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Thin-film CdTe photovoltaics – The technology for utility scale sustainable energy generation

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ABSTRACT

Photovoltaics is an important energy technology for large scale energy generation. In the past few years cost of photovoltaic module manufacturing and installation as well as electricity generation has substantially decreased while the production volume has seen a steep increase. These changes can be attributed to improvement in solar cell efficiencies as well as better manufacturing practices. There are several photovoltaic technologies available in the market but the two primary technologies commercially manufactured for large scale installations are polycrystalline thin-film CdTe and crystalline silicon. Crystalline Si is the oldest and the most widely installed technology while thin-film CdTe is the technology that has demonstrated the largest growth and lowest LCOE (levelized cost of energy). In this study, commercial modules from both these technologies are installed side by side for an accurate comparison of their performance. The modules for comparison are installed with the same approximate nameplate capacity in three different configurations viz. Roof-top, floating on water and ground. Their performance is monitored and analyzed over a 3 month period. Thin-film CdTe demonstrated substantial advantage under all three conditions over crystalline Si in Thailand's tropical climate which is characterized by high temperatures and humidity throughout the year. Advantage demonstrated by thin-film CdTe is further supported by greater economic, environmental, reliability and life-cycle advantages that are summarized in the later part of the study.

1. Introduction

About 174,000 terawatts (TW) of energy from sun is received by the upper atmosphere of earth and after losses 94,800 TW is available on earth's surface that can be consumed for energy generation. World energy demand is currently estimated at about 18 TW which is a small fraction of the energy received on earth's surface. By 2030, world energy demand is expected to grow by about 30% to maintain the current living standards. However, the growth in photovoltaic development and installations is much faster than the growth of energy demand (Haegel et al., 2017). Due to the steep increase in production and installation of photovoltaics as well as improvement in conversion efficiency the cost of photovoltaics is seeing a sharp decline (Haegel et al., 2017; Branker et al., 2011; Lazard, 2014). These among other factors contribute to making photovoltaic electricity a major source of energy generation.

Crystalline silicon photovoltaics is the dominant photovoltaic technology globally for solar installations (Fraunhofer, 2018). Apart from crystalline silicon, there are two thin-film technologies that are prominent in the photovoltaics market – cadmium telluride (CdTe) and copper indium gallium di-selenide (CIGS). Over 17 GW of CdTe photovoltaics has been installed globally (First Solar, 2017) and CIGS annual manufacturing capacity currently is estimated at about 1.5 GWp (Fraunhofer, 2018). Thin-film CdTe being one of the prominent photovoltaic technologies, it is important to understand scope and impact of CdTe photovoltaics for large scale energy generation. To evaluate the performance of CdTe photovoltaics against crystalline silicon photovoltaics under different installation conditions, same approximate nameplate capacity (~3 kW) were installed and monitored. The three installation conditions investigated were roof-top, floating on water (Trapani et al., 2015; Miguel Redón Santafé et al., 2013) and ground. Based on the collected data their performance was compared. The collected results were also used to generate a prediction model for thin-film CdTe and the predictability of thin-film CdTe module was evaluated. Other researchers have performed similar studies to understand the performance of solar modules in the field (Kichou et al., 2018;

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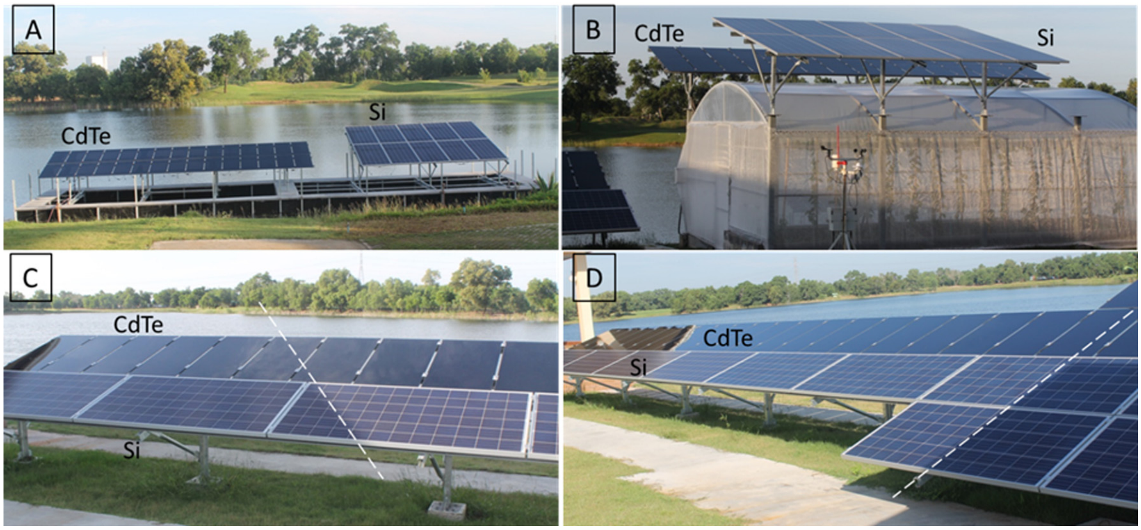

Fig. 1. Equal capacity (~3 kW) of ground installation of CdTe and c-Si for performance evaluation. (A) Floating (B) Greenhouse rooftop (C) Ground installation morning shadow (D) Ground installation evening shadow.

Rajput et al., 2018). The comparison of c-Si and thin-film CdTe performance is presented here in terms of performance over 3 month study, performance per day over one month period and performance over an entire day of operation. The study presented here also addresses various questions such as effects of humidity and temperature, power generation advantage, reliability, environmental impact and toxicity.

2. Performance and reliability of thin-film CdTe modules

To evaluate the performance of the two most prominent photovoltaic technologies under field operating conditions, about 3 kW of CdTe and c-Si modules were installed under different conditions. These installations included ground installations, roof-top and floating type on a lake. These installations were constructed at a golf course in Thailand. The goal of this study was to compare the performance of CdTe against c-Si under exactly same operating conditions. In addition, the modules on ground were so installed that both CdTe and c-Si modules had similar shadowing from nearby construction in the morning as well as the evening. Fig. 1 shows the shadowing of these installed arrays. These structures help to accommodate different types of panel and differentiate their temperature dependencies.

The installed capacity of CdTe thin-film panels at each installation was about 3150 W and poly crystalline is about 3050 W details for which are given in Table 1.

A temperature data logger is used to record the ambient and module temperature using thermocouples which are attached to the rear side of the panels (Sreewirote et al., 2017). The duration between consecutive readings was 10 min. DC and AC electrical parameters were monitored by respective sensors which measured voltage, current and power output of the installed solar panels. Solar radiation was measured using pyrometers which were placed at the same tilt angle as panels. Recording of the data was continued for 2 months.

Table 1
Different installations.

Type of installations	Type of panel	Max rating of panel (W)	No of panels	Total (W)
Green house roof-top	Crystalline	305	10	3050
	Thin-film	105	30	3150
Floating on water	Crystalline	305	10	3050
	Thin-film	105	30	3150
Ground installation	Crystalline	305	10	3050
	Thin-film	105	30	3150

Fig. 2 shows the normalized power output for all 3 conditions over an entire day. In all three cases, CdTe thin-film produced considerably higher power than polycrystalline Si. This higher performance is primarily due to better temperature coefficient of CdTe thin-film photovoltaics as compared to c-Si. More details regarding this will be discussed in the discussion section.

For the arrays that were installed on ground with the same amount of shading for CdTe thin-film and c-Si, CdTe thin-film demonstrated a much greater advantage over polycrystalline silicon as can be seen in Fig. 2. As mentioned earlier, the arrays of ground mounted panels are so installed as to allow partial shading of the arrays in the morning and evening.

Though equal shading occurred in both CdTe thin-film and polycrystalline panels, CdTe thin-film panels showed much better output. The maximum difference in the performance was predominantly in the morning hours. The normalized power difference is shown in Fig. 3. At its peak, CdTe thin-film demonstrated about 1.6 kW advantage over the polycrystalline Si panels. Effect of shading during evening hours was observed to have less effect on the arrays. Performance output of CdTe thin-film arrays on ground installation was also compared to same capacity CdTe thin-film rooftop mounted panels. The maximum difference between these was observed to be only 310 W. This further provides evidence that CdTe thin-film modules are substantially less sensitive to environmental conditions than polycrystalline silicon panels.

The energy production during shading hours for these arrays is shown in Table 2. It is evident from these results that polycrystalline silicon panels show a greater loss in power generation when compared to CdTe thin-film panels. While performance of thin-film CdTe panels was seen to be better under various field operating conditions over an entire day, it was important to analyze the performance of these arrays over a longer period of time. For this purpose using the data logger described earlier, performance of these arrays was monitored over a period of one month. Thin-film CdTe modules substantially outperformed the performance of c-Si as well. A comparison of the peak power output of thin-film CdTe panels against polycrystalline Si panels is shown in Fig. 4. The output here is plotted in terms of percentage of installed capacity of both arrays.

The analysis period was further extended to a period of 3 months. The ratio for output in terms of installed capacity to actual peak power generation was monitored for these arrays and performance for each over this 3 month period is shown in Table 3.