

Performance of BIPV Systems under Shadows

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Abstract. This paper presents the study on the performance of two BIPV systems under the various partial shade conditions. Two PV systems are identical, each consisting of 1.792kW_p amorphous silicon(a-Si) triple junctions thin-film PV modules. The systems were installed on a link way between two teaching blocks that caused different partial shadows on the systems in different months. The analytic results of their yearly operation with the aid of solar accesses on site help to reveal the effect of partial shade on the performance of BIPV systems.

Keywords: BIPV; partial shade; energy yield and performance ratio(PR)

1. Introduction

Building Integrated Photovoltaics(BIPV) refers to the use of PV as part of the structure of a building (roofing and facades)[1-2]. As a substitute alternative building material, BIPV is more cost effective compared to normal PV system that needs additional land and supporting structure to install. Global BIPV installations have expanded at a buoyant pace from 2006 to 2010, at a CAGR of 121% pushing annual installations to 682 MW in 2010 from 29 MW in 2006[3]. As the average selling price of modules continued its declining trend in the last couple of years due to a reduction in mass production costs, the advent of new technologies for higher conversion efficiency of PV cells/module and market competition, it is expected to reach the price of \$1.00/W_p in near future which will make PV generation be competitive to the generation using fossil fuel.

A BIPV system is normally installed either on the rooftop of a building or on the facades of a building. Its surrounding conditions will be of paramount importance because any partial shade on the PV modules from adjacent structures or trees will dramatically deteriorate the operational performance of PV system. To investigate and demonstrate the effect of partial shading on the operation of BIPV system, two identical grid-tied BIPV systems were installed on the roof of linkway between two teaching blocks in Singapore Polytechnic. Two BIPV systems were installed in such a way that one system had more partial shade than another in a year. The assessment of solar energy profile was conducted on the site to analyze the Sun path, partial shading on the PV systems and the monthly solar access. Finally, the yearly performance of two PV systems is presented and compared to the solar profiles measured by use of the Suneye.

2. The BIPV Systems

Two identical BIPV systems were installed on the linkway between teaching buildings T12 and T14 as shown in Fig. 1. The PV array of each system has two PV strings in parallel, each consisting of fourteen Uni-Solar PVL-128 triple junctions a-Si thin-film PV modules (see Fig.2).

The output of PV array is connected to SMA 1.7kW_p grid-tied inverter (SB1700) where the DC power is converted to AC power for grid integration. The specifications of the PV module are given as in Table 1. The triple junctions of PV module on three layers are arranged in such a way that the top layer of junction absorbs the blue light, the middle layer of junction the green light and the bottom layer of junction the red

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light. This spectrum splitting capability helps to attain higher conversion efficiency. Compared to other types of silicon PV modules, a-Si PV module has lower temperature coefficient of module P_{max} . As a result, a-Si PV modules can provide better performance in a hot area like tropical region.

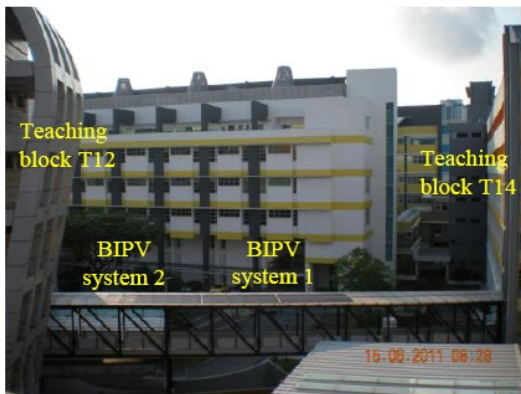


Fig. 1. 2 BIPV systems installed between two teaching blocks.

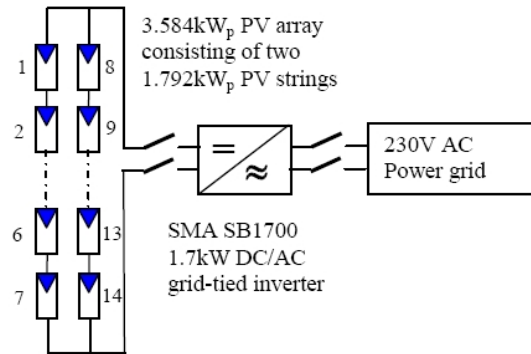


Fig. 2. Schematic diagram of a 1.7kWp BIPV system

3. Solar Access on Site

The site condition for a BIPV system is one of the most important factors to be considered by the system designer as well as the system owner because any partial shading on PV modules will dramatically reduce the energy output of the system. It has been proved[4-6] that in operation of a PV system, the PV module(s) shaded by neighboring objects act as a load to consume energy and may produce heat to cause hotspot damage to the shaded cells. Therefore, survey on site condition needs to be performed to assess the solar energy profile before the PV system is designed. To investigate the site conditions for our two BIPV systems, Solmetric SunEye 210 was used to measure the sun path, to analyze the shading to the PV systems and to get monthly solar access.

Table 1. Specifications of PV module measured under Standard Testing Conditions(STC)

Data	I_{sc}	V_{oc}	V_{mpp}	I_{mpp}	P_{mpp}	α	β	γ	η_{module}
parameters	Short circuit current	Open circuit voltage	Max. power point voltage	Max. power point current	Max. power point power	Temperature Coefficient of I_{sc}	Temperature Coefficient of V_{oc}	Temperature Coefficient of P_{max}	Conversion efficiency of module
Values	4.8A	47.6V	24V	3.88A	128W	5.1mA/K	-160mV/K	-260mW/K	6.0%

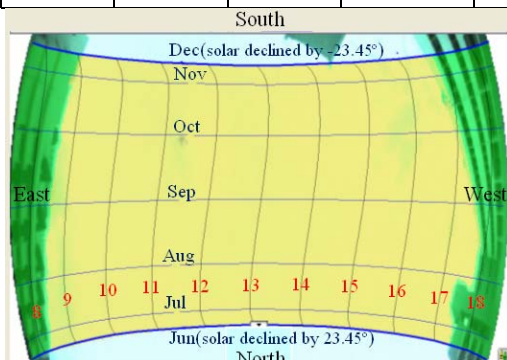


Fig. 3. The sunpath measured on the site



Fig. 4. measurement of partial shade for BIPV systems at A & B

The Sun path shown in Fig. 3 illustrates the changes of Sun positions referring to azimuth angle and sun elevation in different months. It is noticed that the Sun is towards the South from Sept to Mar(via Dec), whilst towards the North from Mar to Sept(via Jun). On the equator, the solar declination angles varies from

23.45° on 21 June to -23.45° on 21 Dec as indicated in Fig. 3. The Sun path provided can help to estimate what time in a year the neighboring buildings may cause the shadows on the systems. To obtain more accurate information on the partial shade in situ, two points at the edges of PV installation shown in Fig. 4 were selected to perform the shade analyses. The obstruction elevations at point A and B are given in Figs. 5 and 6 respectively which clearly show more shade created to PV system 2 than PV system 1. Most of shadow to system 2 occurs after 2 pm in nearly whole year. Compared to system 2, system 1 has much less shadows in a year and most shadows to system 1 only happen either before 9am or after 5pm when the solar irradiances are not strong. The monthly solar accesses to points A and B are summarized in Fig. 7

4. Performance of Two BIPV Systems

The PV systems are equipped with a data logger to monitor and measure operating parameters. Performances of two PV systems from July 2009 to July 2010 are presented and comparison of experimental data with those resulting from solar assess is also conducted in this part.

The performance of a PV system is normally evaluated by its energy yield and performance ratio(PR)[7-8]. The system PR can be worked out by using equ (1).

$$PR = \frac{\frac{AC \text{ energy output (kWh)}}{\text{installed capacity (kWp)}}}{\frac{\text{Solar irradiance (kWh / m}^2\text{)}}{1kW / m^2}} \quad (1)$$

Where the installed capacity of each PV system is 1.792kW_p

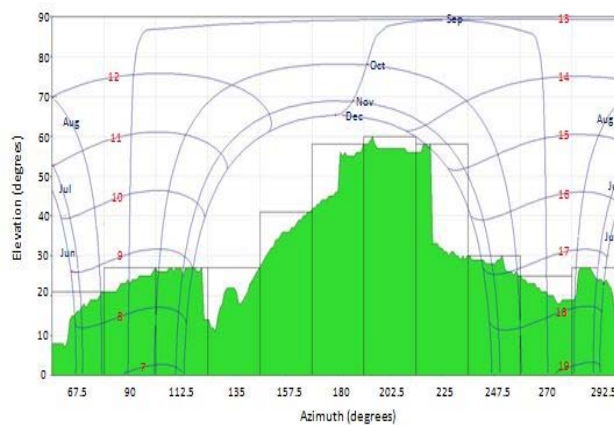


Fig. 5. Obstruction elevation at point A of solar PV system

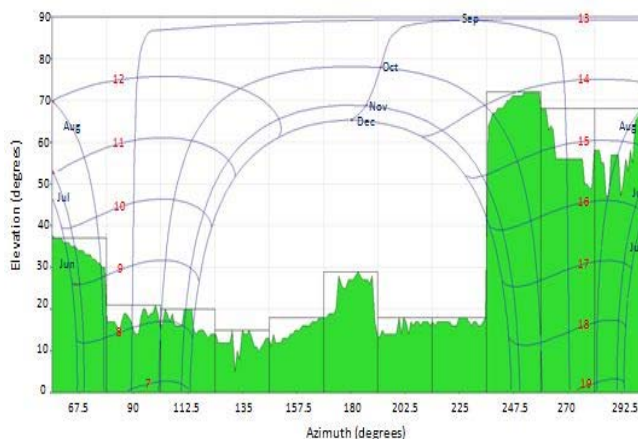


Fig. 6. Obstruction elevation at point B of solar PV system

Fig. 8 presents the monthly energy yields of two BIPV systems. It can be noted that out of 12 months, system 1 generated more energy to the grid than system 2 in 7 months(Apr, May, Jun, Jul, Aug, Sept and Oct), system 1 only produced less energy than system 2 in 4 months(Nov, Dec, Jan and Feb), and the energy yields of two systems are very close in Mar. Referring to the monthly solar accesses in Fig. 7, it can be

found that the analytic results of two BIPV systems are nicely in accordance with the solar accesses on site using Solmetric SunEye 210.

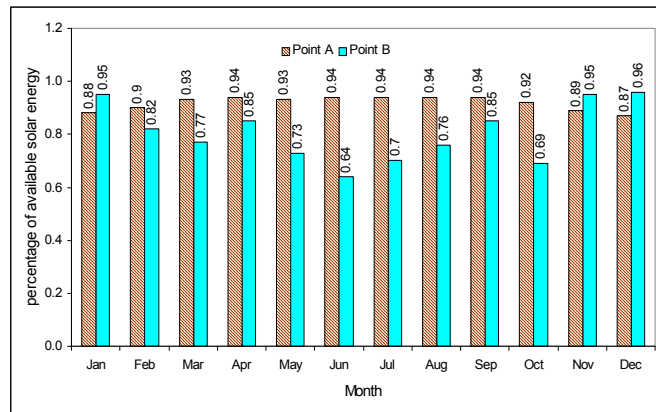


Fig. 7. The monthly solar accesses at points A and B

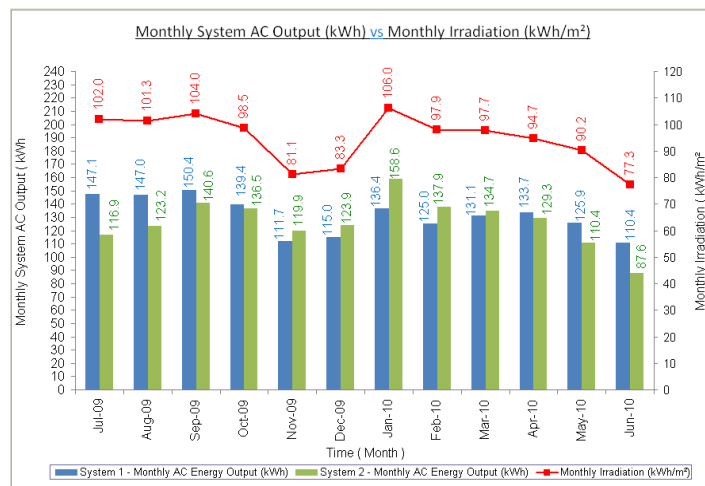


Fig. 8. Monthly energy yields of 2 BIPV systems

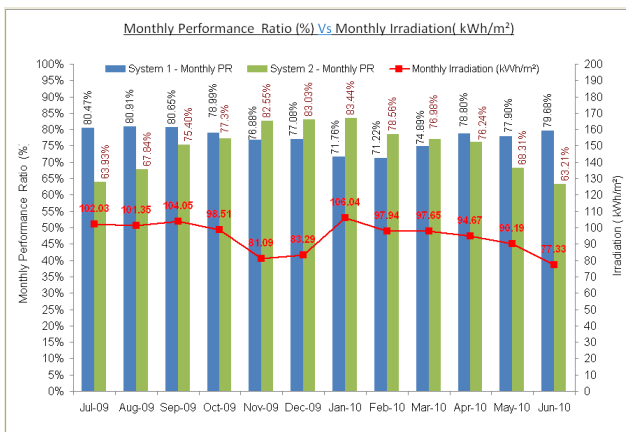


Fig. 9. PRs of two BIPV systems in a year

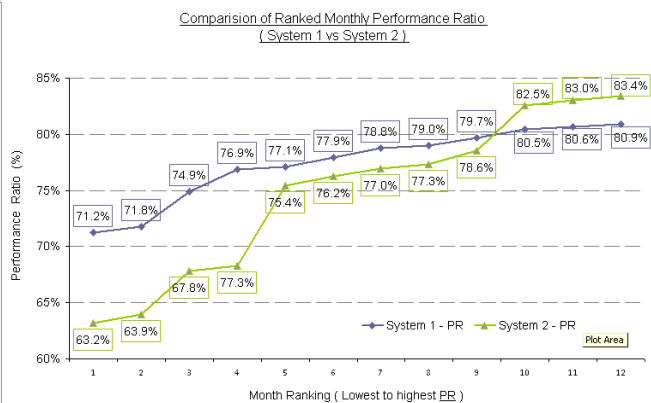


Fig. 10. Comparison of system PRs of 2 BIPV systems

The operational performances of two systems are described by their performance ratio and conversion efficiency as shown in Figs. 9 and 10. Similar to the energy yields, both PRs and efficiencies of system 1 in 7 months are higher than system 2.

If rearranging the PRs of two systems in ascending order of PR values as shown in Fig. 11, it is clearly seen from the figure that system 1 has better performance than system 2 due to less shadow falling on system 1 in a year. Although the highest PRs and the best conversion efficiency occurred in system 2 in Nov, Dec and Jan, system 1 has better yearly PR and conversion efficiency than system 2. Those high PRs and efficiencies in system 2 may be due to the high reflection of sun light from the wall of T12 (Albedo) during Nov, Dec and Jan. Average yearly PR of system 1 are 0.77, while average yearly PR of system 2 are 0.74.

5. Conclusions

This paper addressed the impacts of shading on two BIPV systems. Firstly the solar accesses were performed to investigate the distribution of shadows formed by neighboring building structure and also estimate the availability of solar energy to BIPV systems in a year. Secondly, the performance of two BIPV systems was studied based on one year operating data. Finally, the results of system operation in a year were compared to those of solar accesses using the Suneye to check how accurate solar access the Suneye can provide for system design. The results turn out that the partial shade from surrounding objects does degrade the performance of BIPV system. In order to avoid the partial shading problem and improve the performance of BIPV system, solar access on site should be conducted to provide the system designer with useful information on obstruction elevations and solar energy profile for the system.

6. Acknowledgment

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7. References

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