World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:7, No:6, 2013

The Best Efficiency Point of the Performance of Solar Cell Panel System for Pumping Water at Various Lifting Heads Using 100 W Motor-Pump Unit

S. Himran, B. Mire, N. Salam, L. Sule

***Abstract*—**This study was carried out experimentally and analytically about the performance of solar cell panel system for operating the pump coupled by dc-motor. The solar cell panel with total area 1.9848 m^2 consists of three modules of 80 Wp each. The small centrifugal pump powered by dc-motor is operated to lift water from 1m to 7m heads in sequence and gives the amount of water pumped over the whole day from 08.00 to 16.00 h are 11988, 10851, 8874, 7695, 5760, 3600, 2340 L/d respectively. The hourly global solar radiation during the day is an average of 506 W/m^2. This study also presents the I-V characteristics of the panel at global radiations 200, 400, 600, 800 and 1000 W/m^2 matched with the operation of the pump at the above lifting heads. It proves that the only solar radiations 800 and 1000 W/m^2 could provide lifting head from 1m to 7m. At radiation 200 W/m^2, the pump can't lift water even for 1 m. The analysis shows the best efficiency point of the performance of solar cell panel system occurs at the pumping head 2.89 m.

***Keywords*—**Solar cell, dc- motor-pump, I-V characteristics, best efficiency point.

I. 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, the current flows and the electric power are generated and can be transferred to an outside application [1]-[2].

S. Himran B. Mire, N. Salam, and L. Sule are with the Mechanical Engineering Department, Faculty of Engineering, Hasanuddin University, Makassar, Indonesia (e-mail: syukri_h@yahoo.com).

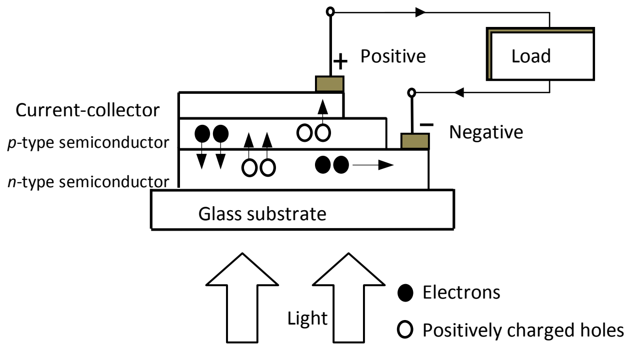

Fig. 1 Power generated by solar cell

II. Experimental Set Up

At the early of this experimental work on the application of solar cells system had been carried out to drive the centrifugal pump [3]-[4]. The solar cells supply power through a battery, a dc-ac inverter to motor-pump unit. The experiment didn't show the variation of the discharge during the experiment from 08.00 to 16.00. In such a case the performance of the system can't be well understood. The next experiment was carried out by S. Himran et. al. [5] without using a battery and dc-ac inverter, with the result that the experiment clearly exhibits the variation of the discharge and output power from solar cells during the day at four different lifting heads from 1 m to 4 m.

The purpose of this paper is to present and to evaluate the performances of a solar cells panel for pumping water. The panel consists of three modules with capacity 80 Wp, area 0.6616 m each, and the total area of the panel is 1.9848 m^2. The schematic of the installation is as shown in Fig. 2. The panel is used to run the dc-motor-pump for water lifting at various heads: 1 m, to 7m, in sequence. The experiments were carried out during October 3rd – 9th, 2012, from 08.00 h to 17.00 h. The data recorded cover the global radiation I_g, short sircuit current I_{sc} and open circuit V_{oc} of solar panel, load current I and load voltage V, discharge q of the pump. The global radiation is measured by pyranometer. The quantities I_{sc}, V_{oc}, I, V are measured by multimeter and the discharges of the pump are measured manually by glass meter and stop watch. All the measurings are carried out on lifting head from 1m to 7m in order.

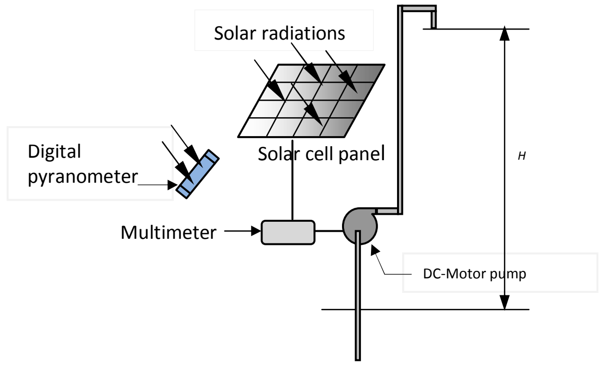

Fig. 2 Schematic of solar cell panel for water pumping

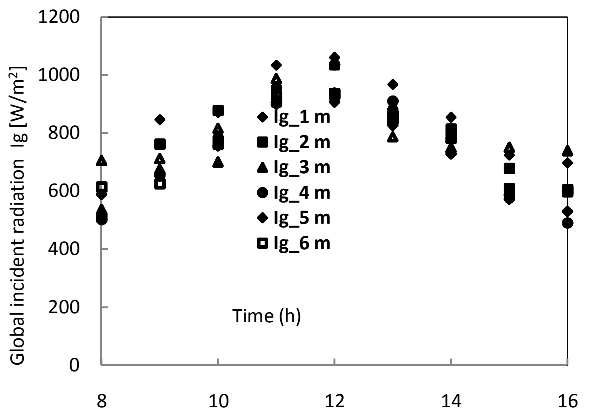

Fig. 3 Variation of global radiation incident on the panel during a day

III. Analysis and Discussions

The experiments have been carried out at Renewable Energy Laboratory, Mechanical Engineering Department, Faculty of Engineering, Hasanuddin University over a day from 0800 h to 1700. The solar cells panel area A_p = 1.9848 m^2, inclined 15^o and facing north. 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 which has been applied in [1] as 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 = 277 to 284 in sequence for dated from October 3rd to 9th.

Latitude angle $\phi = -5.1^o$ LS

Slope of panel $\beta = 15^o$

Hour angle $\omega = (12 - \text{LAT}) \times 15^o$. The LAT is local apparent time and be counted from 08.00 to 17.00 h.

Then normal global radiation reaching the panel is:

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

This I_g is measured by pyranometer

Based on the experimental data written on the research report, the variations of actual global radiation incident normally on the panel and the pumping flow rates for different lifting heads over a day are plotted and shown in Fig. 3, 4 respectively. The two figures 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. Fig. 4 also shows the higher lifting heads the lower discharges and thus agrees with the *H-Q* centrifugal-pump characteristics [9]. Fig. 5 shows the variations of panel efficiencies over a day. It indicates that the efficiencies decrease with the increase in the working temperature of the panel. This is because of as solar temperature increase, the open circuit voltage decreases more sharply than the short circuit current [6], [7]

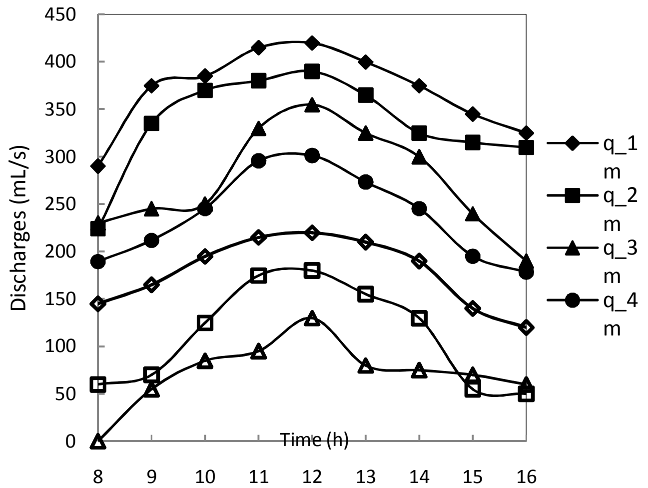

Fig. 4 Variation of pumping discharges over a day at various heads

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 Fig. 6. This figure is based on experimental data and tabulated on Table I. This table shows, the more solar radiation (I_g) the more energy input to dc-motor pump (IV), and the more lifting head can be produced.

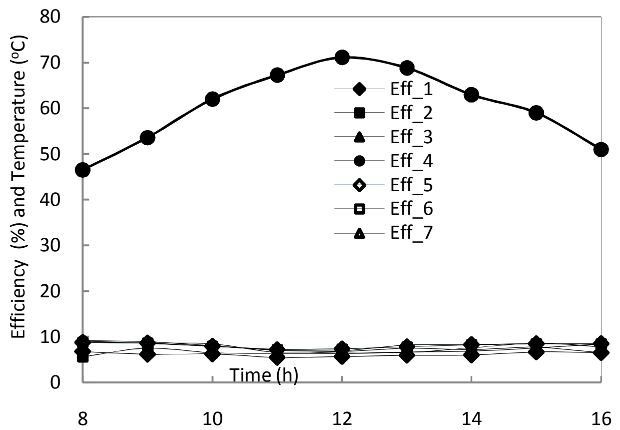

Fig. 5 Variations of panel efficiencies and panel temperature over a day at various lifting heads

The figure also shows that lifting head 1m to 7m can be lifted by the pump at solar radiation 400 to 1000 W/m^2, 4 m to

7m for solar radiation 600 to 1000 W/m^2, 6 m to 7m for solar radiation 800 and 1000 W/m^2. On the contrary solar radiation 200 W/m^2 can't lift even 1m head. It can be conclude that pump needs more energy and thus solar radiation to overcome the higher lifting head.

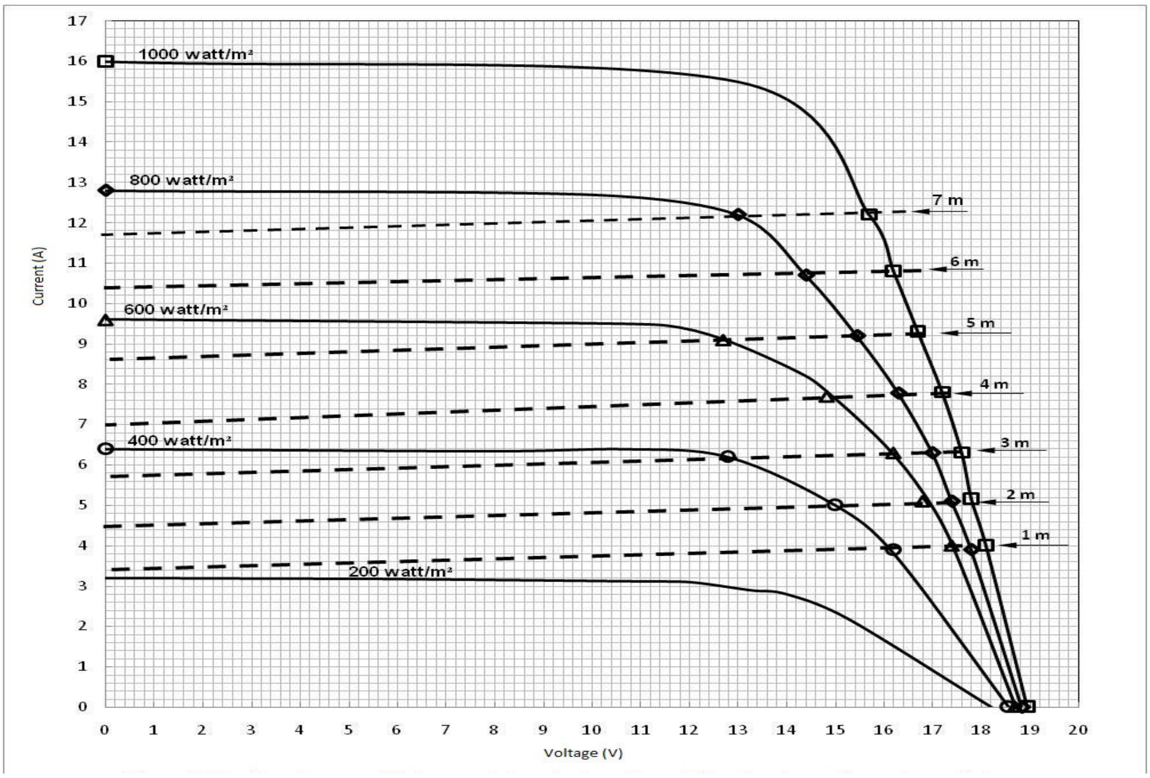

Fig. 6 Matching between I-V characteristics of solar cells and lifting head at various solar radiations

TABLE I
OPERATION DATA OF CURRENTS AND VOLTAGES OF SOLAR PANEL AT VARIOUS SOLAR RADIATIONS

I_g	V_{oc}	I_{sc}	H_{st} = 1m	H_{st} = 2 m	H_{st} = 3 m	H_{st} = 4m	H_{st} = 5m	H_{st}= 6m	H_{st} = 7m
[W/m²]	[V]	[A]	IV [W]	IV [W]	IV [W]	IV [W]	IV [W]	IV [W]	IV [W]
200	18,22	3,20	0	0	0	0	0	0	0
400	18,56	6,40	63.18	75	79.36	0	0	0	0
600	18,70	9,60	69.60	85.68	102.06	114.191	115.57	0	0
800	18,84	12,80	69.42	88.74	107.10	126.81	142.14	154.08	158.60
1000	18,95	16.00	72.40	91.77	110.88	134.16	155.31	174.96	191.54

A good idea is to calculate the 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/d] (1)

Discharge q (L/s)

Energy received by the panel:

$$E_{panel} = \sum_{08.00}^{16.00} A_p \times Ig_{normal} \times t \text{ [W-h]} \quad (2)$$

Energy consumed by the dc-motor pump:

$$E_{motor} = \sum_{08.00}^{16.00} V \times I \times t \text{ [W-h]} \quad (3)$$

Energy produced by the dc-motor pump in water:

$$E_{water} = \sum_{08.00}^{16.00} \rho g q H \times t \text{ [W-h]} \quad (4)$$

To calculate the actual head H, it is used the equations in [8] as follows,

$$H = H_{st} + \sum h_l + \frac{c^2}{2g} \quad (5)$$

where,

$\sum h_l$ = summation of friction and turbulent losses

$\frac{c^2}{2g}$ = velocity head

Efficiency of the system: $\eta_{system} = \frac{E_{water}}{E_{panel}}$ [%] (6)

Efficiency of the pump: $\eta_{pump} = \frac{E_{water}}{E_{motor}}$ [%] (7)

Based the experimental data it is possible to calculate the energies and efficiencies by using (1) to (7), and the results are given on Table II.

TABLE II
THE ENERGIES AND EFFICIENCIES OF THE SOLAR CELL PANEL SYSTEM

Quantity	Pumping head						
	H_{st} = 1 m	H_{st} = 2 m	H_{st} = 3 m	H_{st} = 4 m	H_{st} = 5 m	H_{st} = 6 m	H_{st} = 7 m
$I_{g\_meas.av}$ [W/m^2]	848.67	777.22	716.89	743.33	717.33	745.67	801.56
E_{panel} [kW-h)	15.16	13.88	12.81	13.28	12.81	13.32	14.32
Q [m^3/d]	12.00	10.85	8.87	7.70	5.76	3.60	2.34
E_{motor}[W-h)	953.14	989.33	974.24	1010.24	1040.24	1074.01	1044.67
E_{water}[W-h)	79.25	187.18	196.05	174.84	140.48	85.86	53.20
η_{system} [%]	0.52	1.37	1.53	1.32	1.10	0.64	0.37
η_{pump}[%]	8.31	19.25	20.12	17.31	13.51	8.00	5.09

Table II shows that nearly at the same energies/day received by the panel at different lifting heads will produce the increase in E_{motor}, but E_{water} increases from 1m to 3m and then decreases to 7m. The tendency of E_{water} curve against pumping head is followed by η_{pump}. This tendency indicates that at the lower of pumping head, the water energy losses decrease gradually as pumping head increase until the specific point, thus the useful energy increase, after that water energy losses increase and thus the useful energy decrease; this condition agree with pump characteristic. The behaviors of those parameters are shown on Fig. 7.

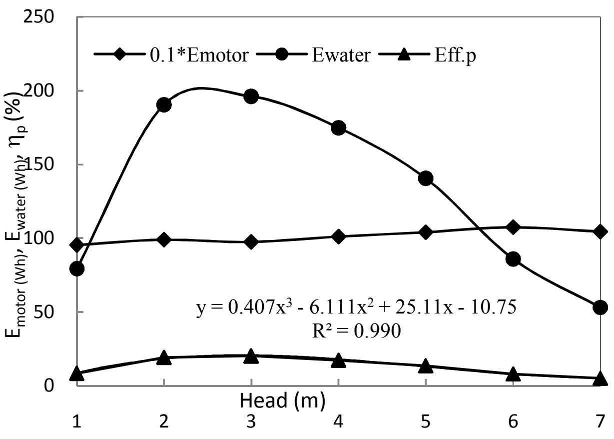

Fig. 7 Variation of motor energy, water energy, pump efficiency at different pumping head

From the pump efficiency curve it is possible to calculate the best efficiency point of the pump operation, i.e. by differenting the equation of efficiency curve and it shows that the best efficiency located at 2.89 m pumping head.

ACKNOWLEDGMENTS

This study had been made possible through a research grant provided by Research and Public Servive Institute of Hasanuddin University, under the grant No. 1642/UN4.20/PL.09/ 2012.

REFERENCES

[1] S. P. Sukatme, J. K. Nayak., 2008, "Solar Energi, Principles of Thermal Collection and Storage", 3rd Ed. Tata McGraw Hill Education Private Limited, New Delhi, pp. 313–331.
[2] F. Kreith, J. F. Kreider, 1978, "Principles of Solar Engineering", McGraw-Hill, pp. 559–573.
[3] S. Himran, et al., 2010, Solar Cell System 240 Wp Providing to Equip the Renewable Laboratory, Mechanical Engineering, Hasnuddin University, Makassar, Indonesia.
[4] Awang, A., Adiasfar Lolo, A., Himran, S., 2010, Analysis the Performance of Solar Cell System for Water Pumping through a dc-ac Inverter, Mini Thesis, Bachelor Degree, Mechanical Engineering, Hasnuddin University, Makassar, Indonesia.
[5] S. Himran, Alfian, Halim, Nurjanah, 2011, "The Performance of Photovoltaic System for Pumping Water at Various Lifting Heads", FTEC2011-The 7th International Conference on Fluid and Thermal Energy Conversion, Zhengzhou, China, September 24–27, 2011 .
[6] A. Q. Malik et al., 2010, "Influence of Temperature on the Performance of Photovoltaic Polycrystalline Silicon Module in the Bruneian Climate", Brunei Darussalam, AJSTD Vol. 26 Issue pp. 61–72.
[7] N. Hamrouniadi et. al., 2008, "Solar Radiation and Ambient Temperature Effects on the Performances of a PV Pumping System", Revue des Energies Renouvelables Vol. 11 No. 1, pp. 95–106, Tunis, Tunisia.
[8] Y. A Çengel, J. M, Cimbala, 2010, "Fluid Mechnics, Fundamentals and Applications", 2nd Ed. In SI Units, McGraw-Hill, Singapore, pp. 343–371.
[9] S. Lazarkiewicz, A. T. Troskolański, 1965, Impeller Pumps, Pergemon Press, Oxford, Wydawnictwa Naukowo-Techniczne, pp. 397-412.