the pump and the values of the simulation results despite the change of some data such as the pump and the photovoltaic array model and manufacturer that were entered in the program.

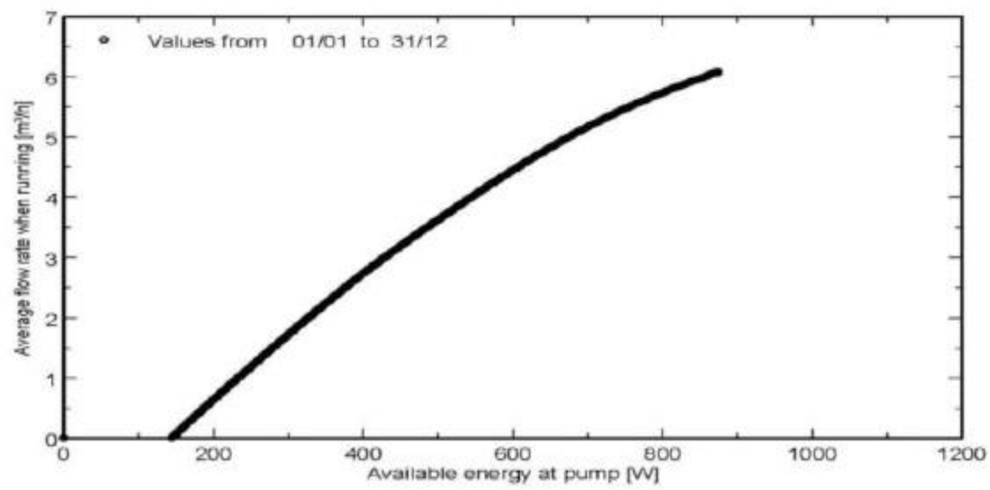

*Fig. 3 Simulated Flow – Power characteristic graph of the pum**p***

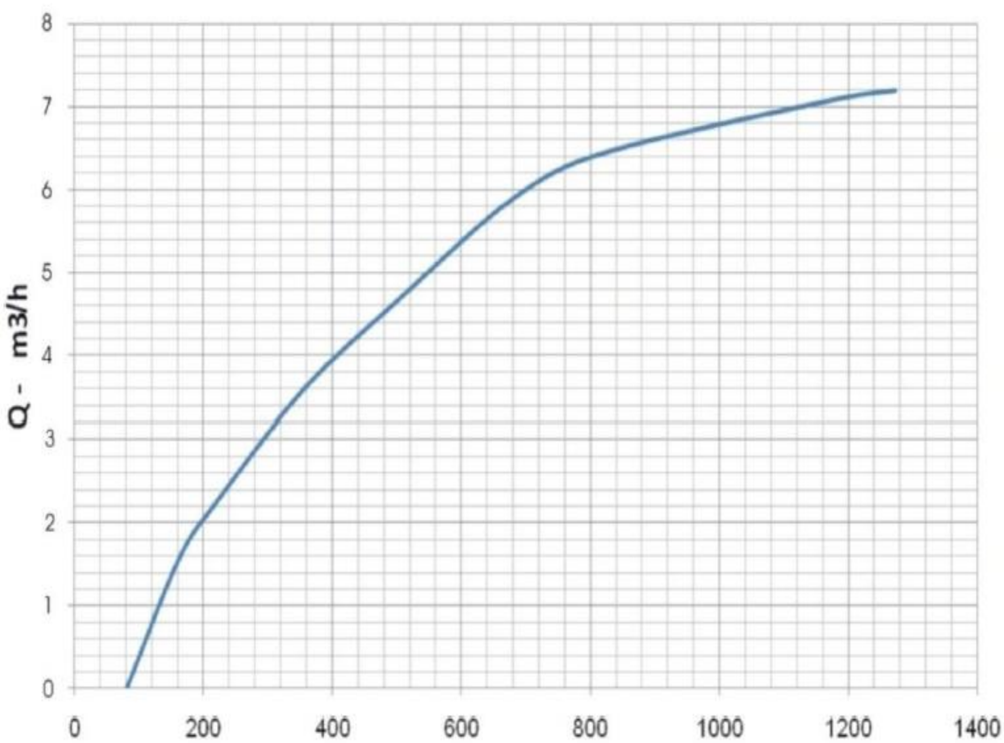

Fig. 4 Measurable Flow – Power characteristic curve of the submersible pump[11]

Table 3. Balances and main results

	GlobEff kWh/m²	EArrMPP kWh	E_PmpOp kWh	ETkFull kWh	H_Pump meterW	WPumped m³	W_Used m³	W_Miss m³
January	141.7	143.3	132.8	1.32	30.66	837.9	844.7	85.35
February	170.1	164.0	141.9	12.83	31.06	852.2	837.0	3.03
March	198.2	189.0	149.9	27.27	31.05	903.6	903.4	26.64
April	208.4	198.3	148.7	38.51	31.16	900.0	900.0	0.00
May	198.7	187.8	149.8	25.19	31.06	918.0	918.0	12.03
June	202.5	187.7	143.8	31.31	31.12	897.6	897.6	2.45
July	221.9	201.9	149.9	39.25	31.17	930.0	930.0	0.00
August	217.7	200.5	150.3	38.52	31.16	928.8	930.0	0.00
September	208.2	190.8	148.3	32.42	31.16	900.0	900.0	0.00
October	178.8	166.9	145.3	11.25	31.02	905.8	921.5	8.54
November	158.1	154.0	142.6	2.23	30.88	892.1	877.3	22.69
December	148.5	149.3	139.7	1.09	30.76	875.7	884.0	46.00
Year	2253.0	2133.5	1743.0	261.19	31.02	10741.6	10743.3	206.73

Legends:
GlobEff Effective Global, corr. for IAM and shadings
EArrMPP Array virtual energy at MPP
E_PmpOp Pump operating energy
ETkFull Unused energy (tank full)
H_Pump Average total Head at pump
WPumped Water pumped
W_Used Water drawn by the user
W_Miss Missing water

Table 3 it represents the simulation results for a PV system, while Figure 4 shows the normal relationship between power and system performance. Simulation results show that in January,

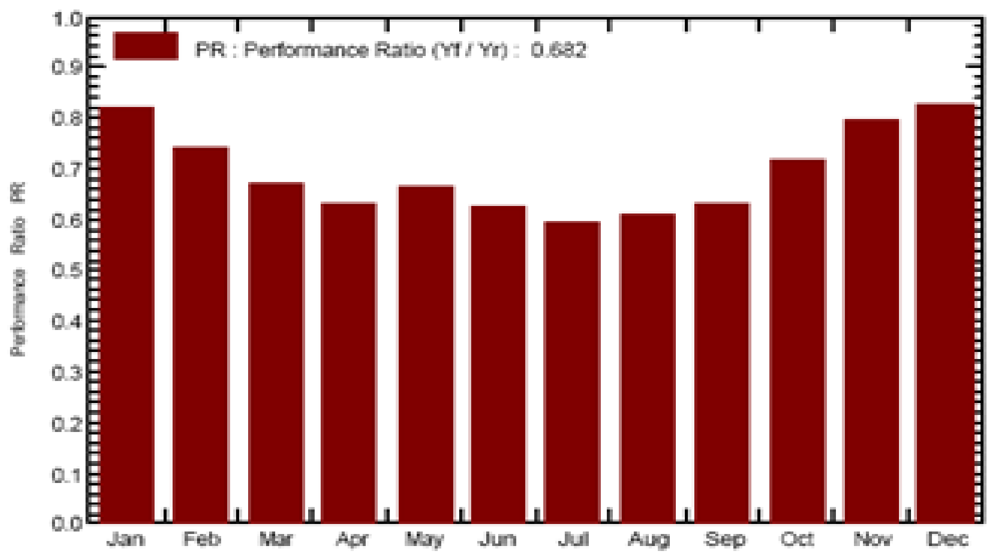

Fig. 5 Power - System Performance Ratio

November and December the system was unable to supply 154 m^3 the required amount of water during these months. This loss is due to the battery capacity. This problem can be modified by reducing the power of the PV modules.

5. Conclusion

The results show a good match of the measurable load line with the simulated maximum power line of the solar panel. In addition, the measurable flow power characteristic curve of the submersible pump has a clear match with the specifications and the shape of the simulated ratio, which means a good performance ratio (68.2%) for a coupling between the matrix of solar cells and centrifugal pump system. It is recommended to use the existing solar energy pumping system in Libya; However, since Libya is one of the richest countries in solar energy, today it suffers from surface water shortages. Furthermore, the proposed system does not require much maintenance in operation and does not pollute the environment. Regarding the long life cycle operation; the proposed solar pumping system is cheaper and easier to manage.

References

[1] Aliyu, M., Hassan, G., Said, S. A., Siddiqui, M. U., Alawami, A. T., &Elamin, I. M. (2018). A review of solar-powered water pumping systems. *Renewable and Sustainable Energy Reviews*, *87*, 61-76. https://doi.org/10.1016/j.rser.2018.02.010

[2] Diaconu, A., Fara, L., Sterian, P., Craciunescu, D., &Fara, S. (2017). Results in sizing and simulation of pv applications based on different solar cell technologies. *Journal of Power and Energy Engineering*, *5*(01), 63.

[3] Hamrouni, N., Jraidi, M., &Cherif, A. (2009). Theoretical and experimental analysis of the behaviour of a photovoltaic pumping system. *Solar energy*, *83*(8), 1335-1344.

[4] Cabraal, R. A., Kennedy, T. G., Hoelscher, J., Hart, T., Sylla, L., Dicko, M., & Annan, R. H. (1991). Photovoltaic-powered Water Pumping in Mali. In *Tenth EC Photovoltaic Solar Energy Conference* (pp. 1158-1161). Springer, Dordrecht.https://doi.org/10.1007/978-94-011-3622-8_296

[5] Van Koppen, B., Namara, R., &Safilios-Rothschild, C. (2005). *Reducing poverty through investments in agricultural water Management: Poverty and gender issues and synthesis of Sub-Saharan Africa Case study Reports* (Vol. 101). IWMI.
[6] Campana, P. E., Li, H., & Yan, J. (2013). Dynamic modeling of a PV pumping system with special consideration on water demand. *Applied energy*, *112*, 635-645.
[7] Faria, I. D., &Montalvão, E. (2012). Energiasustentável para todos.
[8] Chaurey, A., Sadaphal, P. M., &Tyaqi, D. (1993). Experiences with SPV water pumping systems for rural applications in India. *Renewable energy*, *3*(8), 961-964. https://doi.org/10.1016/0960-1481(93)90058-O
[9] Zaki, A. M., &Eskander, M. N. (1996). Matching of photovolatic motor-pump systems for maximum efficiency operation. *Renewable Energy*, *7*(3), 279-288. https://doi.org/10.1016/0960-1481(95)00133-6
[10] Fedrizzi, M. C., Ribeiro, F. S., & Zilles, R. (2009). Lessons from field experiences with photovoltaic pumping systems in traditional communities. *Energy for Sustainable Development*, *13*(1), 64-70.
[11] Habeeb, W. H. (2018). Design and implementation of photovoltaic-water pumping system for use in Iraq. *Journal of Engineering and Sustainable Development*, *22*(6), 141-151.
[12] Girma, M., Assefa, A., & Molinas, M. (2015). Feasibility study of a solar photovoltaic water pumping system for rural Ethiopia. AIMS Environmental Science, 2(3), 697-717.