applied sciences

MDPI

Article

Using the Erratic Application of Solar Photovoltaic Panel Installations to Power Agricultural Submersible Pumps in Deep Wells in Order to Extend Productive Times and Boost Water Production

Nassr Thwaini Ahmed *, Hatem Ahmed Bentaher and Mohammed Turki Fayyadh Al-Mahammedi

National School of Engineers of Sfax, Laboratory of Electromechanical System, University of Sfax, Sfax 3038, Tunisia; bentaherh@yahoo.com (H.A.B.); mscengmohammed@gmail.com (M.T.F.A.-M.)
* Correspondence: nassr.ahmed@enis.tn

Abstract: Due to the surge in oil prices, alternative energy sources, like solar power, are being explored to meet energy demands. Solar power is utilized in various industries, including agriculture. In Iraq and other developed countries, solar power is actively being developed due to the abundance of solar radiation. In agriculture, solar standalone pump systems with variable-speed drives are used. Electric motors operate at different speeds depending on the availability of sunlight. Inverters convert this solar energy from direct current to alternating current, enabling the powering of motors with a fixed voltage per frequency ratio and regulating motor current consumption. The variation in motor speed affects hydraulic pump efficiency and water productivity, making it crucial to optimize solar energy utilization in agriculture. The angle of inclination greatly affects the effectiveness of solar panels. The optimal tilt angle depends on location, latitude, season, and time of day. Adjusting this angle based on these factors maximizes power output. Innovative installation methods are being employed to enhance the benefits of solar power, reduce costs, and optimize sunlight capture. These methods drive sustainable development in various industries, including agriculture.

Keywords: solar power; solar pump system; hydraulic pump efficiency; solar energy; sustainable agriculture; water productivity

Citation: Ahmed, N.T.; Bentaher, H.A.; Al-Mahammedi, M.T.F. Using the Erratic Application of Solar Photovoltaic Panel Installations to Power Agricultural Submersible Pumps in Deep Wells in Order to Extend Productive Times and Boost Water Production. *Appl. Sci.* **2024**, *14*, 29. https://doi.org/10.3390/app14010029

Academic Editors: Alejandro Pérez-Rodríguez and Mustafa M. Matalgah

Received: 18 October 2023
Revised: 11 December 2023
Accepted: 14 December 2023
Published: 20 December 2023

1. Introduction

The demand for water rises along with the global population. The need for water to irrigate land, which will produce more food and clean water for drinking purposes, is crucial to coping with the world's population growth [1]. The connection between energy and society growth is dynamic in that the volume, nature, and value of economic progress are jointly dependent variables on the quantity, sort, and cost of exiting energy. There is increasing consent that effective progress needs a strong agricultural basis. That is why the basic worth of life must be developed for and with the dynamic involvement of the poor bulk of the people living in the rural villages [2].

Furthermore, the availability of power sources to pump water is a great problem in most developing and developed countries. Constructing an electricity network system is often costly because remote villages are commonly far away from existing network power lines. Also, relying on imported fuel stock is difficult and unsafe; foreign exchange rates oscillate, and the economies of many developing nations can then collapse [3]. Even if fuel exists within the country, transportation to these remote and rural villages is very tough, as there are no roads or supportive infrastructure where animal transportation is still common. It limits load capacities, and some loads—diesel generators, for example—may be impossible to bring to such locations [4].

Renewable energy is a promising option for water-pumping applications in remote areas of many developing nations. Moving these systems, like wind machines and photovoltaic (PV) pumps, is much easier than conventional ones because they can be conveyed in parts and reconstructed on site. Traditional windmills have been used to pump water in many developing countries in the last century [5]. Another relatively new technology harnesses solar energy. This technology, called photovoltaics, transforms the sun's energy into electricity via electromagnetic means when the PV panel is exposed to the sun [6]. Solar energy is converted into direct current (DC), which an inverter needs to convert to alternating current (AC). PV has been used to power rural communications. This technology is ideal for water pumping applications because energy storage is not required for night pumping as the energy is stored in the form of water [7]. As a power source, PV systems can be a smart approach to effective community growth in developing countries [8]. Solar power becomes especially interesting considering the reduced cost of solar components and the high yearly radiation in Iraq.

This study investigates the feasibility of a more sustainable solution for agricultural irrigation systems. Due to the low operating costs and environmental advantages, the study will concentrate on a system using solar power via PV technology. The focus will be comparing the solar pump systems in use today with a PV-powered option, showcasing their advantages and disadvantages. It will explore the irrigation methods that would best fit a solar-powered system [9].

2. Related Work

Researchers across the globe are researching how to utilize solar energy for sustainable agriculture and irrigation. A group of researchers in Bangladesh have designed a DC-DC buck converter to design an efficient DC solar water pump. It does away with the requirement for batteries and inverters. The DC solar water pump solves energy challenges in irrigation and supports year-round cultivation. The method has also been explored to purify water in rural areas of Bangladesh [10].

A study was conducted at the Renewable Energy Research Unit in the Saharan region of Algeria, where access to reliable and sustainable water supply is a significant challenge. A group of researchers highlighted the importance of renewable energy in solving water supply problems faced by remote communities. The authors proposed a solar water pump system as a cost-effective solution to meet water demand in remote areas. It details how to choose the right system components, including solar panels, batteries, charge controllers, and pumps. It also discusses the importance of systems optimized for maximum efficiency and performance. They provide an approach to system optimization that includes selecting the appropriate pump, selecting solar panels and batteries, and optimizing the system's hydraulic design. Research shows that optimized solar water pump systems can provide a reliable and sustainable water supply to remote areas. The system has a maximum power of 1.5 kilowatts, which is enough to pump water at a rate of 6–8 cubic meters per hour at a height of 50 m. In summary, this study is a valuable contribution to the design and optimization of solar water pump systems. It highlights the importance of renewable energy in addressing the water supply challenges faced by remote communities and proposes a cost-effective solution to meet their water demand. The proposed system design has the potential to provide a reliable and sustainable water supply to remote areas at a cost-effective price [11].

Photovoltaic water pumping systems have been a promising area of research over the past fifty years. Various sources examine the current state of photovoltaic water pumping systems. Their primary focus is on system components, factors affecting system performance, performance assessment, system optimization, and integration possibilities with other green technologies [12,13]. An overview of research and the current situation of photovoltaic water pumping systems is presented, including the components and benefits of PV systems in addition to the factors affecting system performance [14]. The structure of the array of photovoltaic modules and their interaction with the array of photovoltaic modules, electric motors, and pumps with optimization of consumption and improvement of control was discussed [15]. Generally, the motors used for photovoltaic pumps were classified into (i) DC motors, permanent magnet brushed motors and brushless reluctance motors and (ii) AC motors, asynchronous and synchronous, and the appropriate motor selection was based on size, system efficiency, price, energy consumption, and technical condition [16].

3. Material and Method

Components of a Solar Water Pumping Station

A typical photovoltaic solar water pumping station consists of (i) solar panels, (ii) converter/controller, (iii) pump, (iv) DC gate device, (v) turn off your phone (on/off), (vi) DC isolator, (vii) AC switch (for the pump), (viii) AC fuse, (ix) tank, (x) control panel, and (xi) threads.

The cell receives a lot of sunlight, which penetrates its surface and is partially absorbed by the phosphorus-containing first layer of the cell [17]. The silicon alloy layer is the primary absorber of much of the light that enters this cell and generates an abundance of free electrons. A significant increase is made by the movement of the light striking the cell, which passes through electrical conductors at its ends and creates a steady current. A transformer is used to connect the pump to the desired location by a panel that is specifically made to convert the solar energy that generates this current. It is important to note that this transformer can control the cycle time of the pump, guaranteeing top performance. The transformer fine tunes the power based on the incoming radiation dose and modifies the frequency of the energy supplied to the pump to effectively control the flow of pumped water. When the solar panels receive an abundance of sunlight, the inverter immediately turns on and begins operating the pump at a low frequency that gradually rises in accordance with the amount of solar radiation interacting with the inverter as shown in Figure 1. It is crucial to note that the inverter uses the most recent Maximum Power Point Tracking (MPPT) technology to guarantee maximum efficiency. Finally, it is essential that the solar generator directly transmits the inverter's maximum pump input frequency [18].

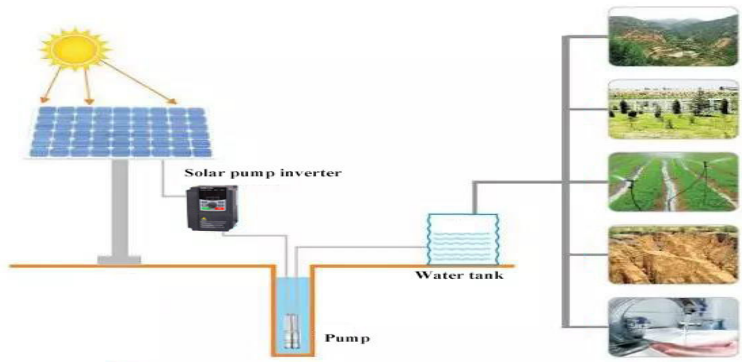

Figure 1. Typical photovoltaic solar water pumping station.

- The inclination angle:

The angle created between a solar panel's surface plane and a horizontal plane is known as the inclination angle and is denoted by the symbol "B". In the northern sphere, it is assumed that the sun is inclined to the south. There is a 0° to 180° range for the inclination angle. To determine the angle value, we used the following equation:

$$\cos(B) = \cos(\theta_z) \times \cos(\alpha_s) + \sin(\theta_z) \times \sin(\alpha_s) \times \cos(\gamma_s) \quad (1)$$

As shown in Figure 2, θ_z is the incidence angle, that is, the angle between the beam radiation on a plane and the normal to that plane. ψ is the latitude, which is the angular position north or south of the equator, north positive ranging $-90° \leq \psi \leq +90°$, and β

is the slope, which is the angle between the surface plane and the horizontal ranging $0^\circ \leq \beta \leq 180^\circ$ ($\beta < 90^\circ$ represents that the surface has a downward-facing part). γ_s is the surface azimuth angle, which is the deviation of the projection on a horizontal plane from the normal to the surface from the local meridian, with zero due south, east negative, and west positive ranging $-180^\circ \leq \gamma_s \leq 180^\circ$, and ω is the solar hour angle, which is the sun angular displacement east or west of the local meridian, which is negative in the morning, positive in the afternoon, equal to zero at solar noon and fluctuates by 15 degrees per hour from solar noon, and δ is the declination angle, which is the sun's angular position at solar noon, with respect to the equatorial plane [19,20].

$$\delta = 23.45\mathrm{s} \ \times \left(365\frac{284+\mathrm{n}}{365}\right) \tag{2}$$

where n is the nth day of the year; thus, $1 \leq n \leq 365$ (i.e., n = 1 to 1 January, n = 32 for 1 February, etc.). It is also the angle between the equator and a line drawn from the Earth's center to the sun's center, positive within the northern hemisphere summer, and negative within the northern hemisphere winter. Since the earth is tilted at a 23.45-degree angle, the angle of the sun's ray incident on the earth differs all over the year. On the spring and autumnal equinoxes, the angle is zero degrees, while on the winter and summer solstice, the angle is 23.45, and −23.45 degrees, respectively, as displayed in Figure 3 [21].

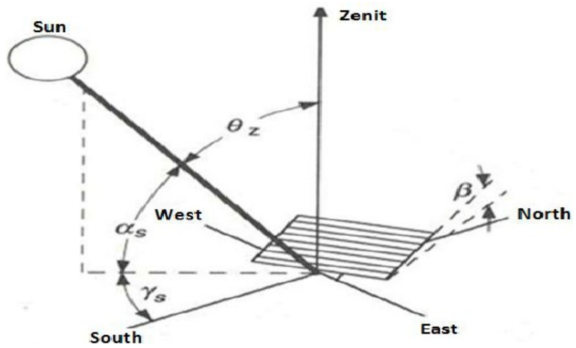

Figure 2. Solar angles.

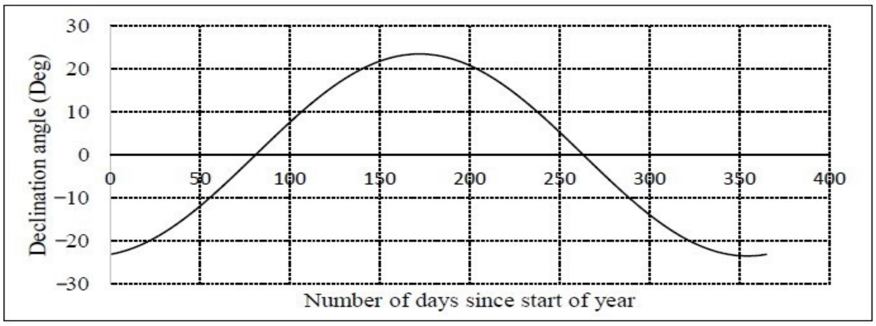

Figure 3. Variation of the declination angle with n days over the year.

Knowing the sun's peak hours allows one to calculate the number of solar panels as follows:

Panel energy is calculated as daily consumption divided by sunlight hours;
Total energy/energy per panel equals the necessary number of panels;
Solar panels currently in use times inverter power;
Pump power is greater than inverter power.

- The nominal current of the pump, which is greater than the inverter output pump efficiency, is calculated as follows.

Pa: active energy;

h: required pumping height.

$$\eta = \frac{\rho \times Q \times g \times h}{Pa} \times 100\% \quad (3)$$

To calculate the flow rate:
L: the number of liters of water required per day;
h: the number of peak hours per day.

$$Q = \frac{L}{\Sigma h} \times \frac{1\ h}{60\ min}. \quad (4)$$

The pump law [22]:

$$Ph = H_{tot} \times Q_s \times \rho \times g \quad (5)$$

where Ph: hydraulic force produced by the pump;
H_{tot}: water column;
Q_s: water flow (m^3/s);
ρ: specific mass of the water (kg/m^3);
The gravitational constant is 9.81 g.
The daily water requirement to calculate the size of the pump [23]:

$$H_d = H_w + H_s + H_f \quad (6)$$

where H_d: dynamic pumping height;
H_w: pumping high water pressure;
H_s: tank's pumping height;
H_f: pipe friction losses.

- The losses are divided into two types [17]:

1. Principal losses, which result from friction losses and can be calculated from Darcy Weissberg's law.

$$h_v = \lambda \frac{\text{ʃ}.v^2}{2gd} \quad (7)$$

h_v: friction loss in the pipe, expressed in meters;
λ: friction factor;
ʃ: The length of the straight pipe is measured in meters;
v: average velocity in meters per second;
g: gravitational pull;
d: the diameter of the pipe is measured in meters.

2. Losses caused by fittings, valves, or pipe bending as shown in Figure 4.

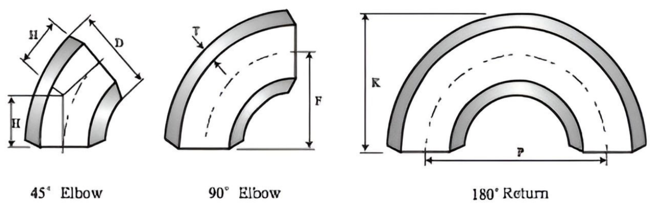

Figure 4. Bending angle pipe elbows.

The value of secondary losses can be calculated with the following equation [17].

$$\text{Secondary losses} = kv^2/2 \times g \quad (8)$$

where k depends on different types of accessories and valves.

4. Solar Pumping System Design

Due to their capacity to reduce carbon emissions and mitigate the effects of global warming, the use of renewable energy has increased recently and received considerable attention. However, the performance of photovoltaic systems is affected by a few variables, such as temperature, shading, and uneven sunlight. The design and optimization of photovoltaic systems can benefit from the use of modeling tools, and two of the most popular programs for doing so are MATLAB 9.10.0.1577079 and SketchUp 8.0.16846. The use of these programs to create a solar pumping system that can produce 7.5 kW will be covered in this study. In the Wafaa area of the Al-Anbar province in Iraq, which covers an area of 7639 square kilometers and depends on wells to meet daily needs, the Ministry of Water Management and the General Directorate for Ground Water applied to the Department of Geology to obtain all the information about the land and the specifications of the well in the area as shown as shown in Table 1. A water well with a depth of 144 m was drilled with the use of a solar panel type (Trina type) with a capacity of 600 watts, which is available in local markets, with the use of a submersible water pump type (Grundfos Lenntech pump SP9-40 Rp2 4″3X380-415/50 7.5 kW pump) that has a capacity of 7.5 kW and includes other details for the design of the system [24].

Table 1. Geographical site data for the Al-Wafaa district in the Al-Anbar province of Iraq in which the study was conducted.

N	33	25	46
E	42	30	20

In the following scenarios, the solar system will be examined and simulated:

1. The first case involves a system with a natural design and knowledge of its productivity;
2. The second instance involves positioning solar panels at various angles and analyzing the system's performance;
3. In the third instance, we divided the matrix into ten panels in the south, four panels in the east, and four panels in the west, and we looked at the system's productivity in each of these areas.

- The First instance: The system consists of 18 solar panels, each with a 600 W capacity, arranged in three rows. It has six panels. A three-phase, 11 kW agricultural inverter was employed. In the first scenario, every panel is in position. As a result, the angle of inclination is 30 degrees after accounting for the fact that Iraq is a sunny country and the site coordinators as shown in Figure 5.
- We found the following results for the Al-Wafaa district in Al-Anbar.

➢ Tests and simulation results

In the first instance, all panels are positioned so that the angle of inclination is 30 degrees, taking into consideration that Iraq is a sunny country and the site coordinators. For the Al-Wafaa neighborhood in Al-Anbar, using modeling, we determined the daily productivity from sunrise to sunset see Table 2, as well as the monthly and annual productivity as shown in Figure 6. And A graph showing Figure 7 the inverter's current and voltages.

The second instance, to increase working hours and compare productivity, the solar panels were installed at different angles, each with six panels at different angles, respectively. We divided the matrix equally into six southern panels, six eastern panels, and six western panels, as shown in the Figure 8, using the SketchUp program, and the data and shape were entered into the MATLAB program as follows: the pump, well, and solar cell data were entered while changing the inclination angles of the solar cells while maintaining the same number of panels. This is called the installation of irregular solar panels, and they can be used in agricultural areas and large industrial projects to achieve the maximum benefit from solar rays and obtain high efficiency.

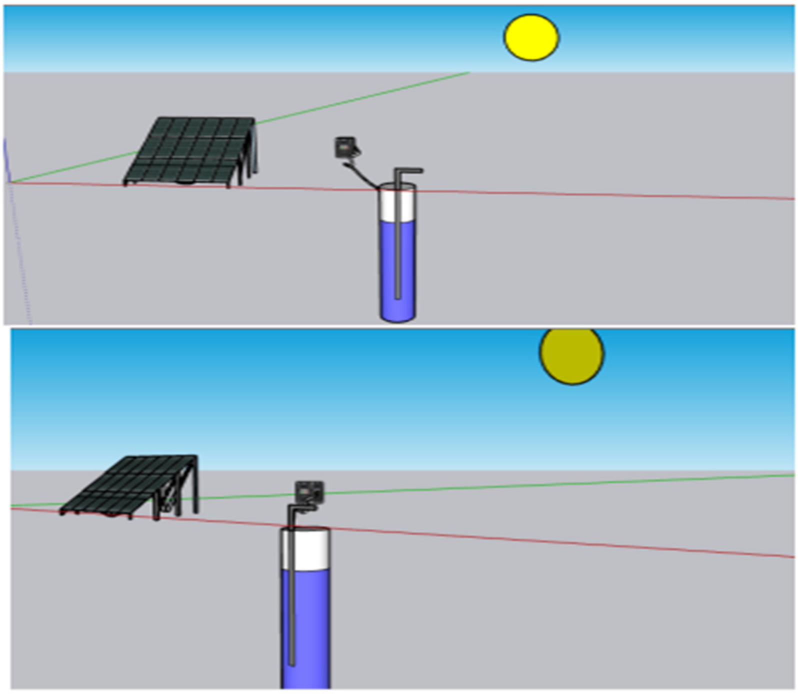

Figure 5. The inclination angle of the solar-powered water pumping system is 30 degrees.

Table 2. The rate of production of the solar water pumping system on a daily, monthly, and annual basis.

Daily Production and Work Hours	
Production_Liters	Work_Hours
137,634 $\times$ 10^5	6
Monthly Production and Days in the Month	
Production_Liters	Days_in_Month
2.56 $\times$ 10^5	31
2.3084 $\times$ 10^5	28
3.1866 $\times$ 10^5	31
3.0734 $\times$ 10^5	30
3.8046 $\times$ 10^5	31
4.2882 $\times$ 10^5	30
4.4312 $\times$ 10^5	31
4.4312 $\times$ 10^5	31
3.6756 $\times$ 10^5	30
3.1866 $\times$ 10^5	31
2.4733 $\times$ 10^5	30
2.5621 $\times$ 10^5	31
Yearly Production and Workday Hours	
Production_Liters	Work_Days_Hours
3.9981 $\times$ 10^6	365

Inverter characteristics: input voltage: 550 V; output current: 25 A; inverter power: 11 kW.

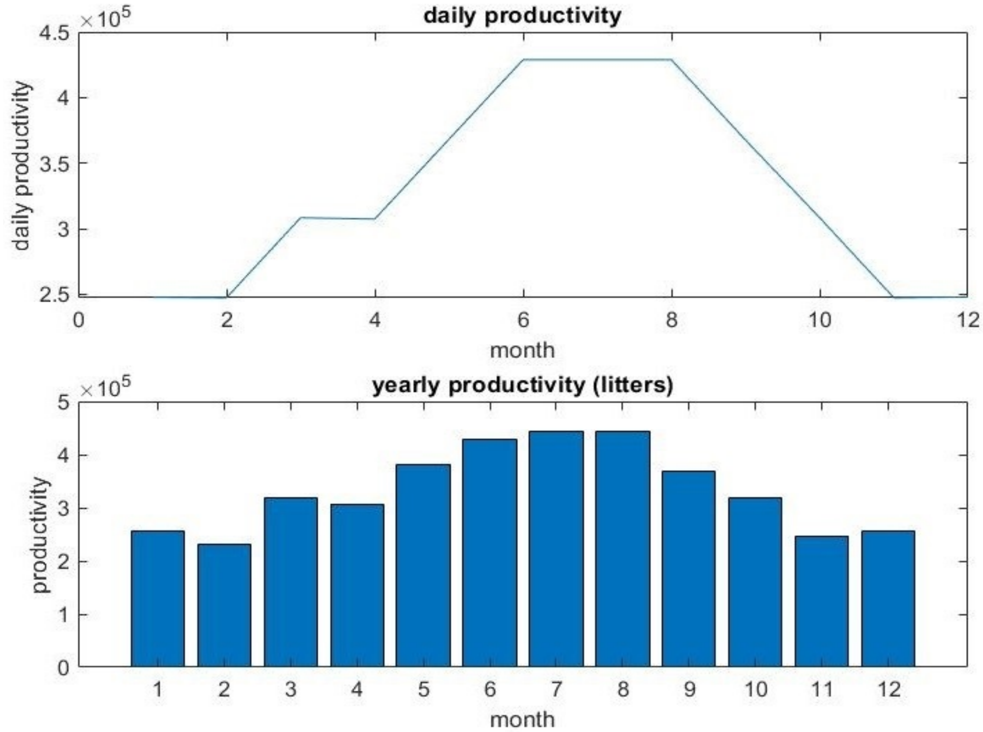

Figure 6. Production chart for each day, month, and year.

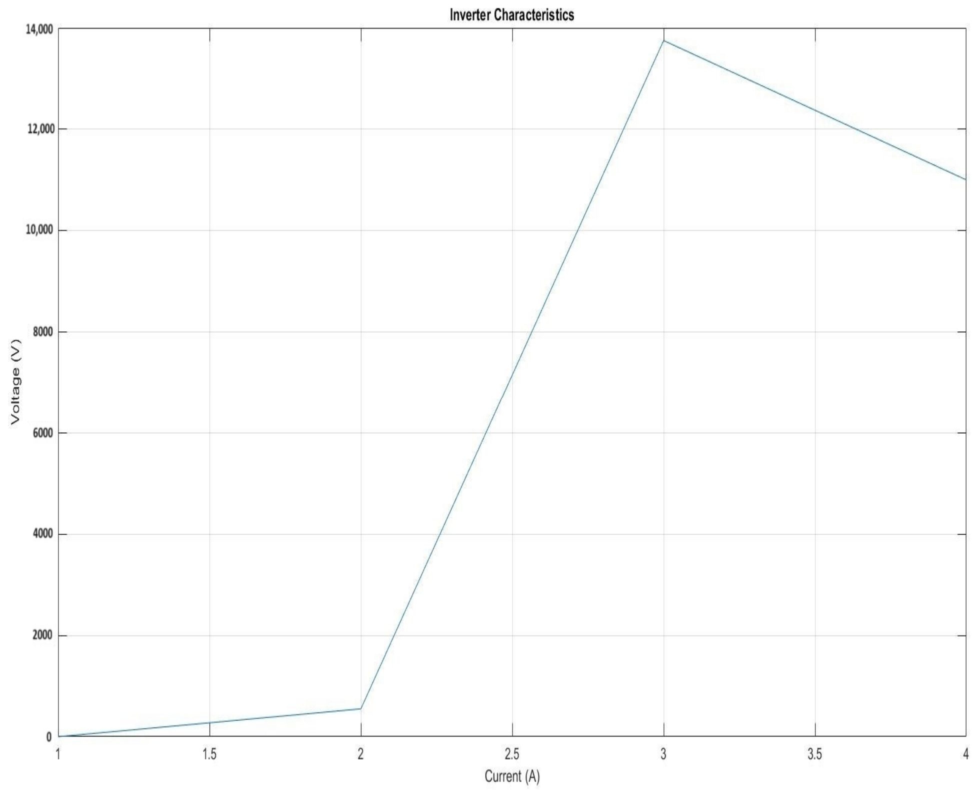

Figure 7. A graph showing the inverter's current and voltages.

And to increase working hours and compare productivity, the solar panels were installed at various angles, every six panels at various angles, from sunrise to sunset, and the daily, monthly, and annual productivity as shown in Table 3 and the production diagram shown in the Figures 9 and 10 for each angle.

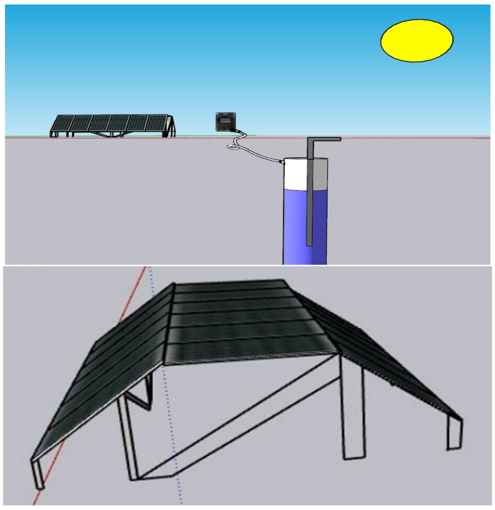

Figure 8. The solar panels were installed at various angles in the water pumping system.

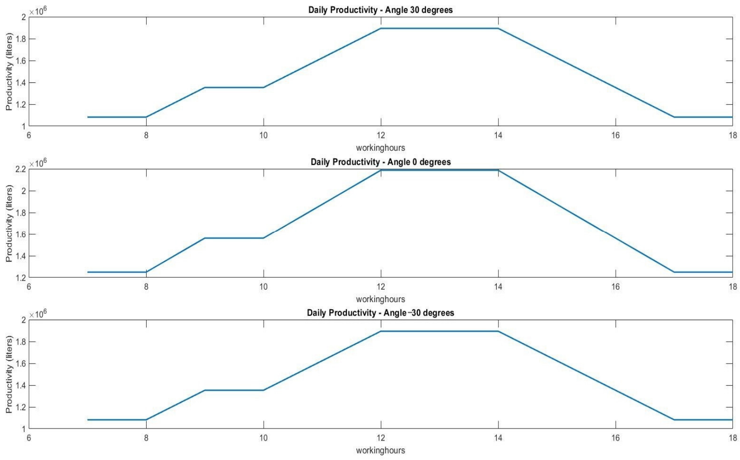

Figure 9. Hours worked and output rate.

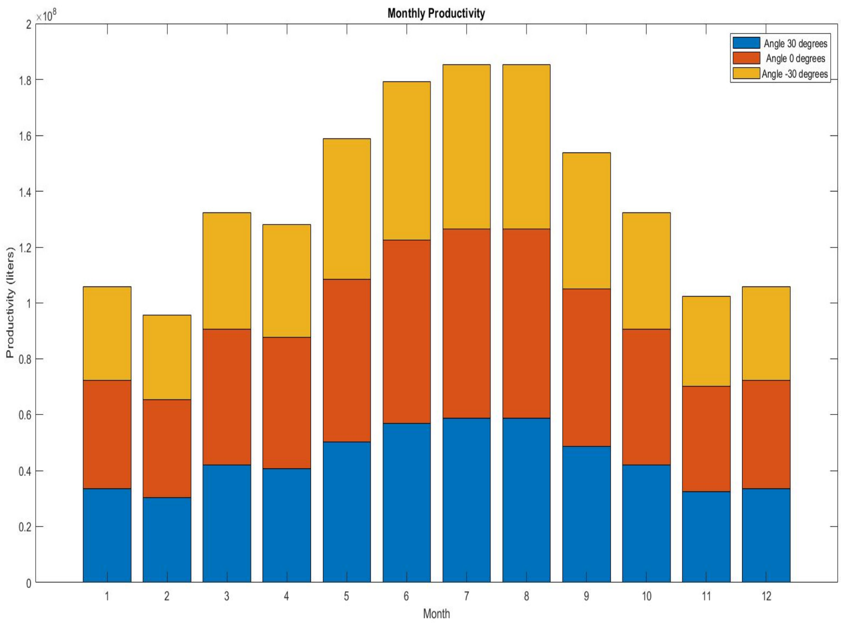

Figure 10. Production rate per month.

Table 3. The table shows the rate of production of the solar water pumping system on a daily, monthly, and annual basis.

Month	Angle	Daily	Monthly	Yearly
1	30	1.0823×10^6	3.3551×10^7	5.2761×10^8
1	0	1.2497×10^6	3.8741×10^7	6.0924×10^8
1	−30	1.0823×10^6	3.3551×10^7	5.2761×10^8
2	30	1.0823×10^6	3.0304×10^7	5.2761×10^8
2	0	1.2497×10^6	3.4992×10^7	6.0924×10^8
2	−30	1.0823×10^6	3.0304×10^7	5.2761×10^8
3	30	1.3529×10^6	4.1939×10^7	5.2761×10^8
3	0	1.5621×10^6	4.8426×10^7	6.0924×10^8
3	−30	1.3529×10^6	4.1939×10^7	5.2761×10^8
4	30	1.3529×10^6	4.0586×10^7	5.2761×10^8
4	0	1.5621×10^6	4.6864×10^7	6.0924×10^8
4	−30	1.3529×10^6	4.0586×10^7	5.2761×10^8
5	30	1.6234×10^6	5.0326×10^7	5.2761×10^8
5	0	1.8746×10^6	5.8112×10^7	6.0924×10^8
5	−30	1.6234×10^6	5.0326×10^7	5.2761×10^8
6	30	1.894×10^6	5.682×10^7	5.2761×10^8
6	0	2.187×10^6	6.561×10^7	6.0924×10^8
6	−30	1.894×10^6	5.682×10^7	5.2761×10^8
7	30	1.894×10^6	5.8714×10^7	5.2761×10^8
7	0	2.187×10^6	6.7797×10^7	6.0924×10^8
7	−30	1.894×10^6	5.8714×10^7	5.2761×10^8
8	30	1.894×10^6	5.8714×10^7	5.2761×10^8
8	0	2.187×10^6	6.7797×10^7	6.0924×10^8
8	−30	1.894×10^6	5.8714×10^7	5.2761×10^8
9	30	1.6234×10^6	4.8703×10^7	5.2761×10^8
9	0	1.8746×10^6	5.6237×10^7	6.0924×10^8
9	−30	1.8746×10^6	4.8703×10^7	5.2761×10^8
10	30	1.3529×10^6	4.1939×10^7	5.2761×10^8
10	0	1.5621×10^6	4.8426×10^7	6.0924×10^8
10	−30	1.3529×10^6	4.1939×10^7	5.2761×10^8
11	30	1.0823×10^6	3.2469×10^7	5.2761×10^8
11	0	1.2497×10^6	3.7491×10^7	6.0924×10^8
11	−30	1.0823×10^6	3.2469×10^7	5.2761×10^8
12	30	1.0823×10^6	3.3551×10^7	5.2761×10^8
12	0	1.2497×10^6	3.8741×10^7	6.0924×10^8
12	−30	1.0823×10^6	3.3551×10^7	5.2761×10^8

Inverter characteristics: input voltage: 550 V; output current: 25 A; inverter power: 11 kW.

In this instance, it should be noted that the data for the pump, well, and solar cells were entered by altering the tilt angles of the solar cells while keeping the same number of panels, where we divided the panels equally into six panels facing south, six panels facing east, and six panels facing west, and the productivity at an angle of 0 degrees was the largest and best, giving the greatest productivity from sunrise to sunset. The productivity is higher than in the first case, and we can see that this method has given us the most working hours.

Third instance, we divided the matrix into ten panels in the south, four panels in the east, and four panels in the west as shown in Figure 11, and studied the system and its productivity. The same data that was entered in the first case were used, but the solar cells were placed in an irregular manner in order to operate the pump during oper-ating hours and increase daily output to receive the maximum radiation for the longest time as shown in Figures 12 and 13. And the output was divided into three totals in order to calculate the current generated in each of these three periods for each angle across all groups as shown in Figures 14 and 15.

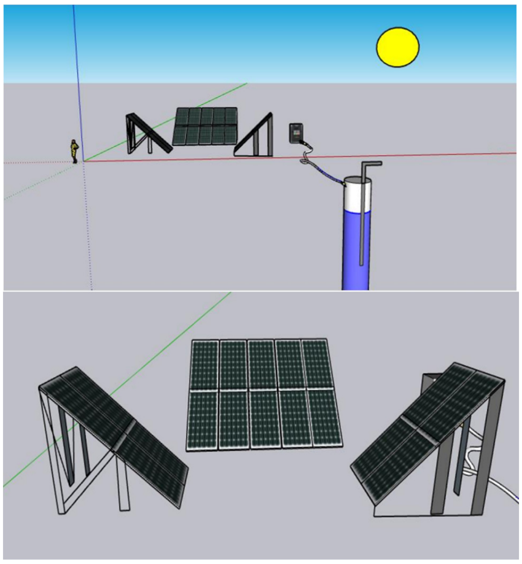

Figure 11. The solar panels were placed in an irregular manner in the water pumping system.

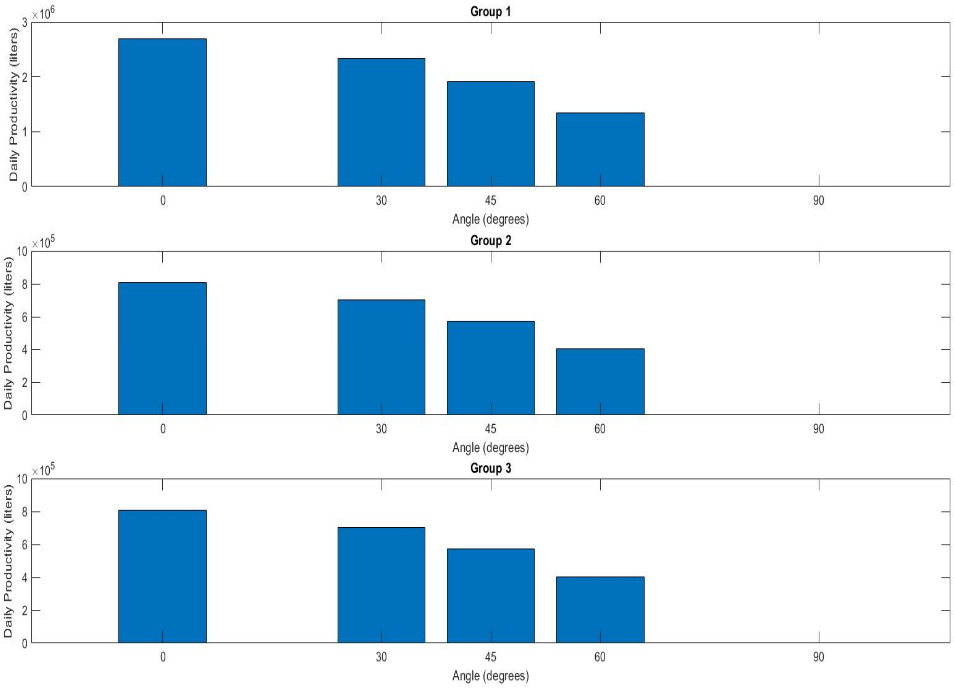

Figure 12. Daytime production rate per angle.

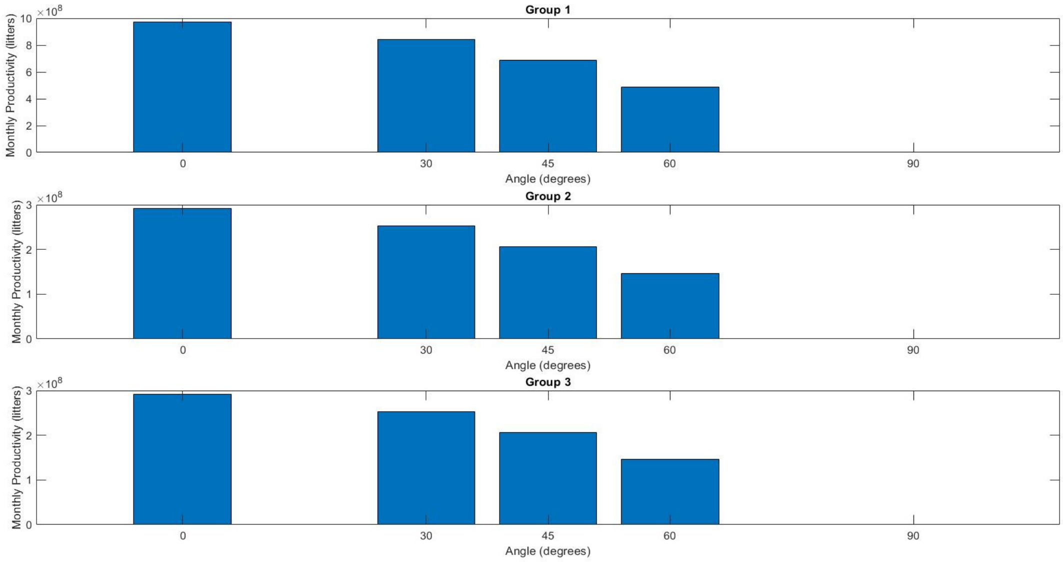

Figure 13. The monthly production rate for each angle.

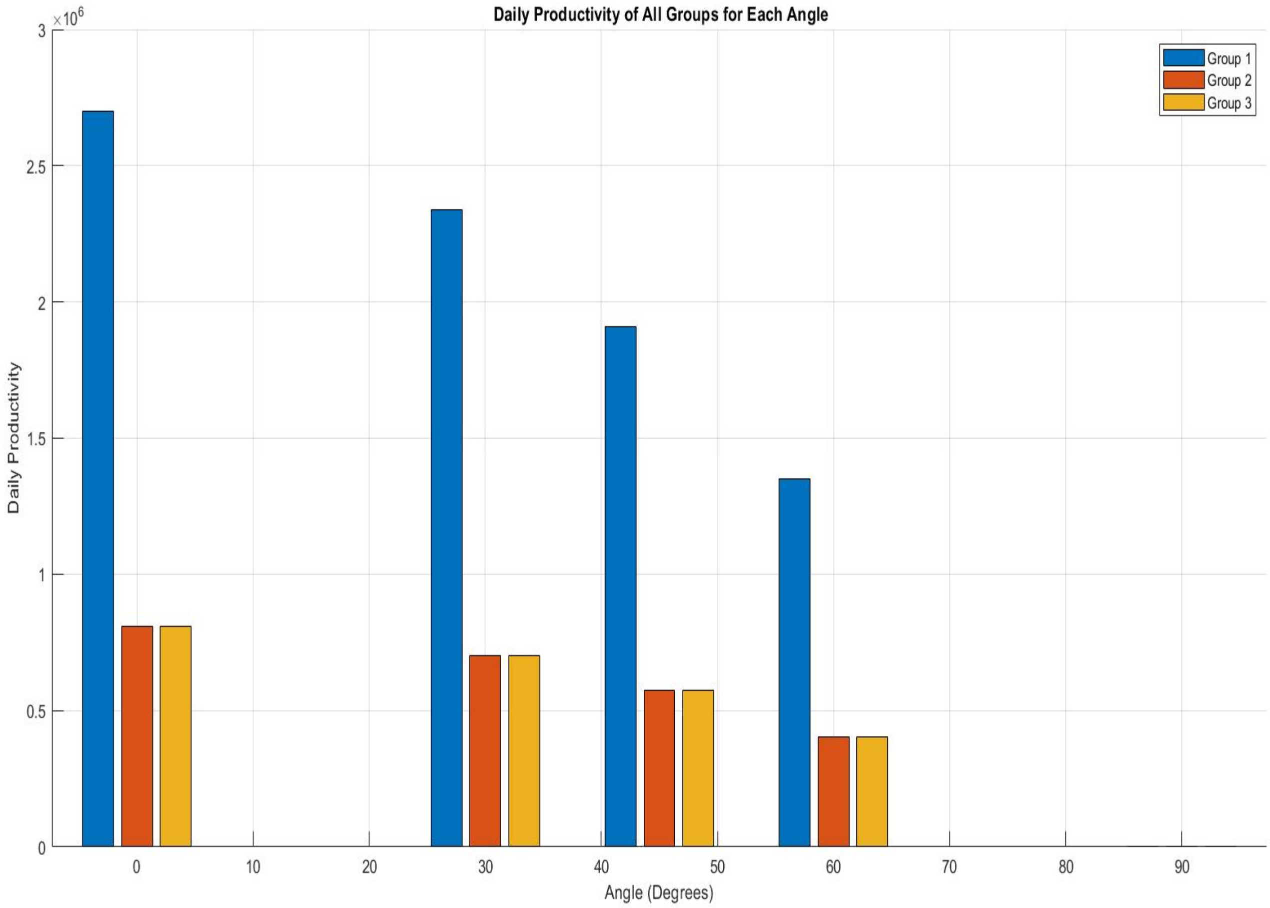

Figure 14. Daily output for each angle across all groups.

We observed that productivity increases as shown in Table 4 significantly compared to its predecessors in the first case and decreases slightly above normal in the second case because the panels, in this case, are oriented east and west rather than what is known to be south. Additionally, we have observed that, in comparison to the first method, the approach was most productive.

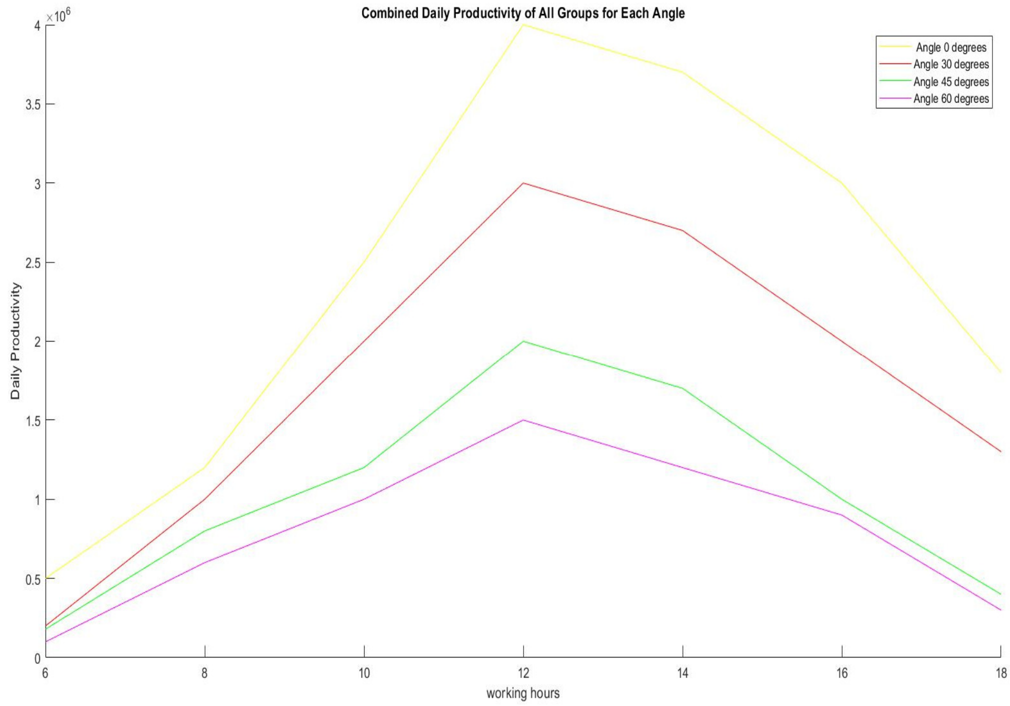

Figure 15. Total daily output for each angle across all groups.

Table 4. The table shows the overall solar water pumping system production rate daily, monthly, and annually.

Daily Productivity at Different Angles:			
Group1	**Group2**	**Group3**	**Angle**
2.7×10^6	8.1×10^5	8.1×10^5	0
2.3383×10^6	7.0148×10^5	7.0148×10^5	30
1.9092×10^6	5.7276×10^5	5.7276×10^5	45
1.35×10^6	4.05×10^5	4.05×10^5	60
0	0	0	90
Monthly Productivity at Different Angles:			
Group1	**Group2**	**Group3**	**Angle**
3.24×10^7	9.72×10^6	9.72×10^6	0
2.8059×10^7	8.4178×10^6	8.4178×10^6	30
2.291×10^7	6.8731×10^6	6.8731×10^6	45
1.62×10^7	4.86×10^6	4.86×10^6	60
0	0	0	90
Yearly Productivity at Different Angles:			
Group1	**Group2**	**Group3**	**Angle**
3.24×10^7	9.72×10^6	9.72×10^6	0
2.8059×10^7	8.4178×10^6	8.4178×10^6	30
2.291×10^7	6.8731×10^6	6.8731×10^6	45
1.62×10^7	4.86×10^6	4.86×10^6	60
0	0	0	90

Inverter characteristics: input voltage: 550 V; output current: 25 A; inverter power: 11 kW.

➢ Irregular solar panels, also known as non-standard solar panels, offer a viable solution for harnessing solar energy in agricultural areas and large-scale industrial projects. These panels are designed to optimize solar ray utilization and achieve maximum efficiency. However, several challenges are associated with their installation. For instance:
  (1) Maintenance poses a significant hurdle. Accessing and cleaning the solar panels can be a cumbersome task, ultimately impacting long-term production efficiency;
  (2) The concentration of land used for solar panel installation can have repercussions on other activities, such as agriculture. Moreover, excessive exposure of the soil to sunlight must be balanced against the benefits of utilizing solar panels while preserving the land for other purposes;
  (3) The visual impact and environmental harmony of this installation should be considered. The presence of such a system could potentially disrupt the natural landscape and impact local biological life.

5. Conclusions

In this comprehensive study, we conducted a comprehensive analysis to determine the procedures needed to create a highly efficient solar pumping system. Using advanced software tools, such as MATLAB, SketchUp, we calculated our system installation and developed a solar pumping system that considers various factors such as losses, location, and more. By effectively eliminating the use of batteries, we achieved a significantly more efficient system that not only reduces losses but also enhances overall production accuracy, thus ensuring a more sustainable future. Our efforts to reduce losses and improve system performance have yielded valuable insights that enabled us to make informed decisions. We focused on optimizing pipe dimensions, including their height and length, to ensure maximum efficiency with the importance of regular maintenance and allocated specific time to each component of the system, ensuring its longevity and reliability. By implementing these measures, standalone PV systems have emerged as a very promising solution for remote locations, offering sustainable energy solutions that empower communities and protect the environment. Through an extensive analytical study, we aimed not only to maximize productivity but also to extend the system's operating hours, ensuring a stable and reliable power supply. We carefully evaluated the three different solar system designs; we noticed distinct features and characteristics in each case. However, it became clear that the second design, with its innovative features and cutting-edge technology, demonstrated superior productivity and achieved the greatest number of man hours. This pioneering discovery also highlights the importance of design optimization and its profound impact on daily and monthly productivity levels, which we continuously monitor throughout different times of the day to ensure optimal performance. Through our research and innovation, we are paving the way to a brighter, more sustainable future.

Author Contributions: Software, N.T.A., H.A.B. and M.T.F.A.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive any external funding or financial support.

Data Availability Statement: Data were obtained from the Ministry of Water Resources/General Authority for Ground Water/Geology Department and are available from the authors with the permission of the Ministry of Water Resources/General Authority for Ground Water/Geology Department.

Conflicts of Interest: The authors declare that they have no conflict of interest related to this research study.

References

1. Pytilinski, J.T. Solar energy installations for pumping irrigation water. *Sol. Energy* **1978**, *21*, 255–262. [CrossRef]
2. Bahadori, M.N. Solar water pumping. *Sol. Energy* **1978**, *21*, 307–316. [CrossRef]
3. Ward, P.B.; Dunford, W.G. Solar-powered groundwater pumping for medium heads. *IAHS-AISH Publ.* **1984**, *144*, 249–258.
4. Mankbadi, R.R.; Ayad, S.S. Small-scale solar pumping: The technology. *Energy Convers. Manag.* **1988**, *28*, 171–184. [CrossRef]
5. Chowdhury, B.H.; Ula, S.; Stokes, K. Photovoltaic-powered water pumping-design, and implementation: Case studies in Wyoming. *IEEE Trans. Energy Convers.* **1993**, *8*, 646–652. [CrossRef]
6. Gad, H.E.; El-Gayar, S.M. Performance prediction of a proposed photovoltaic water pumping system at South Sinai, Egypt climate conditions. In Proceedings of the Thirteenth International Water Technology Conference, IWTC13, Hurghada, Egypt, 13–16 March 2009.
7. Omer, A.M. Solar water pumps clean water for Sudan's rural areas. *Renew. Energy* **2001**, *24*, 245–258. [CrossRef]
8. Eker, B. Solar-powered water pumping systems. *Trakia J. Sci.* **2005**, *3*, 7–11.
9. Shinde, V.B.; Wandre, S.S. Solar photovoltaic water pumping system for irrigation: A review. *Afr. J. Agric. Res.* **2015**, *10*, 2267–2273.
10. Obaideen, K.; AlMallahi, M.N.; Alami, A.H.; Ramadan, M.; Abdelkareem, M.A.; Shehata, N.; Olabi, A.G. On the contribution of solar energy to sustainable development goals: Case study on Mohammed bin Rashid Al Maktoum Solar Park. *Int. J. Thermofluids* **2021**, *12*, 100123. [CrossRef]
11. Palmiro, F.; Pinto JO, P.; Pereira, L.H.; Godoy, R.B. Cost-effective photovoltaic water pumping system for remote regions communities. In Proceedings of the 2014 IEEE Energy Conversion Congress and Exposition (ECCE), Pittsburgh, PA, USA, 15–18 September 2014; pp. 3287–3293.
12. Li, G.; Jin, Y.; Akram, M.W.; Chen, X. Research and current status of the solar photovoltaic water pumping system–A review. *Renew. Sustain. Energy Rev.* **2017**, *79*, 440–458. [CrossRef]
13. Herez, A.; El Hage, H.; Lemenand, T.; Ramadan, M.; Khaled, M. Review on photovoltaic/thermal hybrid solar collectors: Classifications, applications and new systems. *Sol. Energy* **2020**, *207*, 1321–1347. [CrossRef]
14. Shepovalova, O.V.; Belenov, A.T.; Chirkov, S.V. Review of photovoltaic water pumping system research. *Energy Rep.* **2020**, *6*, 306–324. [CrossRef]
15. Verma, S.; Mishra, S.; Chowdhury, S.; Gaur, A.; Mohapatra, S.; Soni, A.; Verma, P. Solar PV powered water pumping system—A review. *Mater. Today Proc.* **2021**, *46*, 5601–5606. [CrossRef]
16. Singh, D.B.; Mahajan, A.; Devli, D.; Bharti, K.; Kandari, S.; Mittal, G. A mini-review on solar energy-based pumping system for irrigation. *Mater. Today Proc.* **2021**, *43*, 417–425. [CrossRef]
17. Kim, J.W.; Lee, J.S. Greening Energy Finance of Multilateral Development Banks: Review of the World Bank's Energy Project Investment (1985–2019). *Energies* **2021**, *14*, 2648. [CrossRef]
18. Lengoiboni, V.N. Simulation of a Maximum Power Point Tracking System for Improved Performance of Photovoltaic Systems. Doctoral Dissertation, Jomo Kenyatta University of Agriculture and Technology, Juja, Kenya, 2016.
19. Saleem, M.U. Gnomon assessment for geographic coordinates, solar horizontal & equatorial coordinates, time of local sunrise, noon, sunset, direction of qibla, size of Earth & Sun for Lahore Pakistan. *Open J. Appl. Sci.* **2016**, *6*, 100. [CrossRef]
20. Leng, G.; Meloche, N.; Monarque, A.; Painchaud, G.; Thevenard, D.; Ross, M.; Hosette, P. *Clean Energy Project Analysis: RETScreen, Engineering & Cases Textbook-Photovoltaic Project Analysis*; CANMET Energy Technology Center: Ottawa, ON, Canada, 2004; pp. 17–28.
21. Wald, L. Basics in Solar Radiation at Earth's Surface. 2018, pp. 12–18. Available online: https://minesparis-psl.hal.science/hal-01676634 (accessed on 11 July 2023).
22. Cengiz, M.S.; Mamiş, M.S. Termal Güneş Enerjisi Kullanımı ve CSP Sistemlerin Verimlilik Analizi. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi* **2016**, *5*. Available online: https://dergipark.org.tr/en/pub/bitlisfen/issue/24347/258057 (accessed on 11 July 2023). [CrossRef]
23. Al-Badi, A.; Yousef, H.; Al Mahmoudi, T.; Al-Shammaki, M.; Al-Abri, A.; Al-Hinai, A. Sizing and modeling of photovoltaic water pumping system. *Int. J. Sustain. Energy* **2018**, *37*, 415–427. [CrossRef]
24. Kim, M.H.; Jeong, J.W. Experimental verification of a virtual water flowmeter applicable to air conditioning systems. *Energy Build.* **2017**, *155*, 425–438. [CrossRef]