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Design, Construction, and Performance Test of a Portable Solar Photovoltaic Water Pumping System for Irrigation and Household Water Supply

Sk. Suzauddin Yusuf [1], Md. Shariful Islam [2], Robiul Islam Rubel [3], Md. Abu Shaid Sujon [4], Mohd. Rafiqul Alam Beg [5]

[1,3] Department of Mechanical Engineering, Bangladesh Army University of Science and Technology, Saidpur, Bangladesh
[2] Engineering Department, Renata Limited, Vawal Mirzapur, Gazipur, Dhaka, Bangladesh
[4] Department of Mechanical Engineering, Islamic University of Technology, Gazipur, Bangladesh
[5] Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh

[1]akash09me@gmail.com, [2]mislam103@gmail.com, [3]rubel.ruet10@gmail.com, [4]sujonmce@iut-dhaka.edu, [5]rabeg.meruet@yahoo.com

Abstract

Agriculture is the single most important sector of Bangladesh’s economy. Due to the lack of power, and higher price of fuel, irrigation system is a great threat to farmers. Therefore, renewable energy like solar will be effective sources of power for them. Photovoltaic water pumping (PVWP) systems represent a feasible and renewable solution to support and promote the sustainable management of the water resources, and the development of the agricultural sector. The goal of this study is to design, and construct a portable solar photovoltaic water pumping system which used for irrigation in the cultivation and also used for water supply in the household purpose. Battery is not used in this project so this solar pumping system is able to reduce cost and complexity. Optimum discharge and efficiency of this system are 6.09 liter/min. and 4.41% respectively for 20 watt solar panel. Furthermore, it shows the comparative study of performance between solar water pump and electric pump based on cost.

Keywords: Photovoltaic water pump, Performance, Green Irrigation.

1. Introduction

Photovoltaic water pumping (PVWP) systems represent a feasible and renewable solution to support, and promote the sustainable management of the water resources, and the development of the agricultural sector [1-4]. Solar water pump is a type of water pumping system that works wherever there is abundant supply of sunlight. During summer time or during the time when sun rays are very strong, water requirement is very high, a solar water pump will prove to be a reliable and effective source of water for a farm. Solar water pump is an effective tool for farmers. Using this pump, they can easily move water from rivers, lake, ponds etc. Farmers and zealous gardeners can make savings on their irrigation budget if they use a solar water pump rather than a fuel powered pump. There are lack of researches of portable solar water pump which is used both irrigation and household water supply purpose. In many studies, battery is used recently for store energy which is produced by solar panel. Life time of battery is short and cost is high. So, cost and complexity of solar water pumping system is increased and farmers are less benefited. A typical solar powered pumping system consists of a solar panel array that powers an electric motor, which drives a pump. The goal of this project is to design, construction and performance test of a portable solar photovoltaic water pump which is used for irrigation in the field and also used for water supply in the household purpose. This project excludes storage battery to reduce cost and complexity.

The need for the optimum utilization of water and energy resources has become a vital issue during the last decade, and it will become more essential in the future. The availability of RESs such as solar photovoltaic, solar thermal, wind, biomass and various hybrid forms of energy sources provides good solutions for energy related problems in India [5]. To meet the energy demands and reduce the environmental impact, the idea of integrating RESs such as solar photovoltaic with water pumps has been proposed by many researchers around the world [6-7]. Earlier reviews reported in this area highlighted the historical development of solar energy water pumping systems for irrigation applications [8-9].

In related work, Mankbadi and Ayad [10] discussed the performance of small capacity direct SPWPS under the meteorological conditions of Egypt and reported that small capacity direct SPWPSs are most suitable for domestic water pumping applications. In a similar attempt, Qoaider and Steinbrecht [11] investigated the technical feasibility of SPWPS in the New Kalabsha village in the Lake Nasser region of southern Egypt. In their work, the technical design and the life cycle cost of the SPWPSs were calculated. The pumping system was designed to pump 111,000 m^3 of water daily to irrigate 1260 ha and also to power the adjacent households. Their studies concluded that SPWPSs are an economically competitive option for supplying energy to off-grid communities in arid regions compared to diesel generation systems. In a similar investigation, the performance of SPWPS was assessed both theoretically and experimentally [12].

In this project various watt rating solar panel was used and tested the performances (discharge, head, flow rate, and efficiency) of the pump at different solar intensity at different time of a day. Analyzing the optimum performance, a suitable watt rating solar panel was chosen. A storage water tank can be installed for storing water which can be used when sun light is not available. Watt rating of solar panel can be increased to increase head and discharge of water. PV powered pumping systems are cost-effective than diesel and ac pumping systems.

2. Design and Construction

Selection of pump

Selection of pump is based on head and discharge of water. The design of impeller is the main task of a pump. Mostly impeller design is based on velocity traingles.

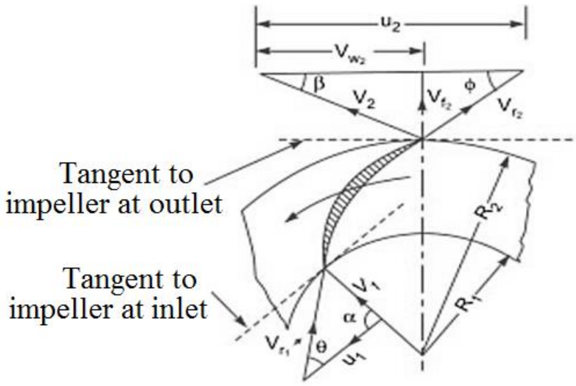


Fig. 1. Velocity triangle at inlet and outlet of water pump

Here,

n= Speed of the impeller in rpm
D_1 =Diameter of impeller at inlet
u_1=Tangential velocity of impeller at inlet
D_2 =Diameter of impeller at outlet
u_2=Tangential velocity of impeller at outlet
v_1=Absolute velocity of water at inlet
v_{r1}=Relative velocity of water at inlet
Θ=Vanes angle at inlet
ϕ=Outlet angle of blades
v_{w2}=Whirl speed of outlet
v_2, v_{r2} are corresponding values in outlet
B_1, B_2 are width of impeller at inlet and outlet

The discharge, head of the used pump in this project is Q, H.

Let, $Q = 14 \times 10^{-5} m^3$/s,

Head, H = 0.6m (with 10% safety factor)

Speed, n = 2050 rpm

Specific speed, $n_s = \frac{n\sqrt{Q}}{H^{3}/_{4}} = \frac{2050\sqrt{(14\times10^{-5})}}{0.6^{3}/_{4}} = 35.6$ rpm

For radial type impeller, 10< n_s<50, so the impeller is radial type.

Diameter of impeller at outlet, $D_2 = \frac{60}{\pi n}\sqrt{\frac{2gH}{\psi}} = \frac{60}{\pi\times2050}\sqrt{(\frac{2\times9.8\times0.6}{1.3})} = 0.028\text{m} = 28\text{mm}$

The tangential velocity of the impeller at outlet, $U_2 = \frac{\pi D_2 n}{60} = \frac{\pi\times.028\times2050}{60} = 3.01$m/s

Work done, $W = \frac{1}{g} v_{w2}u_2$ and Whirl velocity at outlet, v_{w2}=0.37m/s

Discharge, $Q = \pi D_2 B_2 v_{f2}$ or, $14\times 10^{-5} = \pi \times .028 \times 0.001 \times v_{f2}$

Flow velocity at outlet, v_{f2} = 1.59m/s

Outlet angle, $\tan\phi = \frac{\mathrm{Vf2}}{\mathrm{u2-Vw2}} = \frac{1.59}{3.01-0.37}$ or, $\phi = 25.19^\circ$

Number of blades according to approach Stepanoff , $Z = \frac{\phi}{3} = \frac{25.19}{3} = 8.4 \approx 8$

Flow velocity, $v_{f1} = \frac{Q}{A}$ and the tangential velocity of the impeller at inlet and outlet, $u_1 = \frac{\pi D_1 n}{60}$

Vane angle at inlet, $\tan\Theta = \frac{\mathrm{vf1}}{\mathrm{u1}}$ [where, $v_1 = v_{f1}$]

Output power of pump = Specific weight × Head × Discharge

For desired discharge and head, different dimensions are determined using $P_\circ = w \times H \times Q$

Dimensions of DC pump:

- Impeller outer diameter (D_2) = 28mm
- Impeller inlet diameter (D_1) = 14mm
- Width of blade (B) = 1mm
- Number of blade (Z) = 8
- Casing diameter = 30mm
- Clearance around the impeller = 1mm
- Casing length = 120mm
- Suction pipe diameter = 13mm
- Delivery pipe diameter = 13mm
- Suction pipe length = 45mm
- Delivery pipe length = 60mm

Specification of DC motor:

Voltage: 12-24 V, Ampere: 0.3-2 A., Torque: 14.12 Nm, Power: 14 W

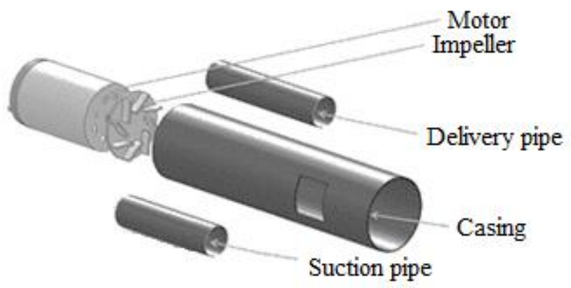


Fig. 2. Exploded views of water pump

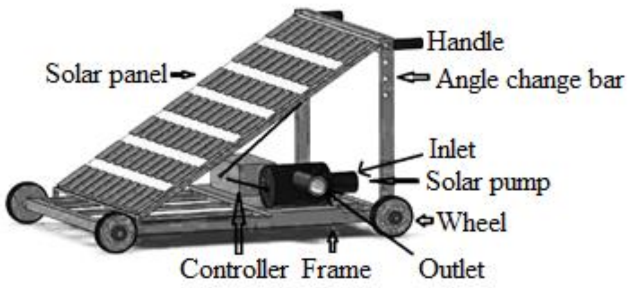


Fig. 3. Model of solar water pumping system

Main parts of PSPW pumping system

Supporting portable structure design: Supporting portable structure is manufactured from wooden bar, ply wood and pipe. Four wooded wheels attached with the structure for the movement of the system. Two wooded angle change bars attached. Two 25cm bars attached vertically and 60cm bar is attached with 25cm vertical bars.

Base design: The base of this portable solar water pumping system is made with wooded bar. The length the base is 75cm and width is 60cm. Two 75cm and two 60cm bars are attached to make the frame. Also, one 60cm bar is attached to support the pump and switch board.

Angle change bar: Two wooden angle change bars are attached to the end of the frame. It is used to change the angle of solar panel according to the change of solar intensity. The angle change bar's height is 84cm.

Inclined frame: Two 75cm iron pipe is used to make incline frame. One end is 1 inch drilled and this end hinge with 25cm vertical bars, and other end is free for easily up and down movement. The free ends are supported with 84cm bars. The solar panel is kept on the incline frame. Two or Three 60cm bars are used to support the solar panel.

Wheels: Four wooded wheels are used to move the system easily. The wheel's diameter is 8 inches.

Solar panel: Solar panel refers to a panel designed to absorb the sun's rays as a source of energy for generating electricity.

DC motor and pump: Pumps that use PV systems are normally powered by DC motors. These motors use the DC output from the PV panels directly. The 12-24 V centrifugal pump is used for this system. The suction end of pump is attached with water source and the delivery pipe is free for discharge water.

Switch board: It is used to control the pump and electricity flow from panel to pump. When the switch is on then the electricity flow from solar panel to pump and the pump begins to discharge.

Water storage: When solar photovoltaic water pumping system is used in household purpose then a water tank is needed to store water. For four people family 1000 to 1100 liters water required every day. In storage tank potential energy is stored in spite of chemical energy store in battery.

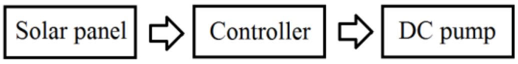


Fig. 4. Flow chart of water pumping system

3. Experimental Setup and Test Procedure

The portable solar panel was placed in such a direction that sunlight incident directly on the solar panel. The solar intensity was measured by a Digital photovoltaic trainer. It was connected to the solar panel in which a sensor was attached. The solar intensity, temperature, voltage, and current were directly shown at the display of this device. Standard value of solar intensity was collected using the *ANSYS* software. Then a correction factor was introduced to get the actual solar intensity.

$$\text{Input power of solar panel} = \text{Area of solar panel } (m^2) \times \text{Solar Intensity } (\text{Watt}/m^2)$$
$$\text{Output power of solar panel} = \text{Voltage across solar panel} \times \text{Current flow}$$

A dc pump was directly connected to the solar panel by electrical wires and a switch. After attaching the inlet port of pump with a suction pipe, priming was done. A transparent flexible pipe was attached to the end of outlet port of the dc pump. When the pump was running, the flexible pipe was kept straight against a vertical scale and the head of dc pump was directly measured from this scale. To measure the discharge of dc pump, water was collected for 20 seconds and its mass was measured. From these data, the discharge rate of dc pump was calculated. The readings were repeated at every 30 minutes interval.

4. Cost Comparison

Three types of water pumping systems such as solar photovoltaic water pumping system, electrical water pumping system (ac) for household use and diesel based water pumping system for irrigation were taken into consideration for estimating and comparing the cost of pumping water. Average life of a pumping system, price per unit electricity, discharge rate of water pumping system, price of diesel and other different parameter were considered to estimate the cost of pumping water.

Table-1: Cost for pumping 1000 liters of water in different types of pumping systems

Types	**Solar**	**Electrical**	**Diesel**
Cost for pumping 1000 liters of water (BDT)	0.46	0.85	4.39

Table-2: Cost saving in SPWP system compared to others for pumping 1000 liters of water

Types	**Cost saving(BDT)**	**Percentage of saving (%)**
Solar compared with Diesel	4.39 - 0.46 = 3.93	89.50
Solar compared with Electrical	0.85 - 0.46 = 0.39	45.80

5. Results and Discussions

The portable solar photovoltaic water pumping system is investigated experimentally from August to December under weather condition of Rajshahi. The readings are taking at day time from 9am to 4pm.

Fig. 5, shows the change of input power of dc pump with solar intensity. From Fig. 5, it is clear that input power of dc pump is almost linearly increased with increasing solar intensity for all the solar panels. The output power of solar panel is equal to the input power of dc pump. The curves for 20 Watt and 25 Watt solar panels are steeper than those curves of 6 Watt, 10 Watt and 15 Watt. Fluctuations of input power of dc pump are observed in some points of curves due to decrease of solar cell efficiency because of increment of solar panel temperature. From Fig. 7, it is observed that voltage across dc pump is increased with increasing solar intensity for all the solar panels (6, 10, 15, 20, 25 Watt). For 25 Watt solar panel, voltage across dc pump is increased from 10.3 V to 16.3 V with increasing solar intensity.

From Fig.7, it is observed that discharge is almost linearly increased with increasing solar intensity for all the solar panels (6, 10, 15, 20, 25 Watt). The minimum discharge is found 2.0×10^{-5} m^3/s, while using 6 Watt solar panel at 150 Watt/m^2

solar intensity. The maximum discharge is found 12.11×10^{-5} m^3/s, while using 25 Watt solar panel at 710 Watt/m^2 solar intensity. The average discharge of the system is increased with higher watt rating of solar panel. Fig. 8, shows the change of head of water with respect to solar intensity. It is shown in the Fig. 9 that head is slowly increased with increasing solar intensity. The minimum head is found 0.21m when using 6 Watt solar panel at 200 Watt/m^2. The maximum head is found 0.45m while using 25 Watt solar panel at 950 Watt/m^2 solar intensity. The head of dc pump is increased with higher watt rating of solar panel.

Fig. 9 shows the variation of dc pump efficiency with solar intensity. The maximum efficiency of dc pump is 5.67 % at 685 Watt/m^2 solar intensity when using 10 Watt solar panel. The efficiency of dc pump is increased with increasing solar intensity. From Fig. 9, it can be easily seen that the average efficiency of dc pump is high when using 10 Watt and 15 Watt solar panels. When 20 Watt and 25 Watt solar panels are used, the average efficiency of dc pump is lower than the efficiency of dc pump where 10 Watt and 15 Watt solar panels are used. The average efficiency of dc pump is 4.41 % when 20 Watt solar panel is used. In some point of curves, the efficiencies of dc pump are fall. It can be occurred because of decreasing solar panel efficiency or input power of dc pump due to increase of solar panel temperature.

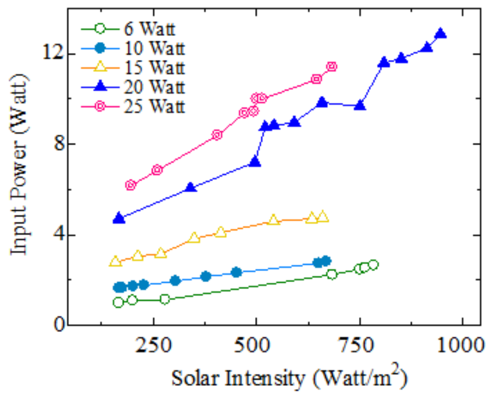


Fig. 5. Solar Intensity vs. Input Power

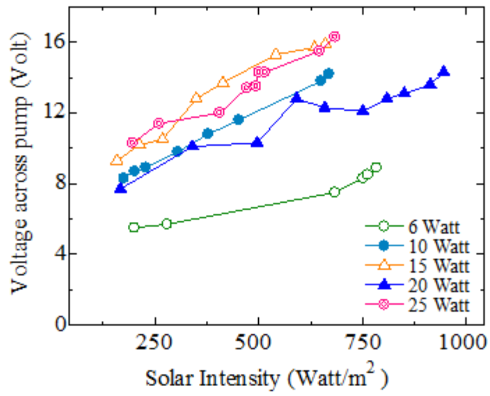


Fig. 6. Solar Intensity vs. Voltage across pump curve

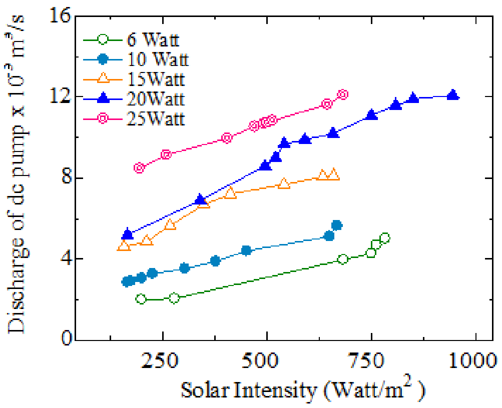


Fig. 7. Solar Intensity vs. Discharge of pump curve

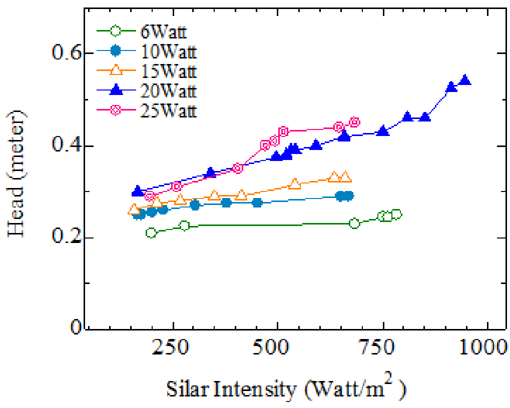
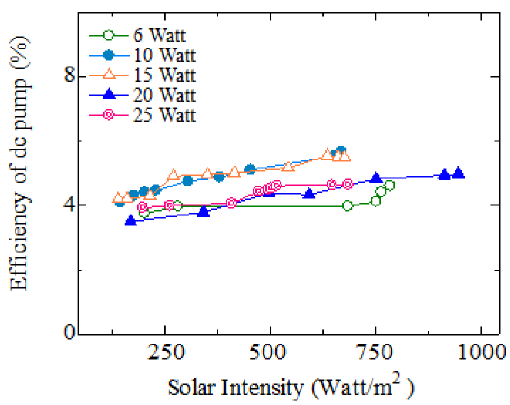


Fig. 8. Solar Intensity vs. Head of pump curve



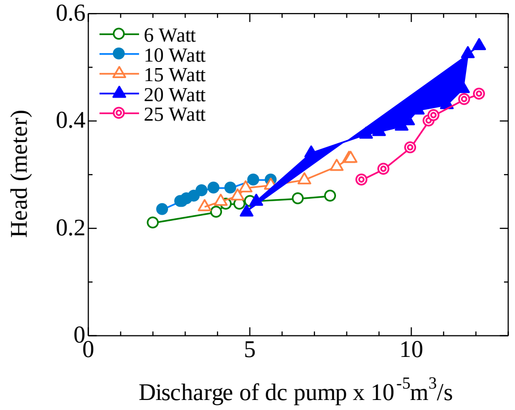


Fig. 9. Solar Intensity vs. Efficiency curve

Fig. 10. Discharge vs. Head of DC pump curve

Fig. 10 shows the variation of head of water with the change of discharge of the dc pump. Head of water is increased with increasing discharge of dc pump for all the conditions with increasing solar intensity. The curves for 6 watts, 10 Watt and 15 Watt solar panels are not so steeper. But the curves for 20 Watt and 25 Watt are steeper than others. Due to high input power, both discharge and head are rapidly increased when 20 Watt and 25 Watt are used in the system. Maximum head of water is 0.54m at 12.1×10^{-5} m^3/s discharge rate of dc pump for 20 Watt solar panel.

6. Conclusion

In this project a solar water pump is designed and tested. For designing, discharge was taken 14×10^{-5} m^3/s and practical value was observed 12.1×10^{-5} m^3/s which is satisfactory. The maximum efficiency of the portable solar photovoltaic water pumping system is 4.85% when using 15 watt solar panel. The maximum discharge of portable solar photovoltaic water pumping system is 6.28 liter/min. when using 25 watt solar panel. But optimum discharge and efficiency are observed when using 20 watt solar panel. The optimum discharge and efficiency are 6.09 liter/min. and 4.41% respectively. The portable solar water pumping system is made which is suitable for both irrigation and household water supply. The main purpose of this this project is to reduce cost and to make it as a general mass use. So, if the utilization of the solar pump is increased in agricultural area, then it will be helpful to our country's economy.

7. Acknowledgement

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