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EFFECT OF TEMPERATURE ON LONG-TERM EXPERIMENTAL PERFORMANCE OF AN AMORPHOUS SILICON PHOTOVOLTAIC THERMAL SYSTEM

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ABSTRACT

Amorphous silicon (a-Si) have a lower thermal coefficient, but the electrical performance is undermined by the fact of Staebler-Wronski (S-W) effect. Study on the effects of temperature on a-Si cells shows that a-Si cells can obtain higher electrical output at higher operating temperatures. This property makes a-Si cells more suitable for photovoltaic/thermal (PV/T) system where the operating temperature can easily reach higher level. At present, a-Si cells have attracted less attention in the PV/T application, but are promising photovoltaic (PV) materials for PV/T system. Research on the effects of temperature on a solo a-Si cell is already available, but the long-term impact on the a-Si PV/T system is still lacking. In a PV/T system, the operating temperature not only affects the electrical and thermal performance, but also the technical and thermodynamic reliability. To investigate the effect of temperature on the performance of a-Si PV/T system, long-term outdoor experiments of two identical a-Si PV/T systems operating at medium temperature (60°C) and low temperature (30°C) have been conducted from December 2017 to June 2019. At the initial phase of the long-test test, the electrical efficiency of the a-Si PV/T system operating at 30°C is 6.14%, which is much higher than that at 60°C (5.69%). During the long-term operation, both the electrical performances at 30°C and 60°C show an obvious download trend owing to the S-W effect. The initial difference in the electrical efficiency between 30°C and 60°C is 0.47%, while the gap eventually narrows to only 0.13%. In the past year and a half, the two a-Si PV/T systems operated stably without significant degradation in thermal and electrical performance. Through the long-term performance monitoring at different operation temperatures, it is demonstrated that a-Si cells are suitable for the PV/T application.

Keywords: Photovoltaic/thermal, amorphous silicon cells, operating temperature, long-term experiments

1. INTRODUCTION

Amorphous silicon (a-Si) cell is a promising photovoltaic (PV) material for photovoltaic/thermal (PV/T) system [1]. The power temperature coefficient of a-Si cells, which is lower than that of crystalline silicon (c-Si) cells (−0.4%/°C), ranges between −0.1%/°C and −0.2%/°C [2, 3]. As the operating temperature increases, the efficiency of c-Si cells decreases significantly, while a-Si cells show relatively small variation in efficiency [4]. Besides, a-Si cells can avoid high thermal stress which leads to the permanent structural damage of the PV cells at fluctuating temperatures in PV/T collectors [5, 6]. A compelling characteristic of a-Si cells is the Staebler-Wronski (S-W) effect which is related with the light-induced degradation and the creation of defect states [7]. The temperature of the a-Si cells plays an important role in the process of light-induced degradation [8]. Although the S-W effect limits the development of a-Si cells, a-Si cells are able to benefit from thermal annealing at high operating temperature (150°C) and reduce defect states, returning the electrical performance to initial state [9]. From the above, on the operating temperature for research is meaningful, since the operating temperature not only affects the electrical performance of a-Si cells, but also the thermal and technique performance of the PV/T collector.

At present, the effect of temperature on a-Si cells have been investigated by many scholars. Cueto et al. [10] conducted controlled light-soaking tests on a-Si cells at different temperatures. Ruther et al. [11] performed four year outdoor experiments in three different climates. The results showed that a-Si cells reached higher stabilized performance levels at higher operating temperatures and the stabilized performance levels attained at DSS depended largely on light exposure and a characteristic temperature. Carlson et al. [12] measured the temperature behavior of a-Si cells. In general, a-Si cells exhibited relatively little temperature dependence when they were operating in equilibrium, but they exhibited a relatively strong temperature dependence in a short period of time. Shima et al. [13] studied the effect of the operating temperature on the output characteristics of a-Si cells, and the advantages of the a-Si cell for practical use have been confirmed, especially in high-temperature regions.

However, the effect of temperature on a-Si PV/T systems is rarely reported so far. Although Rozario et al. [14] and Pathak et al. [15] proposed the PV/T system using a-Si cells, the study on the electrical performance is based solely on a-Si cells rather than PV/T system. Especially the PV/T systems always operate in recurrent alternating heating and cooling conditions [16]. During the day time, the PV/T collectors operate at high temperature, while can be at significantly low temperature at night. The stability of the PV/T system and whether the technical problems will occur are also worth studying. Therefore, it is impossible to predict the effect of the temperature on a-Si PV/T system simply by relying on existing research on a-Si cells.

To fill the knowledge gap in temperature effect on a-Si PV/T system, two identical a-Si PV/T systems are designed and processed. From December 2017 to June 2019, long-term outdoor experiments of the two a-Si PV/T system are conducted at different operating temperatures. The thermal and electrical performance at operating temperatures of 30°C and 60°C are presented and compared. During the long-term operation, the two systems still operate stably without significant degradation and no technical failure and observable deformation appear in the two a-Si PV/T collector. Finally, the results show that a-Si cells are more suitable for using in the PV/T system with medium-high operating temperature.

2. MATERIALS AND METHODS

2.1 a-Si cells and PV/T collector

The a-Si cells used in the PV/T system are provided by Xunlight (Kunshan) Co., Ltd [17]. As shown in Fig 1, the a-Si cells utilize the triple-junction thin film solar cells made from a-Si and a-Si germanium (a-SiGe), and the substrate is the stainless steel plate. The triple-junction a-Si cells each are a-Si cell, a-SiGe cell and a-SiGe cell from top to bottom. This structure makes a-Si cells convert a wider spectrum of light into electricity than conventional a-Si modules. There are fifteen pieces of a-Si cells laminated onto the aluminum plate though the EVA in an a-Si PV/T system.

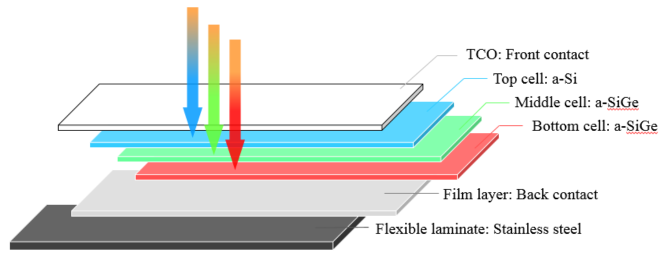

Fig 1 Structure of the triple-junction a-Si cells

2.2 Experimental methods

Two identical a-Si PV/T systems are conducted at a low temperature of 30 °C and a medium temperature of 60 °C, respectively. Fig 2 shows the actual setup of the two a-Si PV/T systems. The operating temperature is controlled by the thermostatic water tank (DC-0515), so that the system is able to operate at a steady temperature. The maximum power point tracking (MPPT) solar charge controllers are employed to track the current and voltage at maximum power point. During day time, the two PV/T systems are running at 30 °C and 60 °C, while the systems are shut down and cooled down at night.

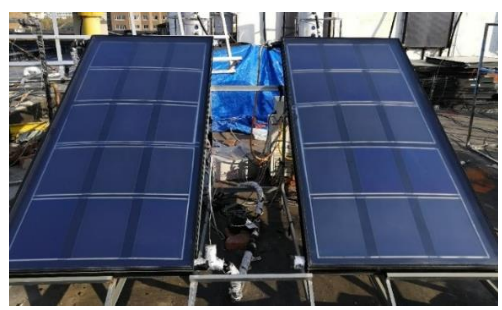

Fig 2 Actual setup of two a-Si PV/T systems

3. RESULTS AND DISCUSSIONS

Outdoor experiments have been carried out on the long-term behavior of the a-Si PV/T system from

December 2017 to June 2019. The experimental results on 56 sunny or cloudy days are summarized and given.

Fig 3 and Fig 4 show the fitting of daily average thermal efficiency against (Tin−$\overline{\text{Ta}}$)/H at 30°C and 60°C according to the experimental results. The thermal efficiency can be expressed as the regression formula:

$$\eta_{\text{th,a,30}} = 0.4172 - 6.39\frac{T_{\text{in}} - \overline{T}_{\text{a}}}{H},$$

$$\eta_{\text{th,a,60}} = 0.4214 - 6.83\frac{T_{\text{in}} - \overline{T}_{\text{a}}}{H}.$$

It is revealed from the regression lines of thermal efficiency at 30°C and 60°C, the intercept daily average thermal efficiencies each are 41.72% and 42.14%. With the increase of (Tin−$\overline{\text{Ta}}$)/H, the daily average thermal efficiencies decrease gradually with the slope of −6.39 and −6.83. Due to the two a-Si PV/T systems make no odds, the values of the intercept as well as the slope at 30°C and 60°C have proximity in number.

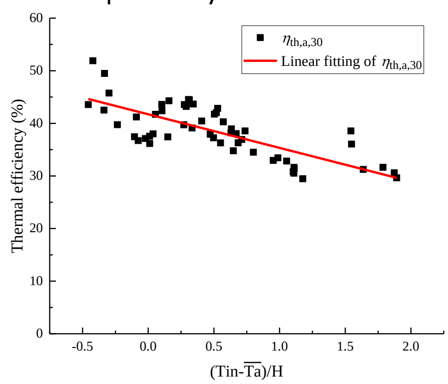

Fig 3 Linear fitting of thermal efficiency at 30°C

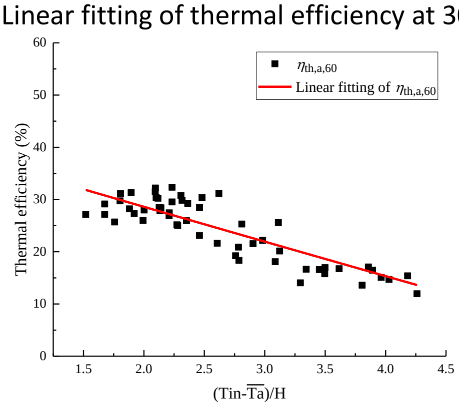

Fig 4 Linear fitting of thermal efficiency at 60°C

The long-term experimental results of the electrical performance at 30°C and 60°C is shown in and Fig 5. It is intuitively observed that the operating temperature plays an important part in electrical performance of a-Si cells. The electrical efficiencies at 30°C and 60°C both are on the decline, which attribute to the S-W effect. However, the difference in electrical efficiency between 30°C and 60°C is gradually narrowing. When the operating temperature is 60°C, the daily average electrical efficiency is the highest at 5.69% on December 25, 2017, while the electrical efficiency is reduced to 5.32% on June 23, 2019 during long-term operation. For the operating temperature of 30°C, the electrical efficiency on December 25, 2017 and June 23, 2019 each are 6.15% and 5.45%. The difference in the electrical efficiency between 30 °C and 60 °C is 0.47% at the beginning. After long-term light-induced degradation, the gap narrows to only 0.13%.

The results show that a-Si cells have a lower thermal coefficient, but performance of a-Si cells is undermined by the fact that long-time light exposure reduces electrical efficiency. Fortunately, the results of this study, which investigated the effect of temperature on the thermal and electrical performance of the a-Si PV/T system shows that a-Si cells have the ability to reduce the degradation with operating at high temperature. This property confirmed the advantages of the a-Si cells for practical use in PV/T collector where the operating temperature can easily reach a high temperature of 60-100°C.

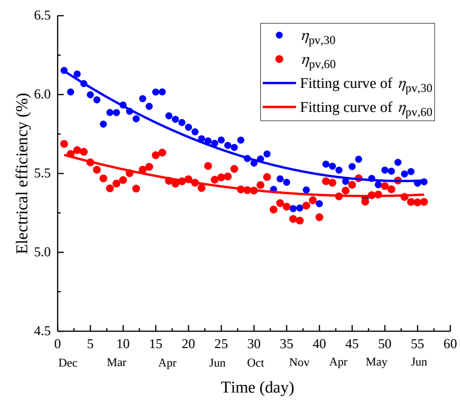

Fig 5 Comparison of electrical efficiency at 30°C and 60°C

During the long-term operation from December 2017 to June 2019, the two a-Si PV/T systems have operated stably all the time without significant degradation in thermal and electrical performance (expect for the light-induced degradation of a-Si cells). Moreover, there is no technical failure and observable deformation appeared in the two a-Si PV/T collector at 30°C and 60°C.

4. CONCLUSIONS

In this paper, the effect of the temperature on the thermal and electrical performance of the a-Si PV/T system has been explored by the long-term outdoor experiments in natural environment from December 2017 to June 2019. For the two identical a-Si PV/T systems operating at temperatures of 30°C and 60°C, the intercept daily average thermal efficiency each are

41.72% and 42.14% and the daily average thermal efficiencies decrease gradually with the slope of −6.39 and −6.83 with the increase of $(T_{in}-\overline{T_a})/H$.

In the initial stage, the electrical efficiencies of the two a-Si PV/T systems at 30°C and 60°C are 6.15% and 5.69%, respectively. The incipient difference in the electrical efficiency between 30°C and 60°C is 0.47%. After a long-term outdoor operation, the gap narrows to only 0.13%. This characteristic makes a-Si cells more suitable for using in PV/T collector where the operating temperature can reach a high level.

During the long-term operation, the two a-Si PV/T systems have operated stably without significant degradation in thermal and electrical performance. The technical and thermodynamic reliability the of the two a-Si PV/T collectors at different temperature can be demonstrated.

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