International Journal of Smart Grid and Clean Energy

Experimental Study of Photovoltaic/Thermal (PV/T) Hybrid System

Chao-Yang Huang[a,b]*, Hsien-Chao Sung[a,c], Kun-Lung Yen[a]

[a] *Green Energy & Environment Research Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan*
[b] *Department of Mechanical Engineering, National Chiao Tung University, Hsinchu, Taiwan*
[c] *Degree Program of Flat Panel Display Technology, National Chiao Tung University, Hsinchu, Taiwan*

Abstract

Photovoltaic/thermal (PV/T) hybrid system is a device which provides the electrical power and hot water simultaneously. In this study, the un-glazed flat-plat photovoltaic thermal system has been established with poly-crystalline PV/T module, storage tank, controller, water pump etc. The results indicate the system thermal efficiency can reach 35.33% and photovoltaic conversion efficiency can reach 12.77% during the testing period. The water tank temperature can be risen from 26.2℃ to 40.02℃.

Keywords: Photovoltaic/thermal, water heating, solar energy

1. Introduction

Photovoltaic (PV) system is one of the renewable energy in the world. Commercial PV module conversion efficiency is 6~15% and the output power is decreased by the PV module temperature increases 0.2~0.5% per 1k temperature. However, in high solar radiation, the solar radiation can cause high electrical output power and increase the PV module temperature at the same time. To improve the temperature loss of PV module electrical efficiency and recycle the heat from PV backside is important issues in solar energy application.

Photovoltaic/thermal (PV/T) system is an application to recycle the heat and improve the temperature loss from PV module. The heat can transfer to hot water or hot air and can be used to bath, industrial preheat, air heating etc. The PV/T system can be separated in natural convection and forced convection depending on the flow dynamic. Hung *et al.* [1] developed an integrated photovoltaic and thermal solar system (IPVTS) consisted of the PV/T collector, storage tank, pump and controller. The daily average thermal efficiency reaches 0.38 and the daily overall efficiency reached 0.5. He *et al*. [2] developed the natural circulation PV/T system and the daily thermal efficiency of PV/T system is about 0.4 and the daily overall efficiency is up to 0.55. The solar photovoltaic thermal module or system technologies are classified with different fluid application including air based, water based, Refrigerant based and heat pipe based [5]. The nature convection photovoltaic thermosyphon water heating system can be applied with aluminium-alloy flat box and the electrical efficiency is 10.3~12.3% and the thermal efficiency is 37.6~48.6% in summer and winter day [6]

Combine the solar photovoltaic and thermal application is high performance utility in solar energy. In this study, the PV/T module uses the tube-sheet design to combine the photovoltaic module. The PV/T system can be installed with storage tank, PV/T module, pump, pipeline and pump controller. The daily performance of PV/T system can be measured and discussed in this paper.

* Manuscript received May 15, 2012; revised June 19, 2012
Corresponding author. Tel.:+886-3-5914216; fax:+886-3-5820218; *E-mail address*: masonhuang@itri.org.tw.

2. System Description

The water based and unglazed Photovoltaic/thermal system can be manufactured in this study. The cross section of PV/T module is present in Fig.1.

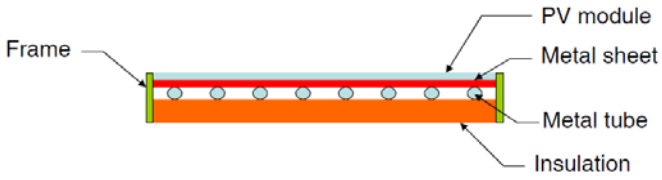
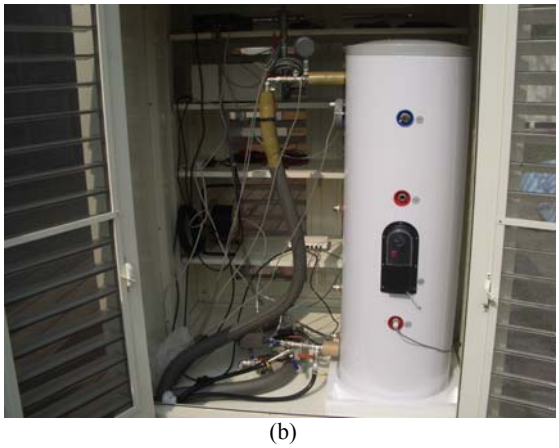


Fig.1. A cross section of unglazed PV/T module.

Photovoltaic/thermal system is composed of 240W poly-crystalline silicon PV/T collector, 120 L storage tank, pump controller and pump. The PV/T collector has manufactured with cooper tube and cooper sheet with supersonic welding and adhesive on PV backside. Fig.2 shows the PV/T collector outline.

(a)



(b)

Fig. 2. (a) the PV/T collector outline (b) storage water tank.

Considering the temperature measured uses high accuracy RTD PT-100 thermocouple in the range 0~100℃ to measure the water temperature and ambient temperature. The solar radiation can be measured with Delta LP PARA PYRANOMETERS in the range 0~2500W/m^2. The electrical power output of PV/T system uses micro inverter to maximum the electrical power in every solar radiation. The system outputs, including solar radiation, water temperature and ambient temperature are collected with Fluke data logger and recorded about 5 second with one data.

The PV/T module specification has been shown in Table1.

Table 1. PV/T module specification

PV module	Specification
Type	Poly-crystalline Si
Module efficiency at STC (ηpv)	14.9%
Maximum power (Pmax)	240 W
Maximum power voltage (Vmp)	30.21 V
Maximum power current (Imp)	8.03 A
Open circuit voltage (Voc)	37.42 V
Short circuit current (Isc)	8.63 A
Temperature coefficient of Pmax (β)	-0.42%/℃
Module area (A)	1.63 m^2
NOCT (℃)	47±2

The experiment measurement parameters include initial water temperature T_i, final water temperature T_f, daily solar radiation H, environmental air temperature T_a, water tank volume V and PV/T electrical power P. The system performance calculation is as follow.

The photovoltaic conversion efficiency has calculated as bellow:

$$\eta_e = \frac{P}{H \times A} \tag{1}$$

The thermal efficiency has shown as bellow

$$\eta_e = \frac{V \times \rho \times C_p \times \left(T_f - T_i\right)}{H \times A} \tag{2}$$

Then the density of Fluid is 1000 kg/m^3 and the Specific heat capacity is 4.18 kJ/kg-$^\circ$C. The overall system efficiency has shown as bellow

$$\eta_o = \eta_e + \eta_{th} \tag{3}$$

3. Experimental Results and Discussion

The PV/T system performance is separate into electrical efficiency and thermal efficiency. The electrical efficiency is influent in module temperature and thermal coefficient of maximum power output. The electrical efficiency is rather stable than thermal efficiency in daily sunny day.

Fig. 3 shows the system performance with water temperature, solar radiation and ambient temperature in testing period. The results have shown the water temperature from initial temperature 17.4 to final temperature 35.72 at 9:00~15:00. The total solar radiation is 12.83 MJ/m^2 in the testing period. The total electrical power is 0.84 and the electrical efficiency is 14.46%. The thermal energy is 9.19 MJ and the thermal efficiency is 43.94%.

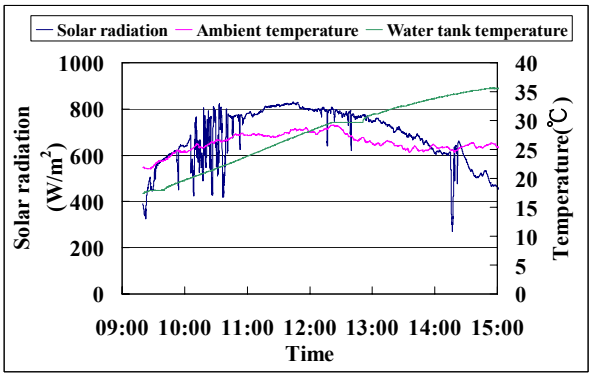


Fig. 3. System performance in experiment period.

Table 2 shows the raw data in the testing experiment. The results have shown the electrical efficiency is decreased when the water temperature is increased. The high water temperature can reduce the thermal and electrical efficiency because the PV module power output can drop in the high module temperature increasing.

Table 2. System performance of PV/T system

No.	T_i(℃)	T_f(℃)	T_a(℃)	H(MJ/m^2)	P (kWh)	η_{th}(%)	η_e(%)	η_0(%)
1	17.4	35.72	26.16	12.83	0.84	43.94	14.46	58.4
2	21.94	33.59	25.32	7.59	0.47	47.21	13.67	60.88
3	26.2	40.02	27.4	12.04	0.696	35.33	12.77	48.1

The overall performance of PV/T system is indicated by the variety with initial water temperature, average ambient temperature and solar radiation. Fig.4 shows the variation of overall efficiency in differential daily outdoor condition.

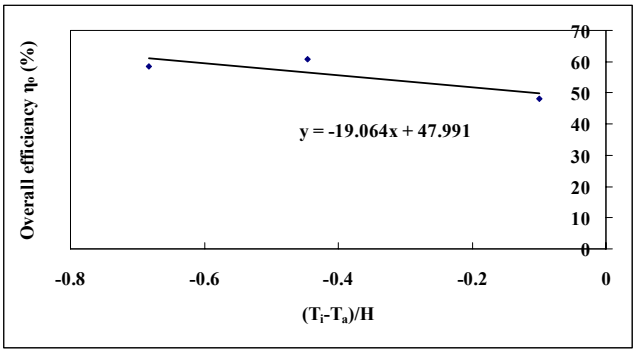


Fig. 4. Variation of overall efficiency with daily outdoor and operating condition.

4. Conclusion

Photovoltaic thermal system is better than unique PV module system because the energy can be recycled and the PV module can be cooled to increase the electrical efficiency. In the study, the PV/T system can be installed be PV/T module, storage tank, pump and controller. In the normal distribution of daily solar radiation condition, Water temperature in the storage tank can be heated up to 40℃. The PV/T system has high thermal efficiency about 35.33~47.21% and the electrical efficiency has 12.77~14.46%.

Acknowledgements

The authors would like to acknowledge the support from the Energy Fund of Ministry of Economics Affairs, Taiwan.

References

[1] Huang BJ, Lin TH, Hung WC, Sun FS. Performance evaluation of solar photovoltaic/thermal systems. *Solar Energy*, 2001; 70(5):443-448.

[2] He W, Zhang Y, Ji J. Comparative experiment study on photovoltaic and thermal solar system under natural circulation of water. *Applied Thermal Engineering*, 2011; 31(16):3369-3376.

[3] Santbergen R, Rindt CCM., Zondaq HA, Ch. Van Zolingen RJ. Detailed analysis of the energy yield of systems with covered sheet-and-tube PVT collectors. *Solar Energy*, 2010; 84(5):867-878.

[4] Chow TT. A review on photovoltaic/thermal hybrid solar technology. *Applied Eergy*, 2010; 87(2):365-379.

[5] Zhang X, Zhao X, Smith S, Xu J, Yu X, "Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies. *Reneable and Sustainable Energy Reviews*, 2012; 16(1):599-617.

[6] Chow TT, He W, Ji J. Hybrid photovoltaic thermosyphon water heating system for residential application. *Solar Energy*, 2006; 80(3):298-306.