DESIGN AND ANALYSIS OF A LOW COST SOLAR WATER PUMP FOR IRRIGATION IN BANGLADESH

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Abstract: *Bangladesh, a developing country of south-east Asia with large population has agricultural economy. About 59 percent cultivable land needs irrigation. During dry season and due to climate change, demand of electricity for electric power irrigation is increasing. Irrigation by electric power is cheaper than diesel pump. Due to severe shortage of electricity it is difficult to meet the demand. Harnessing solar power for irrigation is a good alternative to grid electricity. This paper deals with the design, technical and economic analysis of a low cost 1 hp (746 W) small size dc photovoltaic water pumping system for irrigation. A buck converter is designed and constructed to improve the performance of the dc pump. All components of the system are procured locally except the solar panels.*

Keywords: *Solar water pump, irrigation, buck converter.*

INTRODUCTION

During dry season in December-April, irrigation is necessary for rice and winter vegetable cultivation. There is severe energy crisis in Bangladesh. Only 53 percent population[1] has access to electricity. Per capita power consumption is only 230 kWh. Most of the power supply is limited to urban areas; access to electricity in rural areas is less than 30% . In Bangladesh three types of water pumps are used for irrigation, i.e. Low Lift Pump (LLP), Shallow Tube Well (STW) and Deep Tube Well (DTW). LLP and STW mostly use diesel and DTW is mainly operated by electricity. A solar-powered water pumping system initially costs more than a diesel or electric powered pump but requires far less maintenance and labor. Comparing installation costs (including labor), fuel costs and maintenance costs over 10-year period, it is observed that solar pump is an alternate choice. Bangladesh situated between 20.30-26.38° north latitude and 88.04-92.44° east longitude, with average solar radiation between 4 and 5 kWh/m^2/day, is ideal location for solar energy harvesting.

With the reduction of price of solar panel and electronic components solar power is now an economically viable option for irrigation. A PV operated solar pump was tested for irrigation in Bangladesh Rice Research Institute (BARI) during 80s. It was technically suitable for low lift small scale surface water irrigation. But this was not found economically viable at that time due to high cost of PV panels[2]. A Rutgers University study shows that vegetable growing using solar pump irrigation is cost effective compared to electricity powered drip irrigation[3]. Solar pump irrigation is also found economically viable by studies[4,5,6]. Solar pump may be an alternative for small scale irrigation for vegetable production in the off-grid areas especially in the char (small island) areas[7] of Bangladesh. Solar powered pumping systems are capable of delivering water from rivers and wells in volumes up to 9000 l/minute[3]. A dc solar pump is designed and assembled[8] using locally available components and tested in the Fluid Mechanics Laboratory of Mechanical Engineering Department of BUET. A pump controller using buck converter is designed and implemented to increase the overall efficiency of the pump. Its performance analysis and economic viability are also done and shown in this paper. The present 1 hp (746 W) solar pump is suitable for irrigation using surface water during winter season and during day time. Locally available pump and motor was never used before for solar water pumping in Bangladesh. The usefulness of this type of technology innovation is that farmers and technicians in remote villages can maintain and keep running this type of water pump system.

DESIGN OF DC SOLAR PUMP

A dc permanent magnet motor of 1 hp (746 W), 12 V was procured from local market and solidly coupled to the centrifugal pump. DC motor was chosen as it does not require an inverter. To see the performance, first the dc motor was connected directly to the solar panels. Twelve 75 W$_p$, 12 % efficient, solar modules were used as power source. About 450 watts of power could be obtained as the irradiance was only about 400 watts/m^2. To increase the current, modules were connected in combination of 5 panels in two rows and 2 panels in 1 row. The

performance of the pump without any converter was not satisfactory as it could not supply the initial torque of the motor.

A buck converter is designed to supply initial high current to the motor for starting purpose and smooth running of the motor. The performance improved after the integration of buck converter. Buck converter reduces the panel voltage of 17-18 V (depending on sun shine) to 12 V. Fig. 1 shows the design. The values of the components are, V_{in}=17 V, V_{out}=12 V, Duty Cycle, k=0.705, I_{ripple}=0.117 A, L_1=1.004 mH, C_{out}=211 µF, I_{diode}=15.1689 A.
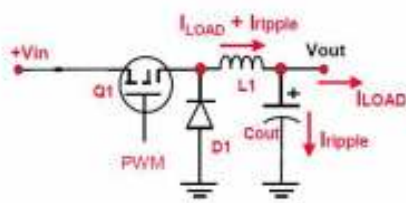

Figure 1. Buck converter for Power Conditioning Unit (PCU).

Figure 2. Top: The solar panels. Bottom: The experimental set-up on roof top near the panels.

DATA ANALYSIS

The solar panels were set-up at an angle of 23° south facing (optimum angle for Bangladesh) on the roof top of adjacent laboratory. First the solar water pump was directly connected to the solar panel. It is found that the system works. However, as the dc motor works at 12 V, a high current of 40-60 A would flow. Moreover, as the back emf of dc motor is related to the speed of the motor, it shows

a lower speed than actually needed to run the pump. Final testing of the pump was done at the reservoir of Fluid Mechanics laboratory.

No Load Test

To check the performance of the pump after integration with the dc motor, no load test was performed. In the no load test, the system was supplied from dc power supply in the laboratory without any load on the system. Supplied voltage, current and speed of the system were recorded as shown in Table 1.

Table 1. No load test data

Voltage, V	Current, A	Speed, rpm
10	11.5	2400
11	12.0	2560
12	12.0	2850
13	12.5	3060
13	14.0	3200

The highest no load speed goes up to 3000-3200 rpm. The result from the no load test reveals that the integration of the dc motor with the centrifugal pump matched satisfactorily.

Direct Coupled System Performance

The pump motor set was directly connected to the solar panels without any power conditioning unit. The voltage, current, speed and discharge are tabulated in Table 2. The performance is not satisfactory, because dc motor requires a high starting current which the panel could not supply. In absence of initial high current, voltage could not be built and the starting torque is low. So the water discharge was also low. Moreover, the alignment of the dc motor was not perfect with centrifugal pump, so the power transfer was less.

Table 2. Direct coupled system data

Voltage, V	Current, A	Speed, rpm	Discharge, l/min
5	20	880	10
5	22	920	13
6	25	950	14
6	28	1000	22
6.1	30	1020	24

System Performance using a Buck Converter

The designed buck converter is connected between motor-pump and solar panels. The performance improved. Data are collected over a period of few days in winter. The data are shown in

Table III. The total head was considered as 18 ft (5.5 m).

Table 3. Characteristics data of the solar pump

| Irradiance, W/m2	Voltage, V	Current, A	Theoretical array power, W	Power consumed by pump, W	Discharge Pressure, kPa	Discharge water, l	Discharge time, min	Discharge, l/min	Total head, m	Efficiency , %
278	5.30	25	253.16	132.50	48.27	7.90	1.12	7.03	5.40	4.60
300	5.60	28	273.20	156.80	41.37	8.30	0.75	10.99	4.69	5.14
330	6.10	31	300.52	189.10	34.48	13.82	0.66	20.99	4.08	7.50
336	6.80	32	305.98	217.60	32.41	14.10	0.50	28.20	3.75	7.70
345	7.00	35	314.18	245.00	28.96	6.50	0.17	38.23	3.44	8.80
356	7.15	38	324.19	271.70	28.27	13.00	0.33	39.39	3.32	9.90
365	7.36	42	332.40	309.10	27.58	9.70	0.17	58.20	3.26	10.10
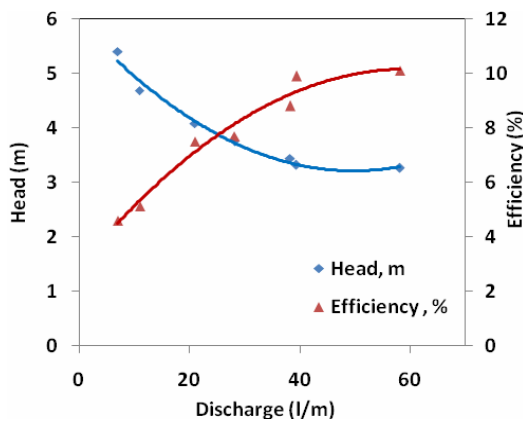
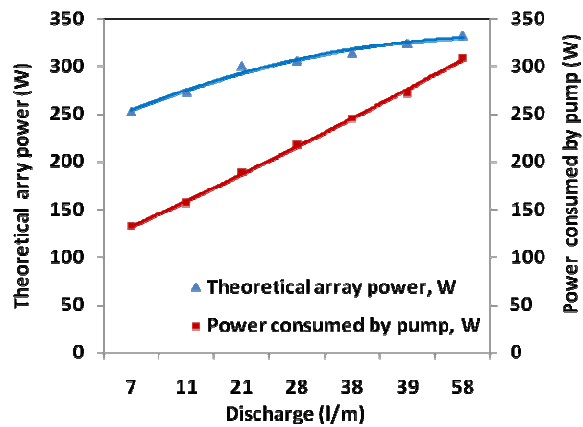Figure 3. Discharge versus head and efficiency of the pump

Figure 4. Discharge versus theoretical array power and power consumed by pump.

The characteristic of solar pump motor is similar to theoretical characteristics. In Fig. 3, discharge increases as head decreases and efficiency increases as discharge increases. In Fig. 4, power consumed by pump is less than theoretical array power. The discharge capacity was found in the range of 35-58 l/min. This discharge capacity is expected to increase in the summer season with increased irradiance.

PERFORMANCE AND COST ANALYSIS

A dc solar pump is designed and implemented using locally available technologies to investigate a way to reduce dependency on diesel and electricity driven water pumps in agriculture. The costs of these locally developed solar pumps will be less than the imported ones and repair, maintenance costs will also be low. Moreover, since these dc

pumps will run without battery and inverter, maintenance will also be less and easy. This one horse (746 W) power solar pump system will cost about BDT.112,000. The BUET designed pump was compared with the results of a study[9] of different typs of solar pump done at Bangladesh Agricultural Research Institute (BARI), Dhaka and is shown in Table 4.

Benefit cost ratio[9] for solar irrigated tomato and brinjal (egg apple) by drip and furrow irrigation were 3.45, 3.71 and 1.57, 1.37 respectively. At present, rice cultivation by solar water pump is not economically viable.

CONCLUSION

Solar photovoltaic pumping offers a way out to the farmers of Bangladesh from the energy crisis. This paper demonstrates that solar photovoltaic technology can be integrated to irrigation systems in Bangladesh. Some technological challenges were overcome through engineering solutions and showed a representative model can be implemented. Upfront cost of the solar pumping systems potentially hinder to popularize the systems in rural areas but private companies, bank and government can come forward for a solution that can fit to rural people of Bangladesh. Advantages of the locally developed solar water pumping system are, cost of indigenous solar water pumping systems will less than imported ones, dependence on the demand of diesel and electricity will reduce, maintenance cost will be less because imported systems after passing of one year (guarantee) period take longer time and higher cost for repair. Moreover, due to use of local pump, local technicians and farmer can easily install and change the pumps whenever necessary. Higher panel efficiency and higher operating voltage will improve the performance of the pump. Carbon credit will be an added benefit.

Table 4. Comparisons of different types of solar pumps.

Specification/features	Designed by BUET	Designed by BARI	Designed by Dhaka University (DU)	Made in USA	Made in Australia	Made in China
Make and model	BUET, Bangladesh	BARI, Bangladesh	DU, Bangladesh	Honeywell, USA	Mono Pumps, Australia	Lorentz, Germany
Pump type	Centrifugal	Centrifugal	Centrifugal	Centrifugal	Submersible	Submersible
Motor type	dc	dc	ac	dc	dc	dc
Suitability	Surface water	Surface water	Surface water	Surface water	Surface and ground water	Surface and ground water
Suction and delivery pipe diameter, mm	38(1.5″)	38(1.5″)	25(1.0″)	38(1.5″)	25(1.0″)	38(1.5″)
Motor capacity, W	746	800	373	373	373	1640
Motor rpm (max.)	3000	2800	2900	2800	3200	3200
Voltage, V	12	48	220	58	180	90
Total panel power, W	900	900	675	600	600	1050
Average discharge, l/min	56	60	34	100	90	120
Price of pump set with controller(BD Taka)	22000	25000	75000	150000	150000	200000
Price of solar panels (BDT)	90000	90000	67500	60000	60000	105000
Total cost of solar pump, BDT*	112,000	115,000	142,500	210,000	210,000	305,000

*US$ 1=BDT 83

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