Conference Proceedings

Solar World Congress 2015
Daegu, Korea, 08 – 12 November 2015

Qualitative analysis of thin-film CIGS and c-Si technologies in tropical environments

Wai Kean Yap[1], Mirza Humayun Baig[1], Edward Halawa[1] and Vishy Karri[1,2]

[1] Centre for Renewable Energy, Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin (Australia)

[2] Codesign Australia Pty. Ltd, Brisbane (Australia)

Abstract

The technological advancement in solar photovoltaic (PV) materials enabled system designers, engineers and end-users to select the best type of system for a given environment. This paper identifies and investigates the key environmental factors that affect the performance of two different PV technologies under the tropical climate; the thin-film copper indium gallium di-selenide (CIGS) and the conventional crystalline silicon (c-Si) systems. The annual Northern Australian climate consists of distinct wet and dry cycles and a cyclone-prone environment. The effects of real-world conditions on the panels were investigated experimentally. The measured performance of the PV systems showed a reduction of 19.6% and 9.2% for the maximum energy output and 34% and 22% reduction of the total daily energy production for the CIGS and c-Si systems respectively during the dry season period. The systems managed to regain their optimal efficiencies during the start of the wet season when the first rainfall occurred. This study highlighted the effects of soiling (dust accumulation), fauna droppings, shading and orientation on the PV system efficiencies in a tropical locale were presented. For the Northern Australian climate, CIGS and c-Si PV systems should be washed at least once during the dry season in order to maintain its original efficiencies. This paper concluded that real-world testing of PV technologies is crucial, and should complement the existing laboratory testing to accurately estimate the system's performance and behavior.

Keywords: *copper indium gallium di-selenide, crystalline silicon, environmental effects on PV, thin-film PV, CIGS, c-Si*

1. Introduction

The systems involved in the study presented in this paper are the thin-film copper indium gallium di-selenide (CIGS) and crystalline silicon (c-Si) panels. The thin-film systems are expected to perform well in slightly diffused light and their performance is not supposed to drop during hot days [1]. The following literature identifies the relevant studies on the thin-film CIGS and other conventional photovoltaic (PV) technologies in the tropical locale.

The most common effects studied on the performance of PV systems are the environmental effects. These effects are generally the effect of temperature, rainfall, humidity, cloud and wind speeds. Along with that, few external effects were also investigated, including the effect of shading, tilt angle and gradual degradation of the PV materials. However, what seems to be somehow ignored in the past studies is the effect of dust accumulation as it can be detrimental, specifically in the extended dry season locales in Northern Australia.

Dust particles can impinge on to the surface of a PV panel. The extent of dust accumulation mainly depends on wind, moisture, electrostatic charge, gravity and surface properties of the panels [2]. Jiang et al. carried out a controlled laboratory experiment to measure the effect of dust accumulation losses in different

doi:10.18086/swc.2015.05.27 Available at http://proceedings.ises.org

PV materials. The experimental results found that the PV output efficiency grew from 0% to 26% for dust deposition density increasing from 0 to 22g/m^2 [3]. However, the difference in reduction of efficiency due to cell types was not evident. On a different occasion, Kaldellis and Kapsali performed laboratory analysis and developed theoretical model to investigate the effect of dust in PV performance losses. However, they recommended performing real-life data analysis to map actual results [4]. Beattie et al. presented numerical and analytical models of dust accumulation that quantitatively coincide with a laboratory investigation of particle accumulation on a glass slide for PV in dry regions. Their study was laboratory based with controlled conditions and did not include real PV systems with environment data [5]. Also, Boyle et al. performed an experiment on dust accumulation on PV cover plates (not actual PV) and found 6% reduction in light transmission per g/m^2 of dust accumulation [6]. Study by Said and Walwil found 6% reduction after 5 weeks of exposure in Qatar [7].

The effect of soiling on PV panels in the Sahara region was investigated by Kalogirou et al. who suggested immediate washing after dust events [8]. Mohamed and Hasan observed gradual decrease of power from PV panels (type unknown) in Sahara environment of Libya due to the effect of dust accumulation. They suggested weekly washing during windy periods and at least a month for other months in order to maintain performance losses between 2 to 2.5% [9]. Piliougine et al., during an analysis of the dust losses in c-Si PV modules with different cover glasses in Malaga (Spain), found losses reached 15% in no rainfall period (> 2 months) and annually 6% losses due to dust accumulation [10]. Adinoyi and Saidfound 50% reduction in power of crystalline solar panels installed in Saudi Arabia which had not been cleaned for six months [11]. Various simulations and experiments to measure the effect of dust losses on PV systems were performed by Qasem et al. in the arid environment of Kuwait. They found that the worst angle for most non-uniform dust accumulation is 30^0 [2]. The PV materials experiencing the most losses due to dust shading are the wide band-gap materials. The materials could be categorized as c-Si, followed by Cadmium Telluride (CdTe) PV, whereas c-Si and CIGS PV systems were found to be less affected. The mean daily energy loss due to dust accumulation on the surface of PV was recorded 4.4% and could extend to 20% during no rainfall periods, as studied by Zorrilla-Casanova et al. [12]. This study was done in Spain with the author suggesting that the losses can vary depending on the location and angle of tilt at which the PV was installed. A study by Lorenzo et al. at their solar park dust investigation found detrimental aspects of homogenous dust accumulation which may also cause hot spot phenomenon, hence, a threat to the PV module lifetime [13].

Darwin, located in the Northern Territory (NT), has a unique climate with high monthly and annual solar radiation, distinct wet (humid and high rainfall) and dry (less humid and no rainfall) seasons, along with a highly cyclone-prone environment. This study, conducted at the Charles Darwin University's Outdoor Solar Facility as detailed in the following scripture, outlines actual quantified production loss figures over the dry and wet periods. In addition, this study also covers a unique tropical locale of Australia involving two often installed types of PV modules of different optical properties and attributes. A highly efficient inverter system was used to analyze the real production of the system.

2. System Description and Background

For experimental measurements, both systems were installed in the Casuarina Campus at the Charles Darwin University (CDU) (-12.37°S, 130.86°E). Fig. 1 shows the picture of the monitoring and evaluation solar facility. The solar facility is an outdoor structure made of composite material, impregnated by thin-film CIGS PV material as roof sheeting, and fastened directly to the steel structure. The thin-film modules are bonded on the composite sheet away from the borders to avoid direct heat transfer from the steel structure. The modules are affixed using pressure sensitive adhesive to the Category 4 cyclone wind resistant glass reinforced composite backing of trapezoidal profile [14]. This 1.5kWp solar facility has local vegetation around and it is a home to numerous local birds and other fauna. Fig. 2 shows the c-Si PV system set up on one of the buildings adjacent to the CIGS setup. This 5.0kWp system was installed in the rooftop of the building, and similarly to the CIGS system, is grid-connected.

The two solar facilities were setup to monitor the influence and impact of environmental factors on the performance and production efficiency of both the systems. Incorporating the data from the Australian Bureau of Meteorology (BoM) weather station mounted at CDU, effects of real-world conditions on the panels such as dust, rainfall, fauna droppings, shading and orientation were investigated and discussed.

This study is in particular extremely interesting with the unique Northern Australian climate with high monthly and annual solar radiation, distinct annual wet (humid, high rainfall and cyclone-prone) and dry (less humid and virtually no rainfall). These two seasons highlight the natural effects of washing (due to rainfall) and soiling (dusts and fauna droppings build-up during the dry season) on the PV systems. The objective of this study is to complement the research of PV performance in the laboratory where the environmental parameters are often ignored in laboratory testings.

Fig. 1: The Outdoor Solar Facility for the 1.5 kWp CIGS system (ENER TSG200-GS2, Inverter: EnaSolar1.5KWGT-AUNZ) [14]

Fig. 2: The installed 5.0 kWp c-Si rooftop system (Auxin AXN-P6T275, Inverter: SunnyBoy SMA SB 5000TL-20)

3. Results and Discussions

3.1 PV power production

The power production for both the 1.5kWp CIGS and 5.0kWp c-Si systems were recorded, together with the rainfall data for the period from March 2014 to July 2015. The profile is shown in Fig. 3.

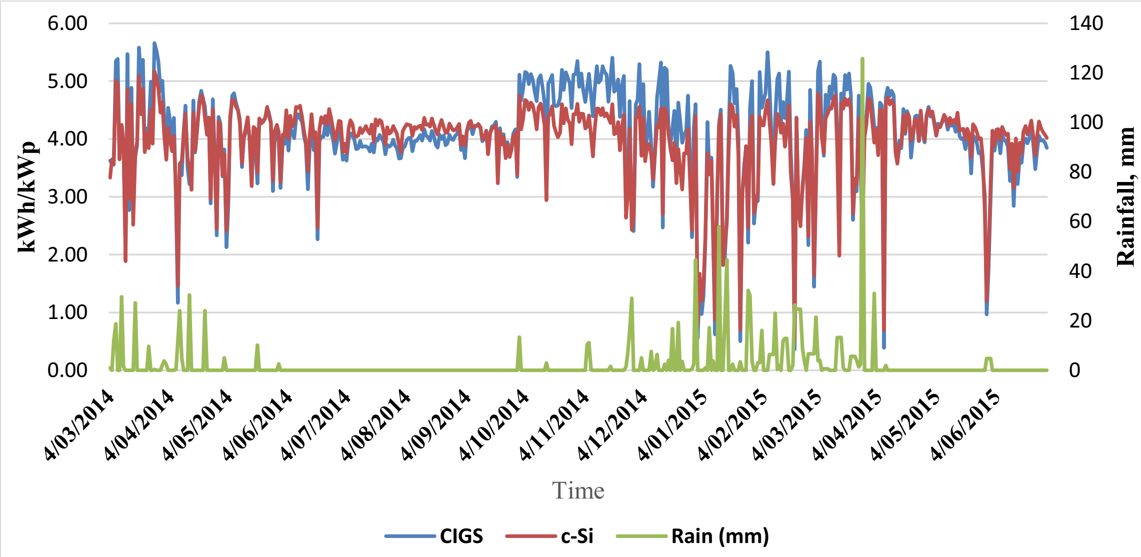

Fig. 3: Daily normalized power output and rainfall profile

From the plot, the power output for the two PV systems were fairly irregular during the annual wet season (March-May 2014 and November-April 2014/15). This was expected due to constant rainfalls, cloud cover and low radiation. During the dry season (June-October 2014 and March-June 2015), the power outputs were constant, which was expected due to clear skies and no rainfall.

The average power output recorded were higher during the wet season (although production was erratic), in the region of 5kWh/kWp for CIGS compared to 4kWh/kWp during the dry season. The c-Si system do not vary much, but similarly do have higher average compared to the dry season. Observing the period from March to June 2015 (start of the dry season), the average power outputs are slowly decreasing to the constant levels similar to the previous dry season (June-October 2014). This performance behaviour was expected. Overall the power output profiles were within the expected behaviour and both systems displayed similar qualitative relationship.

The power output increased significantly after the first recorded rainfall on the 30th of September 2014 for both systems. Taking a closer look at Fig. 3, the escalation in production after the first rainfall was observed to be much higher for the CIGS system as compared to c-Si system. There could be number of possible reasons for this increase in the power generation. One of the reasons is that the CIGS system has a rough surface material, which attracted more dust and accumulated a higher amount of dust particles compared to the much smoother surface of the c-Si system. Also, the efficiency of CIGS system does not drop in slightly diffuse light and on hot days compared to the c-Si system which are more sensitive to cloudy conditions and high temperatures [1].

The daily maximum energy output recorded for October showed a substantial increase of 19.6% and 9.2% (from the previous month, September) for the CIGS and c-Si systems respectively. This 'natural washing' phenomena (due to rainfall) cleaned the surface of the panels, and thus contributes to this increase to the PV's original efficiency (as observed during the wet seasons). This phenomena is critical, especially for the Northern Australian climate, and highlighted to importance of washing during the dry seasons. These natural environmental effects are discussed in the next section.

3.2 Natural environmental effects - dust accumulation, fauna droppings and rainfall

Fig. 4 to 6 shows the amount of dust accumulation and fauna (birds and bats) droppings on the panel surface. This occurs mostly during the dry season, where no rainfalls were observed. The figures were obtained during the end of the dry season to highlight the dust and droppings accumulated over the period.

Fig. 4: c-Si panels, 26th August 2014

Fig. 5: CIGS panels, 22nd August 2014

Fig. 6: Fauna droppings on the panels - 1st August 2014

The increase in the power output, with increasing monthly solar exposure, is observed for the month of October. It is worth noting that the first rainfall recorded for this testing facility is on the 30th of September 2014. This natural washing of the panel surfaces by the rainfall had drastically improved the power output of both the PV systems, as highlighted in the previous section. Fig. 7 shows the CIGS system after the first rainfall where the accumulated dust and soil are washed away.

Fig. 7: Naturally washed panels due to rainfall - 3rd October 2014

Fig. 8 shows the monthly normalized average and maximum production power for both of the PV systems and the maximum monthly solar irradiation. The maximum recorded power output for both systems are consistent with the Darwin climate; wet season (March-May 2014 and November-April 2014/15) and the dry season (June-October 2014 and March-June 2015). The maximum outputs recorded are lower for the dry seasons as compared to the wet seasons. The measured performance of the PV systems showed a reduction of 19.6% and 9.2% for the maximum energy output and 34% and 22% reduction of the total daily energy production for the CIGS and c-Si systems respectively for the dry season compared to the wet seasons. They are further discussed in the following sections

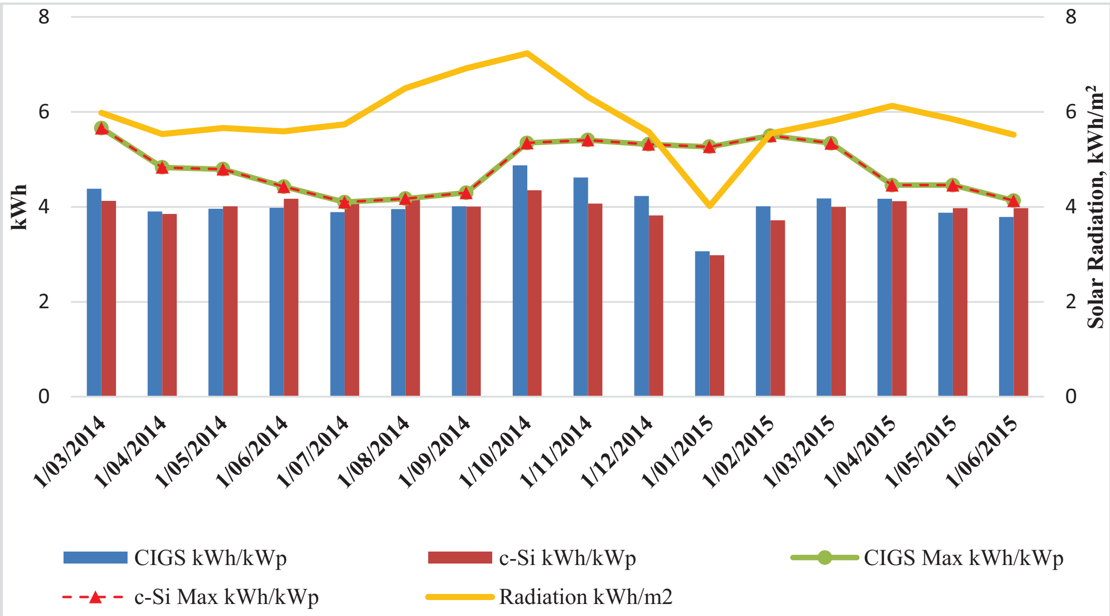

Fig. 8: Monthly normalized average and maximum kWh for CIGS and c-Si and maximum solar irradiation

3.2.1 Effects on the CIGS system

To further observe the role of rainfall on the system's performance efficiency, the maximum daily production was analysed against the rainfall and solar exposure data as shown in Fig. 8. For 2014, at the end of the wet season (March-May), the maximum production power recorded was just over 7kWh/day. Entering to the dry season (May-October 2014), the maximum production power decreased steadily although the solar irradiation increases. The same profile (slowly reduced in efficiency) was observed in 2015 (April-June) during the start of the dry season.It was found that this level of production was not reached until it rained again on the 30th of September 2014. This rainfall washed away the accumulated dust from the surface of the panels. This observation further emphasized the critical effects of soiling and fauna dropppings on the surface of the CIGS panels.

The effect of soiling on the PV panels was investigated in the Sahara region by Kalogirou et al., where the authors suggested that panels to be cleaned after every dust event and once every 2 to 3 weeks during high dust seasons [8]. Mani and Pillai also suggested weekly cleaning during long dry spells [15]. The observations from this study concluded that CIGS systems installed in tropical Northern Australia should be washed at least once during the dry season to maintain its efficiency.

3.2.2 Effects on the c-Si system

The c-Si PV system was installed adjacent to the CIGS system within the same area, hence it experienced similar intensity and pattern of rainfall. Similarly to the CIGS, the increase in power production was observed after the first rainfall (30th of September 2014). The same hypothesis, may apply here that the rigorous natural washing (removing accumulated dust) of the solar panels by the rainfall is the reason for the increment in power generation. Furthermore, the weather conditions recorded from the closest weather stations (CDU and Darwin Airport) are very similar as well on both the days.

Similarly, in order to investigate the role of rainfall in system's performance efficiency, the maximum daily production was analysed against the rainfall and solar exposure data as shown in Fig. 8. For 2014, Darwin experienced its end of wet season rainfalls until May and the maximum power production recorded was about 23kWh/day. Analysing the data it is found that this level of production was not recorded until it rained on the 30th of September, removing the accumulated dust from the surface of the system. The same profile was observed in 2015 (April-June) during the start of the dry season. Similar to CIGS systems, it appears rational to suggest that c-Si PV systems installed in the tropical Darwin should also be washed at least once in between the dry season to maintain its original efficiency.

3.2.3 Performance comparison

The effect of dust accumulation in the case for c-Si system does not seem to affect the production performance to the same degree compared to the CIGS system. Physical observation of the two systems in this period shows that CIGS had attracted and accumulated more dust as compared to c-Si system.

In addition, the physique of the thin-film CIGS can be described as flexible, undulating with rough surface in contrast to a smoother surface of the conventional c-Si PV panels. Moreover, given the smooth surface of conventional panels would also have supported the removal of some dust through the regular moisture flow from the natural morning dew.

3.3 Effect of system orientation

As mentioned previously, both systems were installed in close proximity to each other (approximately 20m apart in the same area). However, the systems each has different orientations. The c-Si system was installed on the east facing roof and the effect of this orientation can be seen in Fig. 9 (in the morning and late evening). The sudden drop in power generation after 3:30PM can be observed when the sun is located behind the building.

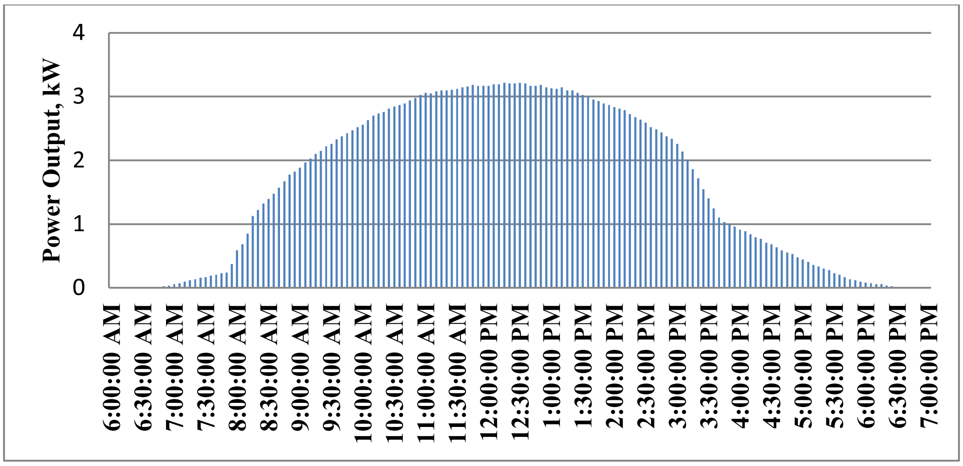

Fig. 9: Intraday power plot for the c-Si system on 17th September 2014

On the other hand, the CIGS system is installed facing north and the effect of this orientation can be seen in Fig. 10. The intraday power plot on the same day exhibits a smooth and uniform profile throughout the day, taking the maximum advantage of the sunshine hours, compared to the c-Si system. The CIGS system however, misses out on some sun time in the mornings and late afternoons. This was due to the fact that the experimental system is installed at a lower height over the ground and hence surrounded by tall trees around the area.

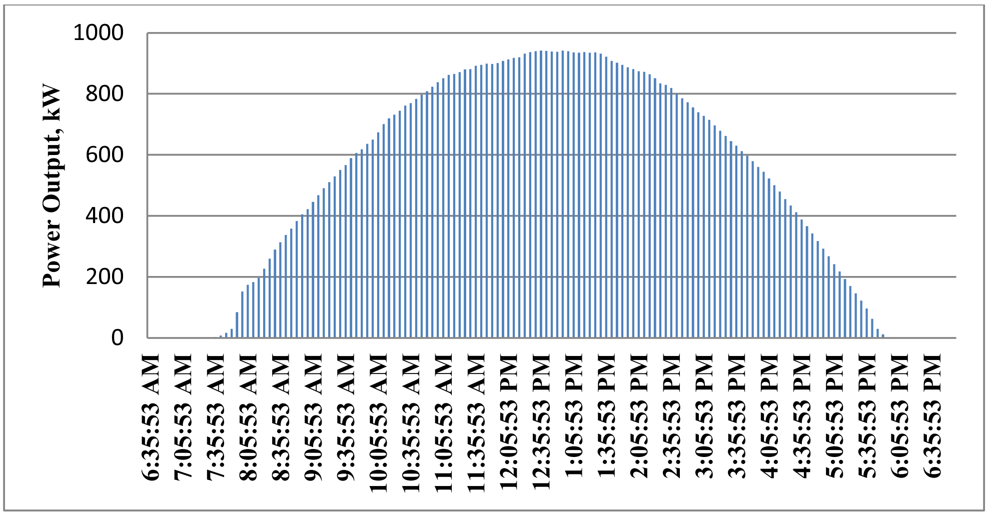

Fig. 10: Intraday power plot for the thin-film CIGS system on 17th September 2014

4. Summary and concluding remarks

This paper identifies and investigates the environmental factors that affect the performance of two different PV systems under the tropical climate; the thin-film CIGS and the traditional c-Si systems. For experimental measurements, both systems were installed in the Casuarina Campus at the CDU (-12.37°S, 130.86°E), where the annual climate for Northern Territory, Australia consists of distinct wet and dry cycles and a cyclone-prone environment annually.

Utilizing the climate data obtained from the BoM, results showed the system performances under that the effect of dust, soiling and fauna droppings (on the respective panel surfaces), especially during the dry season, has significant affects on the power production of the systems. It was observed that during the dry season, such factors have the opportunity to collect on the respective panel surfaces.

The daily power output (Fig. 3) and the maximum monthly energy output (Fig. 8) recorded for both the CIGS and c-Si systems exhibited similar and expected behaviours; a constant decline in efficiency over the dry season, and the systems regain their original efficencies during the start of the wet season. When the first rainfall was recorded (end of September), the daily maximum energy output recorded for October showed a substantial increase of 19.6% and 9.2% for the CIGS and c-Si systems respectively. This 'natural washing' phenomena cleaned the surface of the panels, and thus contributes to this increase to the PV's original efficiency, and the effiencies were maintained over the season. In addition, the measured performance of the PV systems showed a 34% and 22% reduction of the total daily energy production for the CIGS and c-Si systems respectively for the dry season compared to the wet season. This was highlighted in Fig. 3 and 8, from October 2014 to March/April 2015. It was concluded that washing the panels once during the dry season is sufficient to maintain its orginal efficiencies.

The effect of shading and system orientation were also presented and discussed. Analysing the intraday power plot curve for both systems, it was concluded that the north-facing CIGS system exhibits a smoother profile compared to the east-facing c-Si system. However, the CIGS system was missing out on some amount of sun time during the early morning and in the late afternoon.

In conclusion, results showed a significant difference in the percentage increase in the power generation of the two different types of PV systems with same daily average solar exposure before and after the rainfall. There could be number of possible reasons for this difference of behaviour between the two systems. The two systems could have different response to diffuse sunlight/cloud cover, temperature and affinity for dust accumulation. Moreover, difference in the affinity for dust accumulation due to difference in surface material, smoothness, angle of tilt and height of system installed. Therefore, this finding makes a strong implication for further investigation of each system's performance on an intra-day basis, also incorporating the necessary environmental factors of this tropical locale. This study highlighted that real-world testing of PV systems is crucial and important, and this should complement on the additional laboratory testings to accurately estimate the system performance and behaviour.

Acknowledgements

Special thanks to The Specialty Coatings (Aust.) Pty Ltd. for their contribution of the solar testing facility, especially to Dr. Dragos Petrescu for his expertise in developing this facility.

References

[1] Clean Energy Council, 2011. Consumer guide to buying household solar panels (photovoltaic panels). 28.

[2] Qasem, H., Betts, T.R., Mullejans, H., Albusairi, H., Gottschalg, R., 2014. Dust-induced shading on photovoltaic modules. Prog. Photovoltaics 22, 218-226.

[3] Jiang, H., Lu, L., Sun, K., 2011. Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules. Atmos. Environ. 45, 4299-4304.

[4] Kaldellis, J.K., Kapsali, M., 2011. Simulating the dust effect on the energy performance of photovoltaic generators based on experimental measurements. Energy 36, 5154-5161.

[5] Beattie, N.S., Moir, R.S., Chacko, C., Buffoni, G., Roberts, S.H., Pearsal, N.M., 2012. Understanding the effects of sand and dust accumulation on photovoltaic modules. Renew. Energy 48, 448-452.

[6] Boyle, L., Flinchpaugh, H., Hannigan, M., 2013. Impact of natural soiling on the transmission of PV cover plates. 39th IEEE Photovoltaic Spec. Conf. (PVSC), Tampa FL, United States, 6745150 3276-3278.

[7] Said, S.A.M., Walwil, H.M., 2014. Fundamental studies on dust fouling effects on PV module performance. Sol. Energy 107, 328-337.

[8] Kalogirou, S.A., Agathokleous, R., Panayiotou, G., 2013. On-site PV characterization and the effect of soiling on their performance. Energy 51, 439-446.

[9] Mohamed, A.O., Hasan, A., 2012. Effect of dust accumulation on performance of photovoltaic solar modules in Sahara environment. J. Basic Appl. Sci. Res. 2, 11030-11036.

[10] Piliougine Rocha, M., Carretero Rubio, J.E., Sidrach-de-Cordona, M., Montiel, D., Sanchez-Friera, P., 2008. Comparative analysis of the dust losses in photovoltaic modules with different cover glasses. 23rd Eur. Photovoltaic Sol. Energy Conf. Exhibit., Valencia, Spain, 2698-2700.

[11] Adinoyi, M.J., Said, S.A.M., 2013. Effect of dust accumulation on the power outputs of solar photovoltaic modules. Renew. Energy 60, 633-636.

[12] Zorrilla-Casanova, J., Piliougine, J., Carretero, J., Bernaola, P., Carpena, P., Mora-Lopez, L., Sidrach-de-Cordona, M., 2011. Analysis of dust losses in photovoltaic modules. World Renew. Energy Congr., Linkoping, Sweden, 2985-2992.

[13] Lorenzo, E., Moreton, R., Luque, I., 2014. Dust effects on PV array performance: in-field observations with non-uniform patterns. Prog. Photovoltaics 22, 666-670.

[14] Yap, W.K., Baig, M.H., Halawa, E., 2014. Performance monitoring and evaluation of a CIGS-roof integrated photovoltaic system under the unique tropical environment of Darwin, Northern Territory. Asia-Pacific Sol. Res. Conf., UNSW, Sydney, Australia.

[15] Mani, M., Pillai, R., 2010. Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. Renew. Sust. Energy Rev. 14, 3124-3131.