A Design and Fabrication of a Solar Agriculture Water Pumping System

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Abstract

This study explores the use of a solar driven water pump. PV technology replaces conventional electricity and diesel pumps by using solar energy to power DC or AC water pumps. The main objective of this study is to design and construct a solar-powered agriculture water pumping system and to evaluate its performance. The solar agriculture water pumping system used in this project consists of a 40-watt monocrystalline solar cell with an efficiency conversion of between 23% – 24%. This can supply power to a 16.8 W DC Flow Submersible Pump. It could lift the water up to 5m and a flow range of 700 Liter/Hour. The system also includes a PWM 30A Solar Charge Controller to regulate the input power to a 12V, 7.2A Sealed Rechargeable Battery. Finally, a 20m long watering kit with nozzles irrigation system is connected to a 12V DC Submersible Pump to water the plants.

Keywords: Solar panel, water pumped, renewable energy, irrigation system, SPVWPS.

1. Introduction

Electricity is an essential element of nature and a widely utilized form of energy that is vital for various human activities, such as lighting and work. With the ever-increasing global population, energy consumption has surged significantly in recent times. From 2005 to 2014, global energy consumption increased by 18%, and it is expected to grow by 35% by 2035 [1]. Renewable energy sources, including biofuel, waste, hydro, solar, wind, geothermal, and thermal, Comprise merely 13% of global energy consumption. Fossil fuels, such as natural gas, coal, and oil, make up 81%, while nuclear power contributes only 5.7% [2]. Sustainable energy, such as water, sunlight, and wind, is a solution that has no harmful impact on the environment and contributes to achieving sustainable energy goals [3]. The sun is the most significant power source on Earth, providing more energy in one hour than all nations produce in a year. It delivers over 15,000 EJ of energy to the planet every day, which is more than 104 times the daily energy used by human activities [4]. However, only 0.1% of the sun's energy is consumed for electricity [5]. Alexandre-Edmond Becquerel observed the PV effect for the first time in 1839 [6]. The initial contemporary silicon solar cell was invented by Russel Ohl in 1946 [7]. Despite technological advancements, solar power installation costs five times more than coal, gas, or nuclear sources for electricity generation [8]. Agriculture is one of the important sectors in emerging nations. According to a World Bank estimate, rural agriculture areas employ nearly 86 percent of the global population (World Bank,2008). High water consumption coincides with periods of high solar irradiation. As a result, PV water pumping can help to alleviate the water shortage problem [9]. Climate change and population growth cause droughts and agricultural losses, prompting farmers to adopt solar-powered irrigation systems as an alternative energy source [10]. The world is facing a crisis in water and energy, both of which are critical for agricultural productivity. To cater to the needs of an expanding populace, a sustainable solution is necessary. The employment of solar photovoltaic water pumping systems is a feasible and economical substitute, especially in distant and undeveloped regions of developing nations. With continual innovation, these systems have gained widespread use in the industrial, residential, and agricultural sectors [11]. Solar Powered Photovoltaic Water Pumping Systems (SPVWPS) offers an alternative to traditional water pumping systems that rely on non-renewable sources like diesel, coal, and gas for electricity. Diesel systems require a lot of fuel, cause noise pollution, and result in environmental problems such as acid rain and greenhouse emissions [12]. Replacing diesel pumps with solar PV pumps costs 2-4 times as much. SPVWPS have eco-friendly operations and low maintenance costs [13]. Solar water pumping systems are in the nascent phase of development and require addressing several obstacles, including intermittent performance, steep upfront expenses, low efficiency of 15%-16%, and weather conditions that affect sun availability. Sun availability is not constant, and it varies from day to day, making it difficult to rely solely on solar power [14]. The performance of SPVWPS relies on factors such as the number of solar panels used, the type of controllers employed, and the energy storage system utilized. The pump, PV array adjustment, and ambient conditions also impact system efficiency. The maximum conversion efficiency of solar panels is 18%, and controllers like MPP tracking and charge controllers can increase efficiency and battery life. As SPVWPS only generates electricity during daylight, energy storage systems are used [15].

2. Methodology and Experimental Setup

The experimental setup comprises a 40-watt monocrystalline solar panel that generates a 12V DC output and 1.5A current. This panel is linked to a 30A PWM solar charge controller featuring an LCD controller and dual USB, which regulates the charging of 12V sealed lead-acid batteries with a 7.2AH capacity connected to the system. In addition, the charge controller is connected to a 12V DC submersible pump for water flow. This pump has a power range of 16.8W to 26.4W, a Nylon PA66 shell is placed in a 20L water tank. It can deliver a flow range of 700 to 800L/H and is programmed to operate at specific times via a timer. The pump is connected to a 20m water pipe and is part of a watering kit that includes spray nozzles, and tee connectors, designed for plant irrigations. Fig. 1 depicts the overall prototype.

Fig. 1 Solar agriculture water pumping system prototype

2.1. Design of solar agriculture water pumping system

The design of the system is presented in Fig. 2 SolidWorks has been employed to produce a detailed representation of the design. The external frame of the system is constructed using wood. Additionally, two sheets of plywood, each measuring 40cm by 45cm, are used as supporting pieces. One of these pieces accommodates the solar panels, while the other houses the battery, charge controller, and timer. A submersible pump located inside the water tank and the tank itself are other essential components of the system.

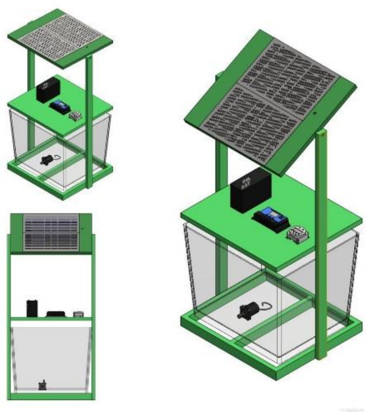

Fig. 2 Different views of the prototype

The overall connection is illustrated as a block diagram in Fig. 3. To acquire an accurate experimental result and compare it to the theoretical outcome.

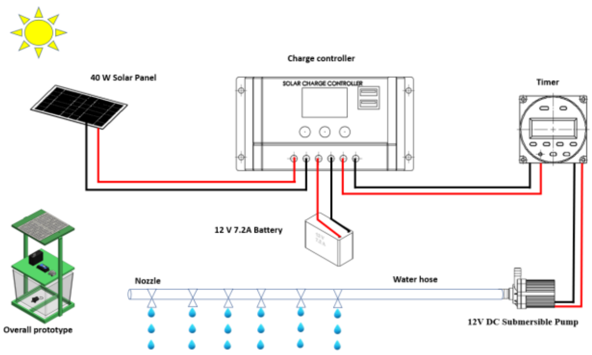

Fig. 3 Overall connection of the prototype.

3. Results and Discussion

In this section, Table 1 presents the average results for the three different solar panel orientation angles, with two different direct solar radiation of 854.3 W/m2 and 542.7 W/m2. Table 2 presents the average results of charging duration, solar panel voltage input, solar panel current input, and solar irradiations when the solar panel of three different tilt angles was placed directly under the sun. Additionally, Fig. 3 is displaying the average results of voltage drops, the discharge rate of water under two different conditions of discharge (nozzles connected to hoses of different lengths and free discharge), and the time required for the battery to be fully discharged. The readings shown in Table 3 are taken with a constant water volume of one litre per minute.

Table 1. The average readings throughout different tilt angles at Indoor two constant solar flux values.

	Direct solar radiation of 854.3 W/m²				Direct solar radiation of 542.7 W/m²			
Angle (°)	Charging Duration (Hour)	Solar Panel Voltage Input (V)	Solar Panel Current Input (A)	Light Intensity (W/m²)	Charging Duration (Hour)	Solar Panel Voltage Input (V)	Solar Panel Current Input (A)	Light Intensity (W/m²)
16	10	12.64	0.72	693.2	20	12.28	0.36	367.7
25	11.8	12.36	0.61	585.7	27.7	12.17	0.26	340.9
45	15.6	12.31	0.46	508.1	36.05	12.06	0.2	303.4

Table 2 .The average outdoor readings through different tilts angle of solar panel

Angle	Charging Duration (Hour)	Solar Panel Voltage Input (V)	Solar Panel Current Input (A)	Solar Irradiances (W/m²)
16°	5.76	12.68	1.25	961.67
25°	6.79	12.64	1.06	896.3
45°	7.58	12.44	0.95	783.5

Table 3. Overall average results for hoses of different lengths

Tube length	Voltage output (V)	The discharge rate of water using a nozzles (L/min)	The discharge rate of water without a nozzle (L/min)	battery fully discharge (hours)
5m	13	0.866	1.44	3.5
10m	12.98	0.636	1.10	3.28
15m	12.94	0.566	0.75	3.03
20m	12.9	0.458	0.625	2.47

3.1. *Light Intensity*

Fig. 4 illustrates the light intensity recorded by the solar panel at different tilt angles. As the tilt angle increases, the amount of light received by the panel decreases significantly, particularly when the light source is positioned further away from the solar panel. This reduced light exposure results in a diminished input of voltage and current, ultimately leading to a lower power output generated by the solar panel.

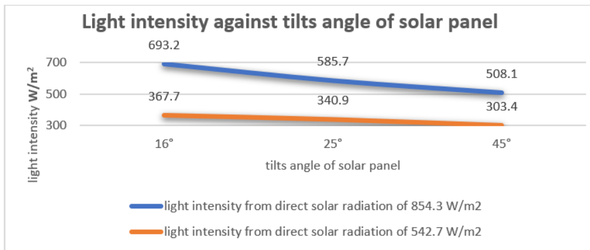

Fig. 4 Light intensity vs different tilt angles at two different indoor direct solar radiations

3.2. *Solar Irradiations*

Fig. 5 illustrates the solar panel's received solar irradiance at various tilt angles when placed directly under the sun.

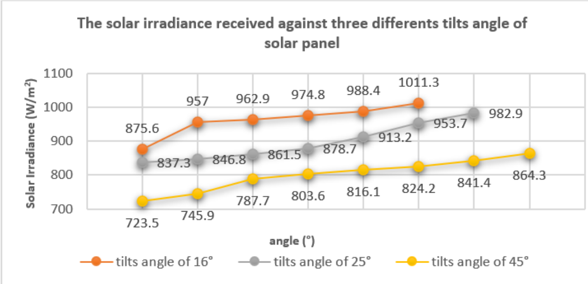

Fig. 5 Solar irradiance received at various tilt angles

Furthermore, it is observed that the solar panel receives the most radiation when placed at a smaller tilts angle, which leads to the generation of more power this can be seen in Fig. 6. Hence, it can be concluded that the tilts angle of the solar panel has a significant impact on the amount of radiation received and the subsequent power generated.

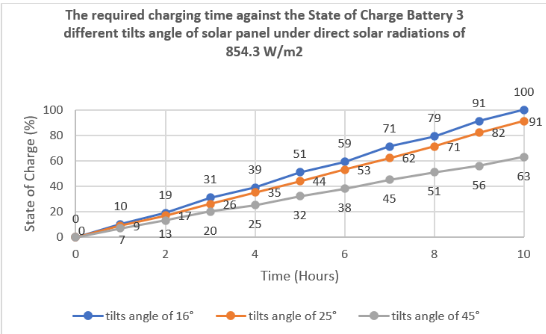

Fig. 6 Time required to charge battery against the state of charge at direct solar radiation of 854.3 W/m2

3.3. *Time required to charge the battery.*

In Fig. 6, the charging duration of the battery for three different tilts angles is shown as up to 10 hours when the height difference between the solar panel and the 1000-watt halogen bulb is 50 cm. Similarly, Fig. 7 illustrates the charging duration of the battery for the same tilt angles, but up to 20 hours and when the height difference is 70 cm. Furthermore, in Fig. 8, the duration to charge the battery for six hours is exhibited when it is situated directly under sunlight.

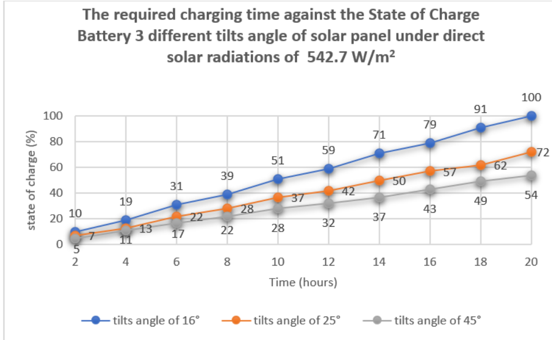

Fig 1. Time required to charge battery against the state of charge at direct solar radiation of 542.7 W/m^2

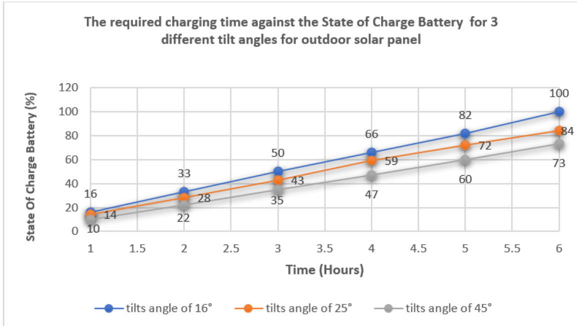

Fig 8. Time required to charge battery against the state of charge under outdoor sun light

Fig. 6 and Fig. 7 illustrate that the differences in the time required to charge the battery can be attributed to the amount of current generated by the solar panel, which is related to the amount of radiation received by the solar panel.

3.4. *The discharge rate of water*

Fig. 9 illustrates the collective findings of the water discharge experiment conducted with hoses of varying lengths and nozzle openings. The experiment involved the flow of one litre of water per minute from a 20L water tank. The presented results are based on the different percentages of nozzle openings tested.

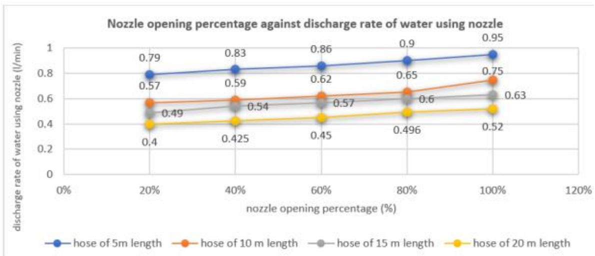

Fig 9. Discharge rate of water against nozzles of different percentage opening

According to Fig. 9, the highest water discharge rate achieved is approximately 0.95 L/min, which occurred when a 5m long hose is connected to the nozzle while maintaining a 100% opening. Conversely, the slowest water discharge rate of 0.4 L/min is observed when the hose is 20m long, and the nozzle opening percentage is 20%, unlike the hoses of 10m and 15m lengths. It is worth noting that friction between the water and the hose's inner surface, as well as changes in elevation or flow direction, contribute to losses in water pressure, known as head loss, during water pumping through a hose. Consequently, it can be inferred that hoses with smaller nozzle opening percentages offer more resistance to water flow, which leads to reduced water pressure and discharge rates.

3.5. *Maximum height water can reach*

Fig.10 presents the findings obtained by using hoses of different lengths which are 0.5m, 1m, 1.5m, 2.0m, 2.5m, and 3m to determine the maximum height that water can reach using a 12v DC submersible pump.

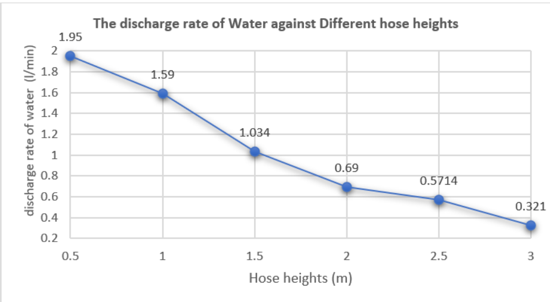

Fig. 2 The discharge rate of water against hoses of different heights

The graph shows that the pump can lift water to a maximum height of 3m with a discharge rate of approximately 0.321 l/min, while the minimum height of 0.5m has the fastest discharge rate of water at around 1.95 l/min. This indicates that the pump's lifting ability decreases as the height of the hose increases, resulting in a decrease in the water discharge rate. This is due to the longer hoses creating more resistance and reducing the flow rate.

4. Conclusion

The designed prototype for a solar irrigation system has been fabricated and tested. The study indicates that more solar radiation will result in higher charging power, which is useful for running the solar irrigation system. Additionally, the system is capable of pumping water up to 20 meters by fully utilizing solar energy.

To maximize the efficiency of the system, it has been found that the solar panel should be tilted at an appropriate angle for each location, which enables the collection of more solar energy and facilitates faster battery charging. Moreover, the system is capable of pumping water up to a height of 3 meters.

To maintain long battery life, it has been found that shorter irrigation pipes are more suitable. Furthermore, the study revealed that the solar collector efficiency is 80%. Overall, the designed solar irrigation system has demonstrated its capability in achieving its intended objectives, and the findings of the study have provided valuable insights for future system improvements.

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