International Journal of Smart Grid and Clean Energy

# Electrical/thermal performance of hybrid PV/T system in Sharjah, UAE

Amna A. Alzaabi[a], Nadine K. Badawiyeh[a], Hind O. Hantoush[a], A. K. Hamid[b*]

[a] *Department of Sustainable & Renewable Energy Engineering, University of Sharjah , Sharjah, United Arab Emirates*
[b] *Department of Electrical & Computer Engineering, University of Sharjah , Sharjah, United Arab Emirates*

**Abstract**

The paper proposes a design to improve the electrical efficiency of PV panels using Water Hybrid Photovoltaic Thermal (PV/T) system. A prototype of a PV/T system is built and the electrical and thermal performances of the system are investigated under ambient temperature conditions in SHARJAH, UAE during April 2014. The system is composed of a polycrystalline PV panel with a solar thermal collector adhered to its backside. Experiments were performed with and without cooling process to observe the improvement in the PV panel efficiency. The results show that the electrical power output for the PV/T system increased by 15 to 20 % when compared to PV panel. The thermal efficiency of the system was calculated from measured data and obtained values close to 60%-70% were achieved.

*Keywords: Hybrid Photovoltaic/ Thermal, efficiency, solar energy*

## 1. Introduction

Globalization and economic growth led to a massive consumption of non-renewable energy sources which caused environmental problems. Therefore, there was a need for an environmental friendly source of energy such as solar energy. The UAE is capable of producing 3.5-7.5 (kWh/m2/day) [1] of solar energy depending on the emirate which makes it suitable place for solar energy technologies such as Solar Photovoltaic (PV) and Solar Thermal systems.

Photovoltaic system converts solar energy into direct current; however, its performance is affected by various factors. Temperature is one of the important factors to investigate in the UAE, where in summer the panel's temperature can reach up to (50-60)$^{\circ}$C resulting in 3% to 4% reduction in the output power [1]. PV panel surface temperature increases due to low solar energy to electricity conversion efficiencies as not all of the solar energy absorbed by PV cells can be converted to electrical energy. To satisfy the law of conservation of energy, the remaining solar energy must be converted to heat and this contributes to a drop in the panel electrical efficiency. To address this undesirable effect, heat extraction by fluid circulation can be done to reduce PV panel temperature and produce hot water using PV/T system, thus achieving a higher energy conversion rate of the absorbed solar radiation.

Research in the field of PV/T collectors has been carried out in the middle of 1970s and many publications have introduced the main concepts of hybrid PV/T [2]-[5]. A technical study was done by M. Dalvand [6] on hybrid photovoltaic thermal solar collectors. He analyzed the parameters (factors) affecting PV/T performance such as glazing, mass flow rate, absorber parameters, and coolant type.

It was found that the thermal efficiency of PV/T liquid systems was found in the range of 45% to 70% for unglazed to glazed panel designs. Kalogirou [7] designed a PV hybrid system to test the electrical and thermal efficiency of polycrystalline silicon (pc-Si) and amorphous silicon (a-Si) PV modules, TRNSYS software was used to simulate the results.

* Manuscript received May 1, 2014; revised June 19, 2014.
Corresponding author: A-K. Hamid; Tel.: +971 6505 0932; *E-mail address*: akhamid@sharjah.ac.ae.
doi: 10.12720/sgce.3.4.385-389

Most researchers have focused on analysing the thermal performance of the PV/T system, while only few of them studied the electrical performance. However, this paper focuses on the overall performance of the PV/T system that will aid in increasing the electrical output of the PV panel.

## 2. System Design

The Design combines two technologies; a solar photovoltaic panel and a solar thermal collector that generate electrical and thermal energy simultaneously. The thermal collector made of rectangular copper pipes is configured as a Parallel-tube Flat-plate collector and is mounted to the backside of the 100 W Polycrystalline PV panel. The collector pipes rectangular shape helps in increasing the contact area between the pipes and PV panel, thus increasing the heat transfer. Each collector pipe was covered by insulation and enclosed with electrical truncated channels to allow air circulation and cooling in the space between the channels.

Water will be circulating inside the collector by using 5 W DC pump powered from the same PV panel. The heated water will go back to a 200 liter hot water insulated tank to be used by domestic applications. The schematic diagram and cross-section of the PV/T system are shown in Fig. 1 and Fig. 2, respectively. The built PV/T system is shown in Fig. 3.

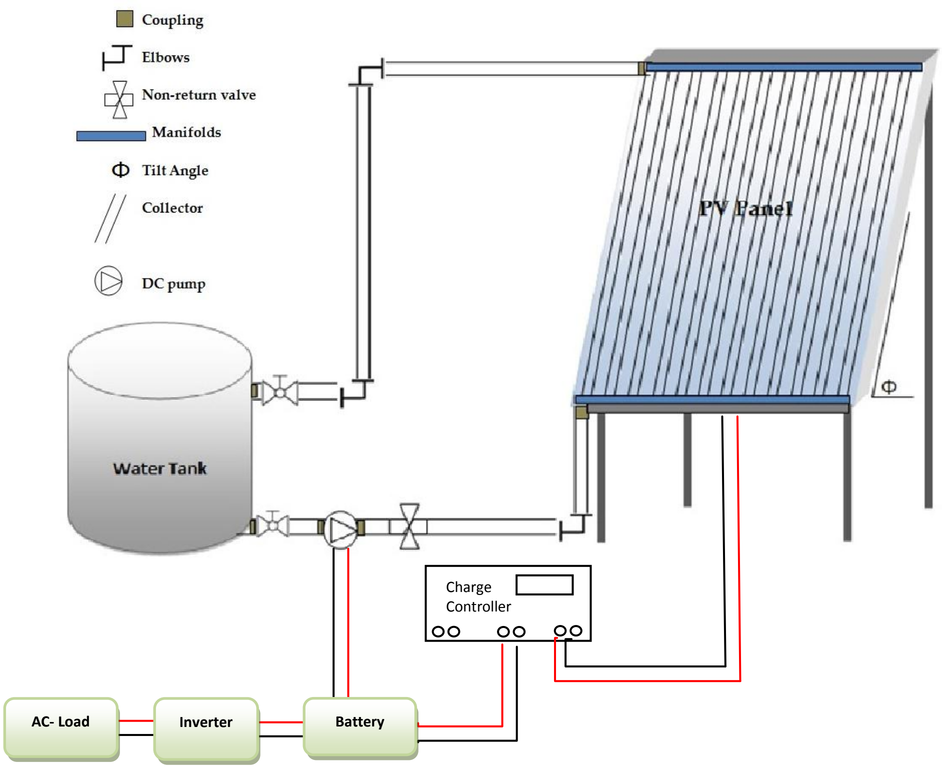



Fig. 1. Schematic diagram of PV/T system.

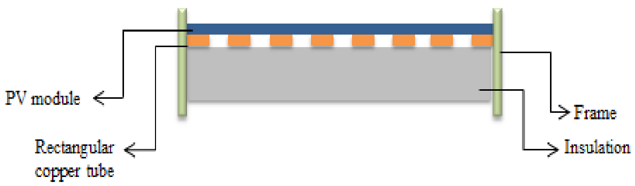
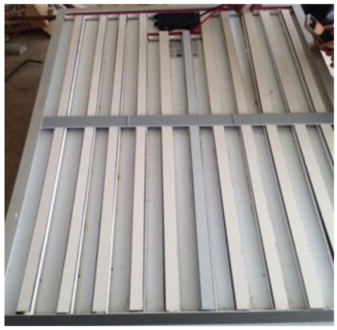



Fig. 2. Cross-section of the PV/T module.

(a)



(b)

Fig. 3. PV/T system: (a) the system and (b) back-side of the PV panel.

Table 1. PV/T system specifications

| PV/T system | Specification |
|---|---|
| **PV** | |
| Type | Poly-crystalline Si |
| Nominal DC voltage for standard output | 12 V |
| Pmax at STC | 100 Watts |
| Vmp | 18 V |
| Imp | 5.55 A |
| Voc | 21.24 V |
| Isc | 6.11 A |
| Operating temperature | -40 ℃ to 85 ℃ |
| Weight | 7.1 kg |
| Dimensions | 1.17m*0.67m*0.03m |
| **Flow rate** | 5.4 L/min |
| **Collector pipes** | |
| Material | Copper |
| Number of pipes | 11 pipes |
| Pipes dimension | 0.5” * 0.25” |
| **DC Pump** | 5 Watts |
| **Battery** | 12 V |
| **Temperature sensor** | -50$^{o}$C to 250$^{o}$C |

The experimental parameters collected include: inlet water temperature, outlet water temperature, tank temperature, and ambient temperature were measured using temperature sensors. The PV panel characteristics, solar irradiation, PV panel temperature were measured using PROFITEST PV ANALYZER. The PV/T system specification is shown in Table 1.

Analyzing the performance of the PV/T system is separated into electrical and thermal performances. The electrical efficiency ($\eta_{elect}$) depends on the incoming solar radiation and the PV module temperature, and is calculated by the following formula [3]:

$$\eta_{elect} = \frac{I_m V_m}{AG} \tag{1}$$

where $A$ is the aperture area (m$^2$) of the PV/T model, $G$ is the incoming solar radiation (W/m$^2$), $I_m$ and $V_m$ are the current (A) and the voltage (V) of the PV module operating at maximum power.

The steady state thermal efficiency ($\eta_{th}$) of the PV/T module depends on the incoming solar radiation, the flow rate, and is calculated by the following formula [3]:

$$\eta_{th} = \frac{mc\left(T_{outlet} - T_{inlet}\right)}{AG} \tag{2}$$

where $\dot{m}$ [kg/s] is the water mass flow rate, $C_p$[J/kg.K] is the water specific heat capacity, $T_{inlet}$ and $T_{outlet}$ the input and output water temperatures (℃), respectively.

The overall system efficiency is calculated as shown below:

$$\eta_o = \eta_{elect} - \eta_{th} \tag{3}$$

## 3. Experimental Results and Discussion

The effect of cooling the PV panel causes an increase in the open circuit voltage as it can be shown in Fig. 4. By comparing the two curves, it can be seen for almost the same irradiance the Voc=18.7 V for uncooled PV panel, whereas for the cooled panel is $V_{oc}$= 20.3 V at an ambient temperature of 37°C. This value indicates that the open circuit voltage increased to a value close to the STC value as shown in Table 1, although there is a significant difference between the operating temperature (37°C) and the STC temperature (25°C). It can be seen that the short circuit current for the both curves: with/without cooling are slightly different than expected due to the small difference in the operating irradiance, The irradiance was 902W/m$^2$ and 912W/m$^2$ for with/without cooling curves, respectively.

A PV module has been built using Simulink in order to validate the experimental data. It can be noticed that both experimental and numerical data are close, however, there is a small deviation due to systematic error.

Table 2. Testing results

| Data Point | Time | Solar Irradiance (W/m$^2$) | $T_{ambient}$ (°C) | $T_{inlet}$ (°C) | $T_{outlet}$ (°C) | $P_{max}$ (W) | $\eta_{el}$ (%) | $\eta_{th}$ (%) | $\eta_{overall}$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12:30 PM | 899.7 | 35.8 | 35.5 | 36.6 | 81.1 | 11.5 | 58.8 | 70.3 |
| 2 | 2:30 PM | 714.5 | 34.1 | 38.0 | 39.1 | 67.1 | 12.0 | 60.5 | 72.5 |
| 3 | 3:30 PM | 545.4 | 33.8 | 39.2 | 39.9 | 52.8 | 12.3 | 61.7 | 74.0 |

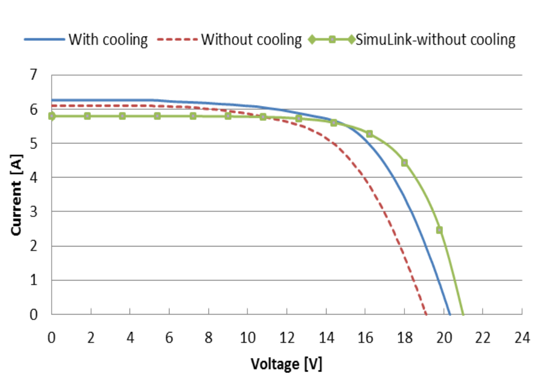



Fig. 4. PV panel I-V characteristics with/without cooling.

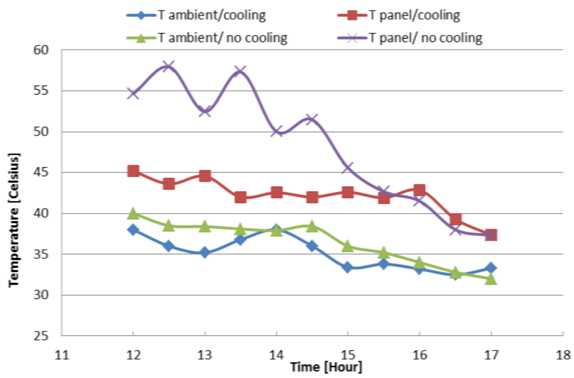



Fig. 5. Panel & ambient temperatures with/without cooling.

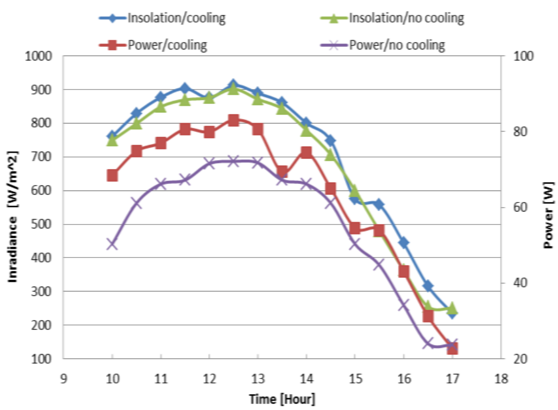



Fig. 6. Electrical power output with/without cooling.

The $\eta_{elect}$ and $\eta_{th}$ were computed using equations (1) to (3) as well as the measured data. The overall efficiency, Inlet and outlet water temperature at different times of the day is shown in Table 2. It can be seen that thermal efficiency may reach 60% to 70% during the system operation.

Fig. 5 shows the effect of the cooling process on the PV panel by comparing its temperature with and without the cooling. It can be clearly seen that at nearly the same ambient temperatures, the temperature of PV panel during the cooling process is significantly lower by 15- 20% than the PV panel temperature without cooling. Hence, the PV panel electrical performance will highly improve.

The electrical power output of the PV panel is plotted with and without cooling process in Fig. 6. It is observed that at nearly same solar irradiation, the electrical power output for the PV/T system increased by 15% to 20 % when compared to PV panel. This is due to water circulation inside the collector pipes which reduced the overall temperature of PV panel leading to a higher electrical efficiency.

## 4. Conclusion

The efficiency of Photovoltaic Panel is sensitive to its operating temperature and decreases when the temperature of the PV panel increases. Hence, hybrid PV/T systems are one of the ways used to improve the panels' electrical efficiency. In the study, the PV panel temperature reduced significantly by 15- 20% due to water circulation through the collector at the backside of the PV panel. As a consequence, the PV/T system electrical power output increased by 15% to 20 %.

## Acknowledgements

The authors would like to express their deepest appreciation to the University of Sharjah for their technical assistance and support in this research. We also like to extend our thanks to the lab engineer Monadhel Alchadirchy for his technical assistance and support in this research.

## References

[1] Kumar K, Sharma SD, Jain L. Standalone Photovoltaic (PV) Module Outdoor Testing Facility for UAE Climate. Submitted to CSEM-UAE Innovation Center LLC, 2007.

[2] Zondag HA, De Vries DW, Heldenb WGJ, Zolingen RJC, Steenhoven A.A. The yield of different combined PV-thermal collector designs. *Journal of Solar Energy*, 2003; 74 (3): 253-269.

[3] Ibrahim A, Othman MY, Ruslan MH, Alghoul MA, Yahya M, Zaharim A, Sopian K. Performance of photovoltaic thermal collector (PVT) with different absorbers design. *Journal of WSEAS Transactions on Environment and Development*, 2009; 5 (3): 322-330.

[4] Kaya M. Thermal and electrical performance evaluation of PV/T collectors in UAE. MS Thesis. Department of Industrial Engineering and Management, KTH Royal Institute of Technology Industrial Engineering and Management. Stockholm, Sweden; 2013.

[5] Naik P, Palatel A. Energy and exergy analysis of a plane reflector integrated photovolatic-thermal water heating system. *Journal of Hindawi*, 2014; (2014):1-9.

[6] Dalvand M. Mohtasebi S, Rafiee S. A technical study on hybrid photovoltaic/thermal solar collectors. *Jorunal of Agriculture*, 2012; 47:8999-9004.

[7] Kalogirou S.A, Tripanagnostopoulos Y. Hybrid PV/T solar systems for domestic hot water and electricity production. *Journal of Energy Conversion and Management*, 2006; 47:3368–3382.