Solar Photovoltaic/Thermal (PVT) Test-bed

Toh Peng Seng¹, Jiang Fan²* and Goh Leag Hua³

¹Grenzone Pte Ltd, Singapore
³School of Electrical and Electronic Engineering, Singapore Polytechnic, Singapore

Abstract. Solar photovoltaic/thermal (PVT) system that combines solar PV system with solar thermal system into one makes more effective use of solar energy when converting solar energy into both electrical energy and thermal energy. This paper addresses a solar PVT test-bed in Singapore where the different types of solar PVT systems developed in Singapore are installed and tested to investigate their performance under the tropical weather conditions.

Keywords: solar thermal; photovoltaics, solar photovoltaic/thermal (PVT).

1. Introduction

The conversion of solar energy to electrical or thermal energy has been practised for many years. The most popular used solar energy collectors are flat plate solar panel for solar thermal system and flat plate solar PV module for solar electricity. Comparing to solar PV and solar thermal technology, hybrid solar photovoltaic/thermal (PVT) technology that produces both electricity and thermal energy under sunlight simultaneously is relatively new. A PVT collector, the most important component in a hybrid PVT system, is basically composed of solar PV cells/module mounted on top of heat absorber. The hybrid PVT collectors are divided in two groups[1-4]:

- Liquid PV/T collectors that normally produce both hot water and electricity.
- Air PV/T collectors that are usually building-integrated by installing on facade or roof of a building to provide warm ventilation air as well as electricity.

In a tropical country like Singapore, water PVT system is more adequate for medium-temperature domestic applications with temperature ranging from 45°C to 55°C. In applications, a water PVT collector can be divided into two categories, eg. (1). glazed PVT collector and (2). unglazed PVT collector. Fig. 1 illustrates the basic structures of glazed and unglazed PVT collectors. A glazed PVT collector with glass cover, can produce more thermal energy but has slightly lower electrical yield, while an unglazed PVT collector without glass cover produces less thermal energy but more electricity[5-6]. As seen in Fig. 1b, an unglazed PVT collector has simpler structure and consists of solar PV cells or PV module on top and thermal absorber below. It delivers relatively lower thermal energy due to more heat convection loss on its front surface and possesses lower total conversion efficiency than a glazed PVT collector[6-7]. Main advantages of an unglazed PVT collector over a glazed PVT collector are simpler structure, easier to fabricate and lower cost. The simplicity of low-cost unglazed PVT collector is balanced by generally lower thermal performance[8-10] due to high thermal resistance between liquid and PV cell (laminate layers, adhesive bond, irregularities in flatness of absorber, possible air traps or dry contacts, heat exchanger configuration); white
gaps between PV cells in commercial PV modules results in reduced absorption of solar radiation at aperture area.

Fig. 1. Basic structure of liquid PVT collector: (a). glazed PVT collector and (b). unglazed PVT collector

With increasing concern about depletion of fossil fuels, high dependency of energy import and global climate change, Singapore Economic Development Board (EDB) sets aside project funding for development of new solar PVT collectors and research on feasibility of PVT systems in tropical region. One of main tasks is to set up a test-bed to investigate the performance of new PVT collectors developed by local company. This paper presents performances of four different PVT systems installed at the test-bed.

2. Site for the PVT Test-Bed

The solar PVT test-bed was set up on the rooftop of 5-storey teaching block in Singapore Polytechnic as shown in the Fig.2. There are no any other obstacles on the site except a 10 meters high wind turbine. Fig. 3 depicts the shadows at point A of test-bed in a year. As can be seen from the figure, the site selected for PVT test-bed has no shadows all over a year except some afternoon time after 5pm between March and April, August and September respectively.

Fig. 2 Layout of the site selected for solar PVT test-bed

Fig. 3 Measurement of shadows in situ: (a). shadow change in the first half year and (b). shadow change in the second half year

Owing to the negative temperature coefficients of PV cells, PV modules are normally installed in such a way that a certain air gap behind PV modules must be maintained to dissipate the heat of solar cells by natural ventilation. In a hybrid PV/T collector, the PV cells/modules are directly mounted on the top of thermal absorber. Although there is no air gap behind solar cells/module, the fluid flow beneath the PV cells will cool PV cells faster than natural air ventilation of a normal PV installation and improve the power output of PV cells. To explore the impact of cooling effect of PVT collector on PV cells, we also installed
two PV systems, one a-Si PV system and another mc-Si PV system, to compare the performance of PV cells of PV module and PVT collectors respectively.

To date, 3 PVT collectors developed by Grenzone Pte Ltd have been used to build 4 PVT systems to study the operational performance in tropical region. In addition, 2 PV systems were also installed in the test-bed for comparison of PVT system with normal PV system. The layout of PVT test-bed upon completion of installation is shown as in Fig. 4.

3. Structures and Operations of PVT Systems

Three different structures introduced in the test-bed are (1). a-Si stand-alone PVT system, (2) a-Si natural circulation grid-tied PVT system, and (3). a-Si & mc-Si forced circulation grid-tied PVT systems. The schematics of three types of PVT systems are illustrated in Figs. 5a, 5b and 5c respectively.

![Fig. 4. New layout of the PVT test-bed after installation of all systems; 1). 93Wp unglazed a-Si PVT system ; 2). 768Wp unglazed a-Si syphon PVT system ; 3).1.532kWp unglazed a-Si PVT system ; 4).1.8kWp glazed mc-Si PVT system ; 5). 1.024kWp a-Si PV system and 6). 1.2kWp mc-Si PV system](image)

![Fig. 5  The structures of three PVT systems in the test-bed: (a). Stand-alone forced circulation PVT system; (b). Grid-tied natural circulation PVT system and (c). grid-tied forced circulation PVT system](image)
The operational performances of all systems are monitored and recorded by a central data logger that is networked with distributed data loggers of each PVT and PV system. To obtain the accurate data for performance analyses, the central data logger collects both thermal and electrical parameters from all system every one minute. Fig. 6 summarizes the performance of three a-Si PVT systems since they were installed. As can be seen from Fig. 6a, 1.532kWp PVT system shows the best performance and its average conversion efficiency is around 41%, while 768Wp syphon PVT system presents the lowest conversion efficiency(<20%) that may be caused by the poor heat transfer between the collector and water tanks or by not high enough water temperature produced in an unglazed PVT collector. The 93Wp PVT system is the first PVT prototyping system installed in the test-bed and has been operating successfully for 18 months to provide valuable experimental results for the development of later PVT collectors/systems. Its average conversion efficiency is 34.66%[9-10]. Fig. 6b presents the monthly average hot water temperatures in the tanks of three PVT systems. It is apparent from the figure that two forced circulation PVT systems are able to meet the temperature range from 45°C to 55°C in most of time of a year. The average hot water temperature for 93Wp PVT system is 45.96 °C, whilst that of 1.532kWp PVT system is 43.94 °C. Like commercial solar thermal system, there is still a need to install electrical heater in water tanks as back-up source when low irradiance weather persists as shown in January 2011 in the figure.

![Fig. 6 performance of three a-Si PVT systems: (a). system conversion efficiency & (b). average hot water Temp in the tanks](image)

4. Conclusions

This paper presents a test-bed set up in Singapore for research on the operations and performances of different types of solar photovoltaic/thermal (PVT) systems in tropical region. Four PVT systems consisting either a-Si PV modules or mc-Si PV modules have been developed and installed at the test-bed. Long term experiments on three a-Si PVT systems turned out that all three a-Si PVT systems are stable and reliable, two forced circulation a-Si PVT systems possess good operational performance to meet the adequate temperature range for tropical domestic applications and have realised 34.66% of conversion efficiency for 93Wp system and 41.46% of conversion efficiency for 1.532kWp system respectively, but thermal syphon unglazed PVT system may not be suitable for tropical applications. More research work is underway to study on the performance of glazed mc-Si PVT and also to develop other type of PVT system like CIGS PVT collector. The investigation of cooling effect of fluid flow in PVT collector on operation of PV cells is also ongoing.

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6. References

Clarendon, 1892, pp.68–73.


