Investigating the thermal performance of a hybrid pv solar system

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Abstract. Photovoltaic thermal heating systems have gained momentum in the recent years with many investigations being done on how to maximize the heat harnessing mechanisms. In some case copper tubes fixed on the back part of the module, are used to circulate forced water around them by external driving force e.g. pumps and, in the process extract heat from the module and provide the cooling effect as well. As more heat is extracted from the these devices, the final water temperature rises above the ordinary ambient temperature and stays hot for longer hours after the sun has gone down. Water used a coolant affects the electrical performance of the PV system.

1. Introduction

A photovoltaic (PV) hybrid system produces both electricity and hot water simultaneously. In PV modules, as the module temperature increases, the efficiency of the module drops. In hybrid modules, the heat produced by the module is absorbed by water and in the process decreases the cells' temperatures. In this way, PV efficiency is optimized as the heat is transferred into water for hot water production.

When the radiation falls onto the module, part of solar spectrum is converted to electricity and the other part heats the module. Infrared light does not contribute towards the electricity production of the module; instead it heats up the module. Thus, a standard solar panel misses about 75% of the incoming energy. Other paragraphs are indented.

It is a well-known fact that some solar cells experience significant efficiency degradation and a decreased lifetime when operating under high temperatures. If in operation outdoor, the back of the module's temperatures have been found to rise up to around 70°C on sunny summer weathers. Temperature levels of around 40°C have been noted to cause modules to lose up to 7% of their power [1]. In South Africa we have lots of solar radiation throughout the year and this has been found to range from 6000MJ/m2 to 9500MJ/m2 in different provinces in the country [2]. With no cooling, photovoltaic modules' energy production is compromised.

Several researchers have carried out experiments in trying to find out ways of cooling the modules so as to improve the output of the modules. Air, water and glycol have been used as coolants in different research studies. Water or glycol is circulated in copper pipes that are fixed on a copper plate attached to the back of the module. These pipes allow the fluid to circulate, while at the same time providing cooling effect on modules. The silicone gel is usually used to reduce the thermal resistance between the back of the module and the copper plate, thus enhancing heat transfer to cooling water.

Air as a coolant has been used to cool the module [3]. A fan was used to drive air across the module. At low air speeds, the cooling effect on the module was found to be more pronounced while at high air speed the cooling effect was found to be minimal. The heat utilisation of the air was not considered in this research. Air has been noted to have less thermal conductivity as compared to water; hence water would provide a better cooling effect when compared to air.

A photovoltaic hybrid system that involved the use of copper tubes fixed at the back of the module (risers) with water as a coolant was investigated [4]. In their research they used pumps to circulate water in these risers to effect heat transfer. Ibrahim and friends investigated the cooling effects of different absorber designs on the performance of PV thermal collectors [5]. These researchers had seven different designs checked and simulations carried out on all the designs. Based on simulations, the spiral flow design proved to be the best design and was found to give a thermal efficiency of 50.12% and corresponding cell efficiency of 11.98%. The spiral design had tubes wound in such a way that the tubes touch each other hence allowing cross heat transfers.

This paper looks at the use of water in direct contact with the pv module as a coolant. Water has light and heat trapping ability hence the ability to reduce solar-cell surface recombination velocity. A direct contact between the back of module and the water was considered and it was hoped that a new solar module cell-cooling method would be established.

1.1. Efficiency of a cell

The efficiency of a cell is defined as the ratio of energy output from the solar cell to input energy from the sun. This has been found to depend on the spectrum and intensity of the incident sunlight as well as the temperature of the solar cell [6]. The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$\eta = \frac{P_{out}}{P_{in}} \quad (1)$$

Where: $$P_{out} = V_{oc} I_{sc}\, FF \quad (2)$$

And Fill factor is given by $$FF = \frac{V_{peak} I_{peak}}{V_{oc} I_{sc}} \quad (3)$$

$$P_{in} = G A_{collector}\,, \quad (4)$$

Therefore the efficiency of the cell is: $$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (5)$$

Electrical efficiency of the photo voltaic cells has also been found to follow equation 6 [7].

$$\eta_{el} = \eta_o [1 - \beta(T - 25°C)] \quad (6)$$

Where: η_o is the efficiency of the module at Standard Test Conditions (STC).

β is the coefficient of temperature and its value is equivalent to 0.0045 /°C for crystalline silicon cells; T is the temperature of the module.

2. The Experimental Method

Sika Flex sealant was used to provide good electrical-insulation between the module and the water coolant. A perspex box was constructed and fixed at the back of the module. The module with water box was named M2 and the other module used as a control, M1. The system setup was fixed on a module rack as shown in figure 1,

Figure 1: System set up, LHS M1 and RHS M2

The solar rays fall onto the module and produce electricity through photoelectric effect and at the same time the rays not used for electricity generation heats up the module. Heat generated at the back of the module is then transferred from the module to water in the container through conduction, radiation and convection. Through principle of convectional currents, the solar heated water in the perspex container becomes less dense and moves up to the storage tank. Cold water in the storage tank, because of its high density replaces this warm water through thermosyphon effect. The module gets cooled in the process and improves the electrical efficiency of the module.

The back of the module's average temperature and the current-voltage curves were measured. The gross collector area of the modules was found to be of 1.058 x 0.68m^2= 0 .7194 m^2.

3. Results and Discussion

Initially, the SW80 solar modules' I/V characteristics were measured and recorded to get the benchmark of the modules. Both modules were found to have similar I/V characteristics.

After fabricating module M2, both modules M1 and M2 were fixed on the pv rack. Initially M2 had no water when outdoor I/V measurements were taken. Figure 2 shows the response of the modules.

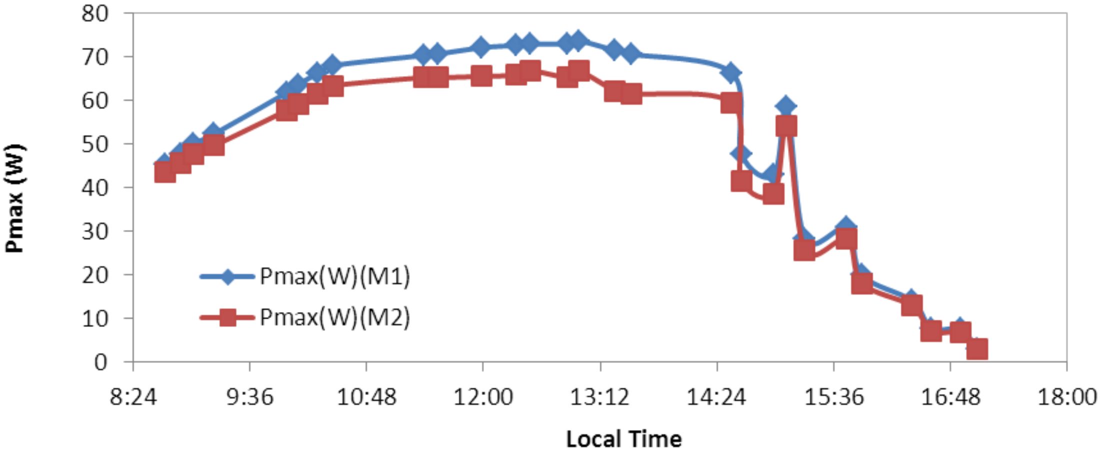

Figure 2: Maximum power output of modules M1 and M2

It was noted that M2's maximum power output at any given time was lower than that for M1.The back of the module temperature for M2 was high and thus had a reduced open circuit voltage and a slightly higher short circuit current. A reduced open circuit voltage contributed towards a reduced maximum power output.

Figure 3 illustrates the maximum power output of the two modules when M2 had water coolant.

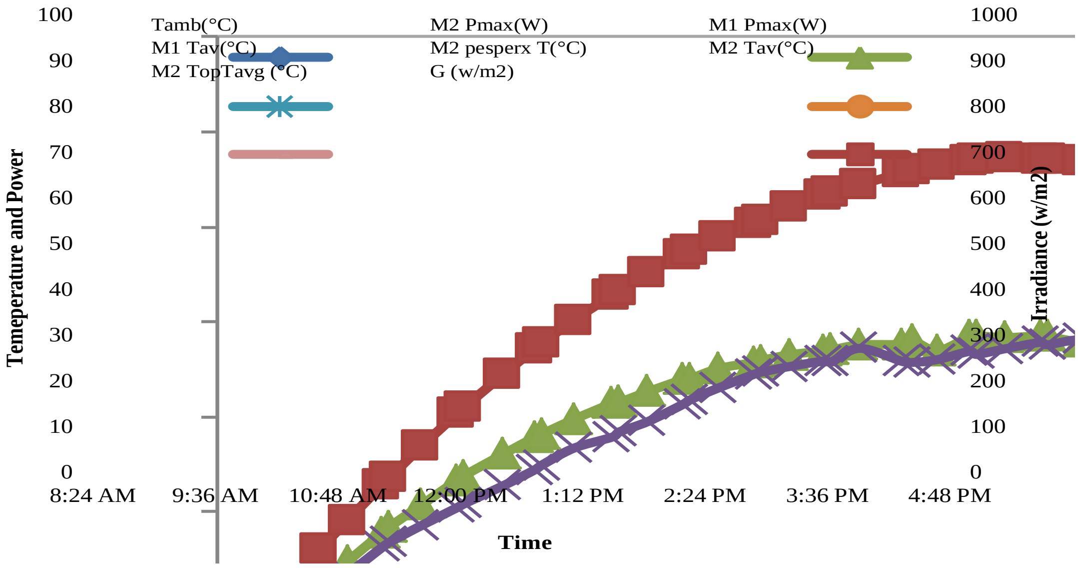

Figure 3: maximum power out of modules when M2 is cooled with water.

From figure 3, it can be noted that M2 had a higher maximum power output for the better part of the day. Theoretically, when the photovoltaic modules' temperatures rises, the open circuit voltage V_{oc} falls and the short circuit current slightly increases shifting the maximum power output to the lower end and the reverse is true. Cooling of module M2 encourages operation of the module at a higher V_{oc} and a slightly lower I_{sc}. This brings about a higher maximum power output. A higher power output would certainly mean an improved efficiency of the module as shown on the efficiency curves of the two modules in figure 4.

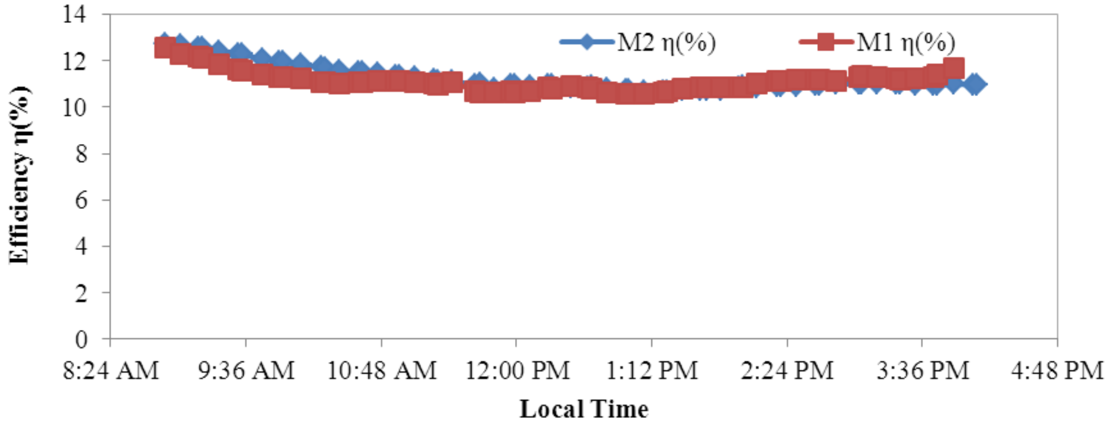

Figure 4: shows the effect of cooling water especially on efficiency.

From figure 4 it can be noted that the efficiency of the water cooled module M2 started off at high efficiency of 12.75% as compared to M1 which was at12.24%, giving a percentage difference of 4.2%. The difference in efficiency was due to water's cooling effect on M2. Figure 4 shows a drop in efficiency values by 1.75% for M2 and 1.24% for M1 from 08:50 to 11:40. Both modules' efficiency values then remained at 11.00%. M2's efficiency was found to be higher as compared to M1's efficiency up to 11:40am. Figure 5 further shows the improvement on efficiency of M2 as compared to M1 due to cooling effect brought about by water.

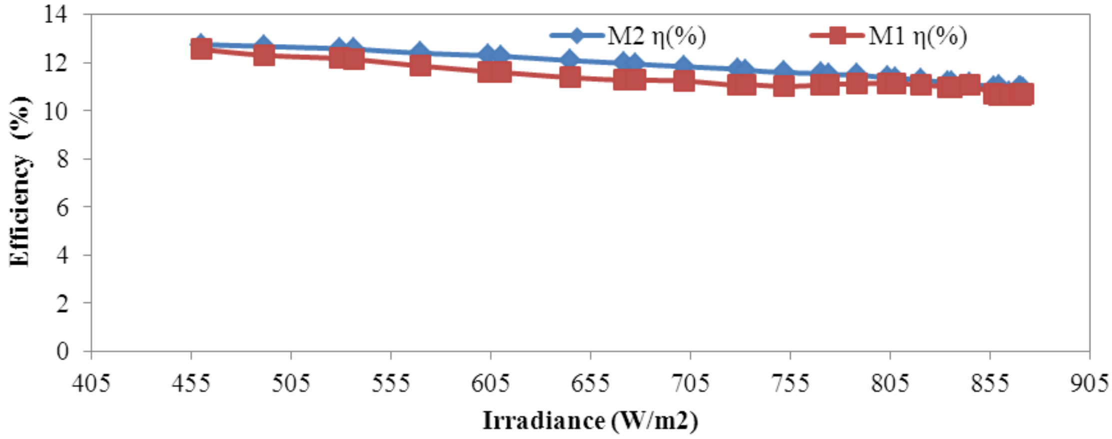

Figure 5: Efficiency of the module as compared to irradiance falling on the module

The parameters for the SW80 modules at solar noon on the 28th of June 2011 were as shown in table 1.

Table 1: Parameters of the SW80 modules.

	Voc (V)	Isc (A)	Pmax (W)	FF(%)	η_{ele} (%)
T_{SW80} =25.00°C	21.5	4.82	80.2	77.4	11.14
T_{M2} =33.72°C	20.65	4.81	66.96	67.35	10.77
T_{M1} =41.55°C	20.63	4.91	66.04	65.15	10.62

The measured values showed an average efficiency of approximately 11% for both modules. Normalising the measured values to STC conditions or cooler conditions would imply higher efficiency and higher energy output.

The findings where that on the 28th of June 2011 the average water output module temperature peaked at 31.9°C, the cooling-medium inlet temperature was approximately 24°C, and the ambient temperature was approximately 14.3°C and the average irradiance on the tilted surface was 711.18 W/m2 for the day.

Conclusion

The cooling water effects on the performance of the pv module where explained in this paper. Two modules were considered, one had water as a coolant and the other was cooled by natural means. The cooler module gave a higher power output as compared to the naturally cooled module for the better part of the day. The efficiency of the water cooled module was found to be higher. Water as a direct contact coolant on photovoltaic modules has been introduced.

References

[1] A.R. Gxashekaa, E.E. van Dyka,, E.L. Meyer. (2005). Evaluation of performance parameters of PV modules deployed outdoors, Renewable Energy 30 (2005) 611–620

[2] [2] AnnualSolar Radiation map for SouthAfrica ; http://www.sunpower.co.za/Incoming%20Radiation.jpg accessed 07/03/09.

[3] Arvind Tiwari et al. (2006). Performance evaluation of photovoltaic thermal solar air collector for composite climate of India.

[4] Anderson. T. N, et al, (2002). Performance of a building integrated photovoltaic/thermal (BIPVT) Solar Collector.

[5] Adnan Ibrahim et al, (2000). Performance of Photovoltaic Thermal Collector (PVT) With Different Absorbers Design

[6] Eikelboom .J.A and Jansen. M.A (2000). Characterisation of PV Modules of New Generations.

[7] Skoplaki E., and Palyvos. J.A (2009). On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations.