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Technical note

Design and evaluation of passive concentrator and reflector systems for bifacial solar panel on a highly cloudy region – A case study in Malaysia

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A B S T R A C T

Photovoltaic (PV) systems are the most promising renewable energy source in Malaysia because it is a tropical country receiving a huge amount of solar irradiation every year. However, Malaysia is surrounded by South China Sea and Malacca Straits. The vapour from the sea water with the blow of seasonal winds causes a large amount of clouds passing over the country, hence creating the variation in the direct and diffused sunlight throughout a day. The performance of the concentrators and reflectors for bifacial solar cells under the variation of direct and diffused sunlight has not been studied thoroughly. Therefore, several concentrators and reflectors have been designed, constructed and placed under a specially designed bifacial solar panel. The setup of each concentrator and reflector is as follows; scattering particles (scatterers) sprinkled across the plane mirror under the solar panel, an array of adjustable small plane mirrors placed underneath the solar panel, and long triangular prisms in between solar cells with a plane mirror underneath. Another solar panel is constructed and placed on top of the plane mirror as a reference. Each setup of the concentrators or reflectors is evaluated by measuring the power output of the tested and the reference panels together throughout a day under the sun. Empirical approaches are developed to compensate for uncontrollable factors including solar cell manufacturing mismatch and unequal degradation between the tested and the reference solar panels. A few potentially working static concentrator and reflector systems are identified based on the experimental results. An assessment is carried out to show the economic viability of the proposed setups with respect to that of the mono-crystalline solar cells.

1. Introduction

Photovoltaic (PV) system is a promising renewable energy source on the equatorial regions due to the substantial amount of solar irradiation available across the regions. However, a few of the equatorial countries are surrounded by the seas where a large amount of cloud is generated and moved to the mainland by the blow of the seasonal wind. Malaysia is one of the examples. Fig. 1 shows the frequency of completely clear sky occurrences across the globe [1]. It is shown that Malaysia does not have a single day with a completely clear sky. With a large amount of clouds passing over the country, there is a variation in direct and diffused sunlight throughout a day.

Bifacial solar cells are able to convert light into electricity with both its front and rear sides. Their direct application is albedo collection of the Earth surface, clouds and the atmosphere: both their front and rear surfaces can capture direct sunlight as well as diffused sunlight from the environment with the use of an appropriate concentrator or reflector [2]. There are several static or non-tracking concentrators and reflectors being developed and tested, such as triangular central prism [3], equilateral triangular prism above or below solar cells [4], RXI concentrator–dielectric rod concentrator encapsulating the solar cells [5–7], tilted grooves dielectric reflector below the solar cells [8], cylindrical reflector [4,9,10], spherical reflector [11], parabolic trough concentrator [4,7], “sea shell” collector [7,12], combined prismatic-parabola-cylindrical stationary concentrators [13], semi-transparent reflector [14], diffuse reflector [14–16], and mirror [16,17]. The performance of those concentrators and reflectors was mostly evaluated in term of actual power output increase under a solar simulator or under the sun at a specific time. However, a concentrator system that improves much on the bifacial solar cells at a specific time does not always improve that much at other time. This

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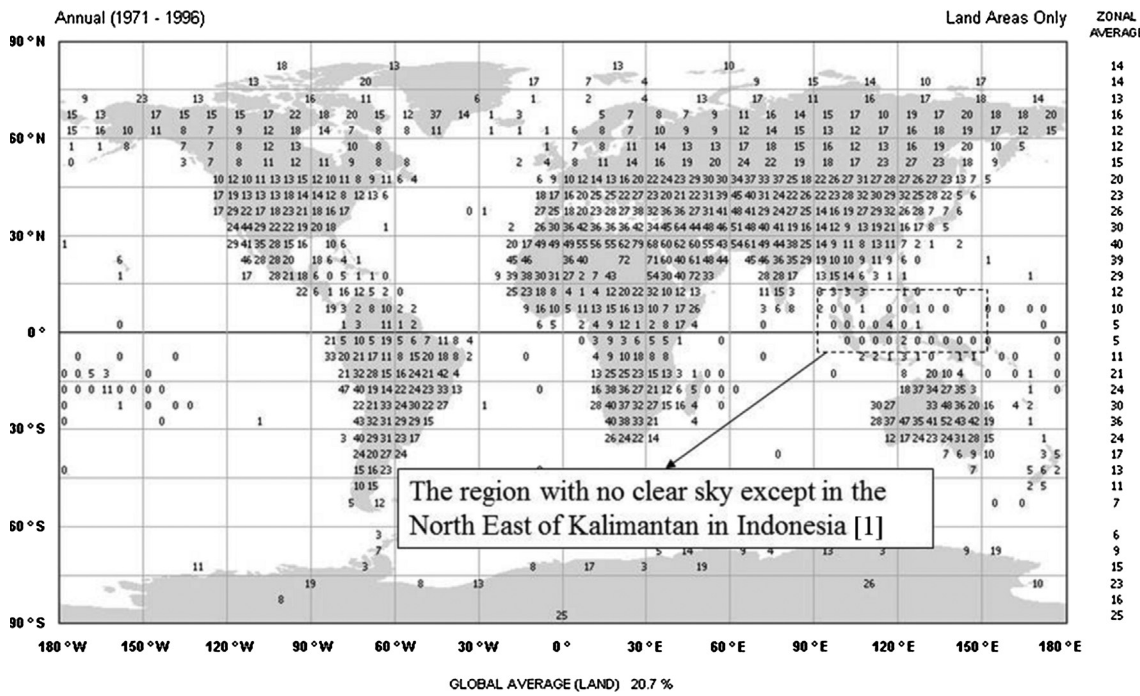

Fig. 1. Frequency of completely clear sky occurrence across the globe (%).

phenomenon is particularly obvious on a highly clouded region where the available direct and diffused sunlight can vary substantially throughout a day due to a large number of passing clouds over the solar concentrator. Therefore, it is necessary to evaluate the concentrator or reflector systems under the sun over a period of time for accurate assessment.

The authors in [18] proposed to use mono-crystalline solar cells to make bifacial solar cells with coloured diffuse reflector as a concentrator. However, the mono-facial solar cells cannot be used to represent the actual performance of the bifacial solar panel as the uniformity of illumination on the rear side will affect the overall power output of the bifacial solar panel. Comparison using the mathematical model on the energy generation as described in [15] is not convincing enough because there are too many environmental factors to be accounted for. Factors such as connector resistance loss, solar cell mismatch and partial shading on the rear side can reduce the performance of a real bifacial solar panel.

In this research work, several concentrator and reflector systems are developed and integrated with a bifacial solar panel. The bifacial solar cells are the commercially available ones. The performance of each concentrator or reflector system is evaluated under the sun over several weeks in Malaysia. The setups of the concentrator and reflector systems are summarized as follows:-

1. Scattering particles (scatterers) sprinkled across the plane mirror with the solar panel above.
2. An array of adjustable small plane mirrors placed under the bifacial solar panel.
3. Long triangular prisms placed in between solar cells with a plane mirror underneath.

The solar panel with the concentrator or reflector is regarded as a tested panel. It is placed side by side with another bi-facial solar panel being used as a reference with a plane mirror placed underneath. The power outputs of these two panels are measured by an IV plotter under the sunlight throughout several weeks for each type of the concentrator and reflector systems. The energy output of the tested panel per day is then determined and compared with that of the reference panel in order to determine the increase in the energy output contributed by each concentrator and reflector system. Empirical approaches are developed to compensate for uncontrollable factors including solar cell manufacturing mismatch and unequal degradation between the tested and the reference solar panels.

Through these experiments, it is able to identify the feasible, simple and cheap static concentrator or reflector system that can increase the bifacial solar cells efficiency under the variation of direct and diffused sunlight. This paper describes the details of the research work and the experimental results. It begins with the methodology, followed by results and finally the conclusion.

2. Methodology

The Earth-On bifacial solar cell [19] is used in this experiment. Each solar cell has a dimension of 15.6 cm × 15.6 cm, rated 4.49 W output power, 0.79 fill factor and 18.8% efficiency at the front side as tabulated in Table 1. Both sides of the solar cell have similar appearance but the rear side efficiency is slightly lower than the front side's.

A bifacial solar panel comprises 6 bifacial solar cells which are soldered in series on a transparent acrylic plate with a distance of 13.5 cm between solar cells, then covered by a thin plastic film to fix their positions, and finally covered by another transparent acrylic plate on top as shown in Fig. 2. In the experiment, two bifacial solar panels were put side-by-side, lifted up a distance of 10 cm from two plane mirrors. One of the bifacial solar panels was used as a tested

Table 1
Rating of an Earth-On bifacial solar cell.

	Short circuit current (A)	Open circuit voltage (V)	Maximum power (W)	Fill factor	Efficiency (%)
Earth-On – 188	8.94	0.638	4.49	0.787	18.8