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The Performance of Photovoltaic System for Pumping Water at Various Lifting Heads

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ABSTRACT

These studies investigate experimentally the performance of photovoltaic system for operating the pump coupled by dc-motor. The photovoltaic panel with total area 1.9848 m^2 consists of three modules of 80 WP each. The small centrifugal pump is operated to lift water 1m, 2m, 3m, 4m heads and gives the amount of water pumped over the whole day from 0800 to 1700 h are 8294, 7296, 5661, 3925 L/d respectively. The hourly global solar radiation during the day is an average of 506 W/m^2. This study is also presented the I-V characteristics of the panel at global radiations 300, 500, 700, 900 W/m^2 matched with the operation of the pump at the above lifting heads.

Keywords: photovoltaic, dc- motor-pump, I-V characteristics

1. INTRODUCTION

Photovoltaic is the most way to convert directly solar energy into dc-electricity. The devices used in photovoltaic conversion are called solar cells. The solar cells have no moving part, environmental friendly, require little maintenance, and work quiet satisfactorily with beam or diffuse radiation. As a result, it is possible that in the future they may become one of the important sources of power for providing small amounts of electrical energy for localized use, particularly in remote locations.

Solar cells are made by bonding together *p*-type and *n*-type semiconductors (Fig. 1). When a solar cell is exposed to light, electron-hole pairs are generated in proportion to the intensity of the light. The negatively charged electrons move to the *n*-type semiconductor while the positively charged holes move to the *p*-type semiconductor. They collect at both electrodes to form a potential. When the two electrodes are connected by a wire, current flows and the electric power thus generated can be transferred to an outside application.

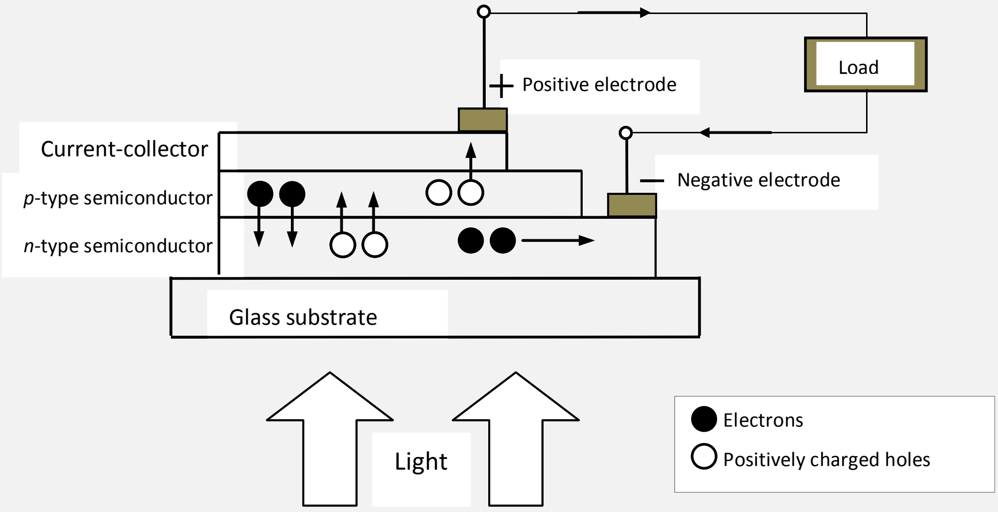

Figure 1. Power generated by solar cells

2. SCHEMATIC DIAGRAM OF THE INSTALLATION

The purpose of this paper is to present and to evaluate measurement of a solar cells panel which consists of three modules with capacity 80 Wp each for pumping water. The total area of the panel is 1.9848 m^2. The schematic of the installation is as shown in Fig. 2. The global radiation is measured by pyranometer in April 14^{th} - 17^{th} from 0800 to 1700 h. The panel is used to run the dc-motor-pump for water lifting heads: 1 m, 2 m, 3 m, and 4 m. The dc-current and voltage of the panel output and of motor input are measured by multimeter. The flow rates of the pump for different lifting heads over a day are measured by glass meter and stopwatch.

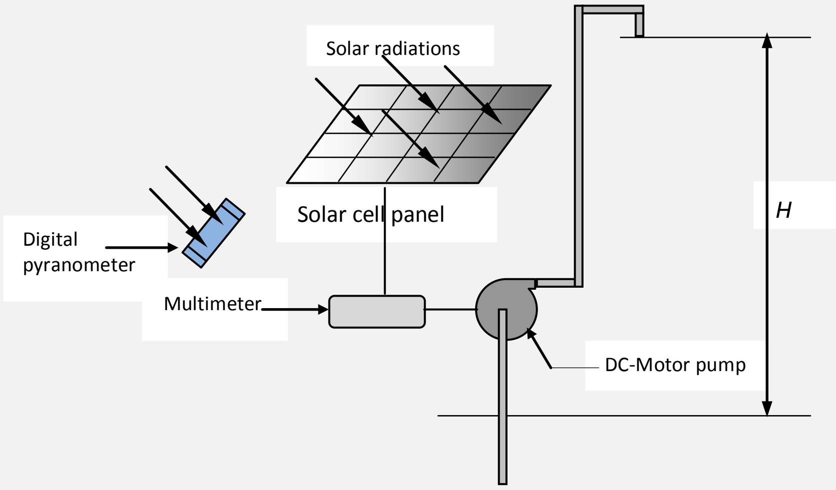

Figure 2 Schematic of Solar cell panel for water pumping

3. ANALYSIS AND DISCUSSIONS

The experiments have been carried out at Renewable Energy Laboratory, Hasanuddin University over a day from 0800 to 1700. The solar cells panel area A_p = 1.9848 m^2, inclined 15^o and facing north. Based on reference [1], the incident angle θ is the angle between the incident beam of flux I_{bn} and the normal to panel can be related as equation below:

$\cos\theta = \sin\delta \sin(\phi+\beta) + \cos\delta \cos\omega \cos(\phi+\beta)$

Declination angle: $\delta = 23.34\, sin\left[\frac{360}{365}(284+n)\right]$

The day of the year n = 104, 105, 106 and 107 for dated from April 14th to 17th.

Latitude angle ϕ = – 5.1^o LS

Slope of panel β = 15^o

Hour angle ω = (12 – LAT) × 15^o. LAT is local apparent time and be counted from 0800 to 1700 h.

Then normal global radiation reaching the panel is:

$I_g = I_{bn} \cos\theta + I_d$

Solar beam and diffuse radiation I_{bn} and I_d can be taken as 85% and 15% from measured global radiation $I_{g.meas}$ in clear sky.

The variations of actual global radiation incident normally on the panel and the pumping flow rates for different lifting heads over a day are shown in Figure 3 and Figure 4 respectively. The two figure show that the variation of the water discharges by the pump over a day indicates a strong dependence in radiation incident on the solar panel. Figure 4 shows the higher lifting heads the lower discharges and thus agrees with the *H-Q* centrifugal-pump characteristics. Figure 5 shows the variations of panel efficiencies over a day. It indicates that the efficiencies decrease with increase in the working temperature. In this condition, the open circuit voltage decreases more sharply than the short circuit current [2,3]

It is also can be drawn the *I-V* characteristics of the panel matched with the operations of the pump at different lifting heads as shown in Figure 6. This figure is based on data on Table 3.

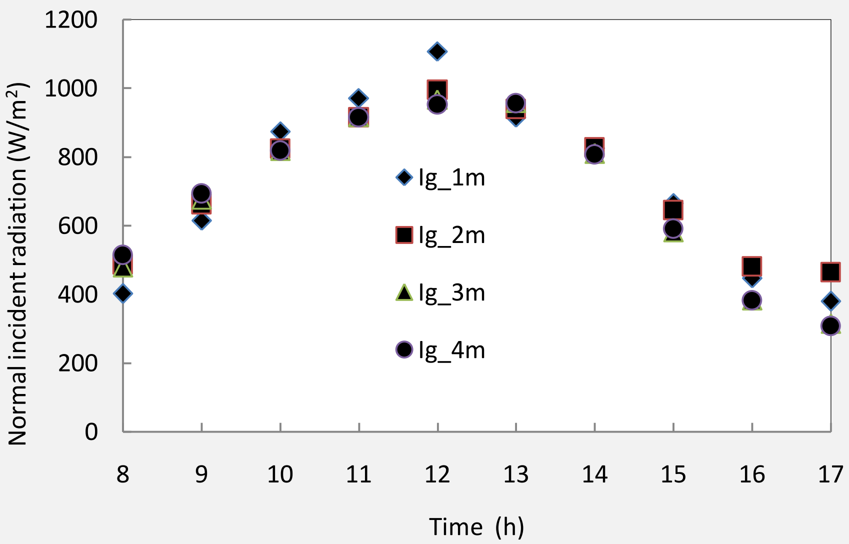

Figure 3 Variation of global radiation incident normally on the panel over a day

The figure shows that lifting head 1m can be operated at solar radiation 300 to 900 W/m^2, 2 m and 3m for solar radiation 500 to 900 W/m^2, 4 m for solar radiation 700 and 900 W/m^2. On the contrary solar radiation 700 and 900 W/m^2 can operate dc-motor pump for 1 to 4 m lifting head, 500 W/m^2 for 1 to 3 m, and 300 W/m^2 for 1 m only. It can be conclude that pump needs more energy and thus solar radiation to overcome the higher lifting head.

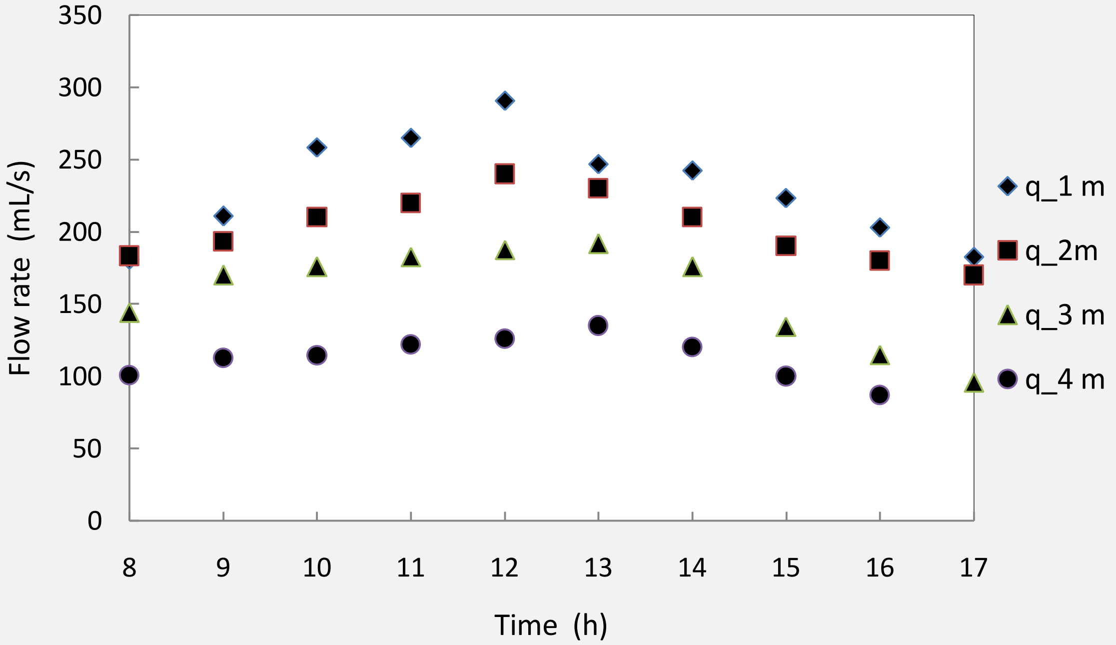

Figure 4 Variations of pumping flow rate over a day at various head

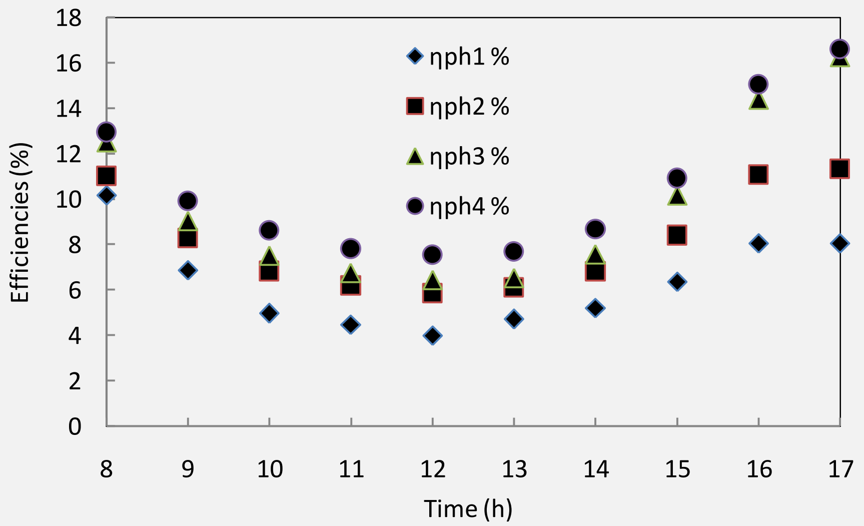

Figure 5 Variations of panel efficiencies over a day

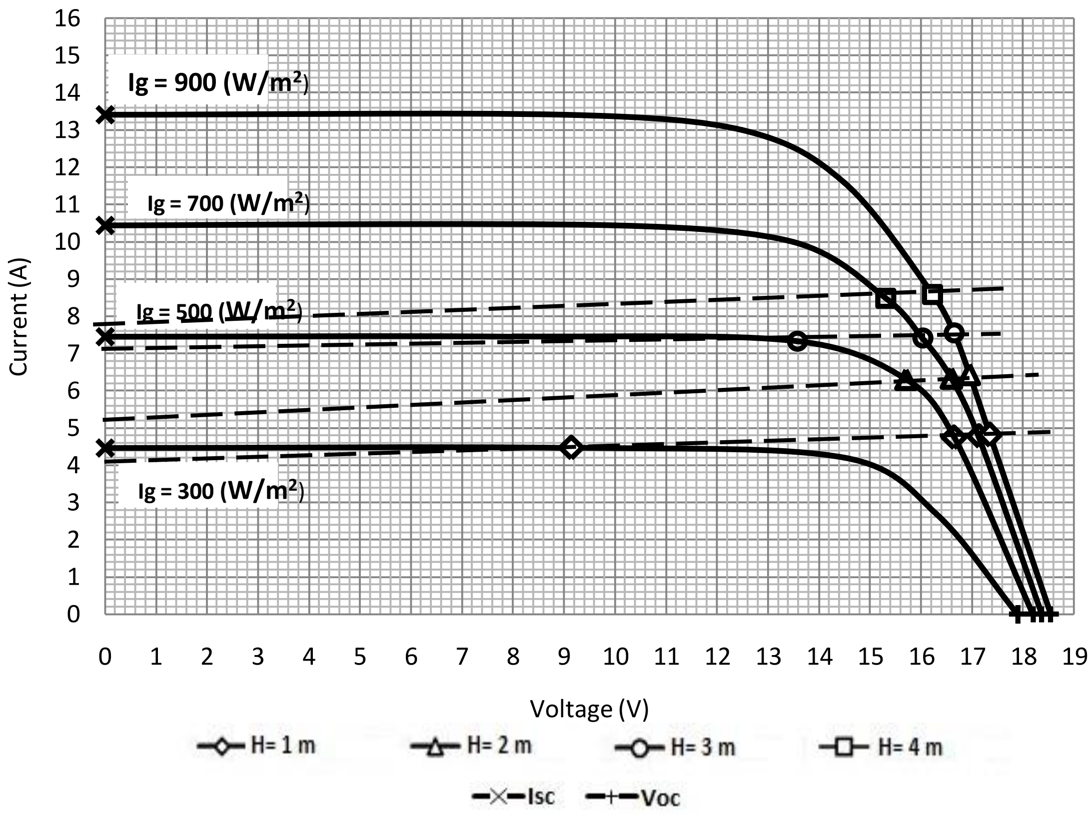

Figure 6 I-V Characteristic of the panel at different Ig and pumping head

Table 3 shows, the more solar radiation (I_g) then the more energy input to dc-motor pump (*IV*), and the more lifting head can be produced.

A good idea is to calculate amount water pumped, energies consumed by the dc-motor pump from the panel and energies produced by the dc-motor pump in water over the whole day.

Amount water pumped: $Q = \sum_{08.00}^{17.00} q \times 3600$ [L]
Energy received by the panel: $E_{\text{panel}} = \sum_{08.00}^{17.00} A_p \times Ig_{normal} \times t$ [W-h]
Energy consumed by the dc-motor pump: $E_{\text{motor}} = \sum_{08.00}^{17.00} V \times I \times t$ [W-h]
Energy produced by the dc-motor pump in water: $E_{\text{water}} = \sum_{08.00}^{17.00} \rho g q H \times t$ [w-h]
Efficiency of the system: $\eta_{system} = \frac{E_{water}}{E_{panel}}$ [%]
Efficiency of the pump: $\eta_{pump} = \frac{E_{water}}{E_{motor}}$ [%]

Based the data on Table 2 we calculated the above energies and efficiencies, and the results are given on Tabel 1.

Table 1 The energies and efficiencies of the solar cell panel system for water pumping at various lifting heads

Item	Pumping head			
	H = 1 m	H = 2 m	H = 3 m	H = 4 m
$I_{g\_meas.av}$ [W/m^2]	513.71	524.39	493.12	492.08
$I_{g\_norm.av}$ [W/m^2]	423.37	425.51	405.85	404.72
E_{panel} [kW-h)	14.29	14.36	13.69	13.66
Q [L]	8294	7296	5661	3925
E_{motor}[W-h)	810.79	1096.12	1181.47	1319.94
E_{water}[W-h)	22.60	39.76	46.28	61.70
η_{system} [%]	0.16	0.28	0.34	0.45
η_{pump}[%]	2.79	3.63	3.92	4.68

It can be seen from the Table 1 that at nearly the same energies received by the panel at different lifting heads, will produce the increase in E_{motor}, E_{water} , η_{system}, and η_{pump}, but the decrease in water pumped Q. The lower efficiencies of the system and dc-motor pump are due to improper construction of the motor-pump, since it is self manufactured, and the decrease of Q because of the restriction of H-Q centrifugal-pump characteristics.

The data given above indicate that increase of the lifting heads are followed by the increase of the efficiencies, these conditions will be further explored since the centrifugal pump characteristic shows the further increase of head will lower the efficiency. This will be done by using standard dc-motor pump with the capacity > 100 W and operated at lifting heads higher than 4 m.

4. CONCLUSION

From the studies one can conclude:

1. The variation of water discharge by the pump over a day indicates a strong dependence in radiation incident on the solar panel.
2. The I-V characteristics of the panel matched with the operations of the pump at different lifting heads show there are interdependent between solar radiations and lifting head of the pump. The higher the radiation the higher the pump to produce the lifting head. At radiation 300 W/m^2, the pump can only be operated for 1 m lifting head.

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Table 2 Measuring data in solar panel system on various pumping heads over a day

Time	*Ig*_meas.[Wm^2]				*Ig*_norm.[W/m^2]				*I* [A]				*V* [V]				*q* [mL/s]			
	H=1m	H=2m	H=3m	H=4m	H=1m	H=2m	H=3m	H=4m	H=1m	H=2m	H=3m	H=4m	H=1m	H=2m	H=3m	H=4m	H=1m	H=2m	H=3m	H=4m
0800	683	826.67	814	830	401.18	485.33	477.90	513.77	4.73	6.28	7.21	8.28	17.13	16.9	16.44	15.94	180.75	183.33	144.25	100.75
0900	811	873.33	891	881	614.83	662.09	675.74	693.17	4.80	6.38	7.25	8.46	17.44	17.03	16.70	16.13	210.75	193.33	170.00	112.50
1000	982	926.00	919	920	873.34	823.54	817.31	818.20	4.84	6.49	7.26	8.60	17.76	17.18	16.79	16.27	258.25	210.00	175.75	114.25
1100	999	941.00	943	941	971.20	914.50	916.45	914.83	4.85	6.52	7.28	8.67	17.79	17.22	16.87	16.35	265.00	220.00	182.5	121.75
1200	1107	994.33	968	952	1106.98	994.31	967.65	952.32	4.88	6.63	7.29	8.71	17.99	17.37	16.95	16.39	290.75	240.00	187.5	125.75
1300	941	966.00	985	983	914.50	938.80	957.59	955.00	4.83	6.57	7.30	8.81	17.68	17.29	17.01	16.50	246.75	230.00	191.75	135.00
1400	927	930.33	910	907	824.72	827.39	809.31	806.34	4.82	6.50	7.26	8.55	17.66	17.19	16.76	16.22	242.5	210.00	175.75	120.00
1500	844	849.00	766	778	665.12	643.64	580.47	589.82	4.80	6.33	7.19	8.10	17.50	16.96	16.29	15.76	223.25	190.00	134.25	100.00
1600	761	819.00	651	650	446.78	480.83	382.40	381.81	4.40	6.26	6.94	7.60	16.22	16.88	15.74	15.01	203.00	180.00	115.00	86.75
1700	645	789.00	536	523	378.68	463.22	314.68	307.05	4.05	6.20	6.68	7.10	14.93	16.79	15.19	14.25	182.75	170.00	95.75	73.50

Table 3 Operation data of current and voltage at various solar radiation

Ig [W/m^2]	I_{SC} [A]	V_{OC} [V]	*H* = 1m			H = 2m			*H* = 3m			*H* = 4m		
			I [A]	*V* [V]	*IV* [W]	*I* [A]	*V* [V]	*IV* [W]	*I* [A]	*V* [V]	*IV* [W]	*I* [A]	*V* [V]	*IV* [W]
300	4.47	17.90	4.46	9.15	40.81	0	0	0	0	0	0	0	0	0
500	7.46	18.10	4.75	16.65	79.09	6.31	15.70	99.07	7.34	13.57	99.60	0	0	0
700	10.45	18.37	4.78	17.13	81.88	6.35	16.59	105.35	7.42	16.03	118.94	8.50	15.30	130.05
900	13.42	18.54	4.81	17.35	83.45	6.44	16.95	109.16	7.57	16.64	125.96	8.60	16.22	139.49