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Shading analysis for rooftop BIPV embedded in a high-density environment: A case study in Singapore

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ABSTRACT

Challenges such as partial shading and non-optimal tilt and azimuthal deviations are common in building-integrated photovoltaic systems (BIPV). Therefore, it is important to be aware of the consequences on systems performance metrics, namely annual specific yield and performance ratio for these specialised applications. This paper describes detailed analyses of shading effects, irradiation resource availability and module temperature on the performance metrics of individual subsystems of a rooftop BIPV installation in a high-rise building embedded in a high-density environment in Singapore. The study indicates that a shading analysis during the design phase can highly improve PV systems performance by giving careful consideration about shaded modules to optimise the PV module string design.

1. Introduction

In 2015, some 60 GWp of new photovoltaic (PV) systems were installed globally [1] bringing the total worldwide installed capacity to nearly 250 GWp, with Asia leading the wave of new installations [2]. Information Handling Services Inc. (HIS) has raised its global solar PV forecasts for 2016–65 GWp, and over 70 GWp is expected to be installed in 2019 [3]. By 2020, the cumulative global market for solar PV is expected to triple to around 700 GWp [4].

In addition to being a renewable and pollution-free energy generation technology with no moving parts, PV modules can also be integrated into buildings as BIPV systems, adding aesthetic value [5]. When installed in an optimized way, BIPV systems can reduce heat transferred through the envelope and reduce cooling load components decreasing the CO_2 emissions [6]. Apart from some façade installations, the rooftop segment represented more than 23 GWp of total installations in 2015, with projections of more than 35 GWp to be installed by 2018 [2].

Due to its position close to the Equator, Singapore enjoys high solar irradiation with minimal seasonal variation, making solar PV a natural choice for this location [7]. However, it is only with the recent continued reduction in solar module prices and the strong support through government policies to encourage the adoption of solar PV, this form of renewable energy started to prosper in the Southeast Asian island-state. The capacity of PV installations in Singapore rose from close to none in 2008, to more than 33 MWp by the end of 2015 [8,9]. According to the Sustainable Energy Association of Singapore (SEAS) [7], Singapore has enough space to accommodate 6 GWp of solar PV using available rooftops, which can generate approximately 17% of Singapore's electricity demand.

As in many other parts of the world, the share of PV in Singapore will also continue to increase [2], and, in this context, a large number of new BIPV systems will be installed in urban environments in the coming years. Challenges such as partial shading and non-optimal tilt and azimuthal deviations are common in BIPV systems; therefore it is important to be aware of the consequences on their performance [10,11].

This paper describes detailed analyses of shading effects, irradiation resource availability and module temperature on the performance metrics of individual subsystems of a rooftop BIPV installation in a high-rise building embedded in a high-density environment in Singapore.

2. Method

The BIPV system in this investigation has an installed capacity of 75 kWp and is mounted on the tilted roof of a commercial high-rise building in a densely-built environment in downtown Singapore (Central Business District) (Figs. 1 and 2). There is a large gap (~10 m) between the PV modules (mono-crystalline silicon wafer based, heterojunction technology, 205 Wp) and the building rooftop infrastructure, allowing for good ventilation, which is

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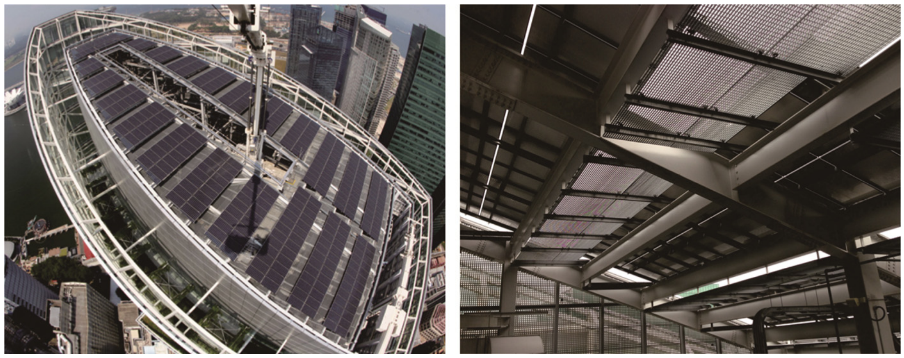

Fig. 1. Bird's-eye view of high-rise BIPV system in the study, on the left side. The image was taken from the building's service crane. Gap between rooftop and PV module structures, on the right.

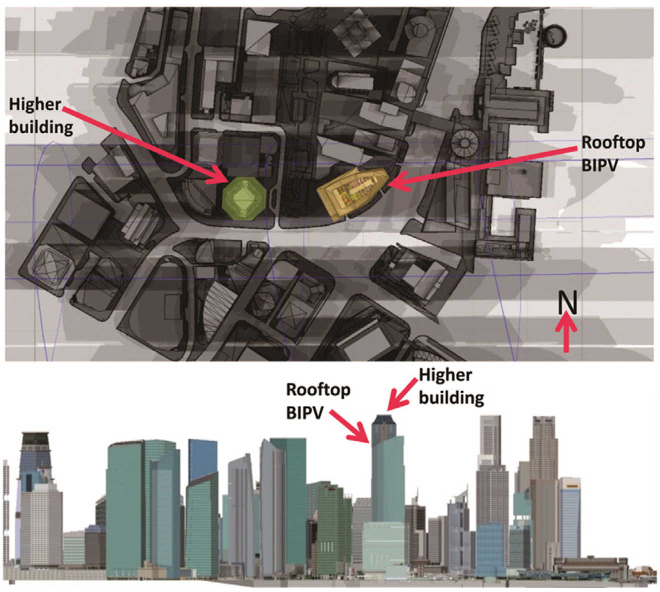

Fig. 2. Plan view and elevation of Rooftop BIPV system under study and nearby surrounding buildings.

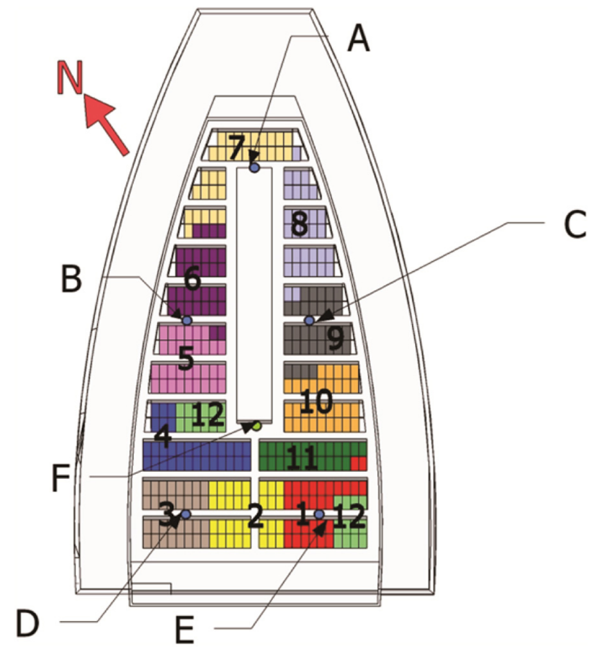

Fig. 3. Subsystem layout (1–12), location of global tilted irradiance and module temperature sensors (A–E) and global horizontal irradiance and ambient temperature sensors (F).

Table 1
subsystems configuration.

Subsystem	Nominal Power [kWp]	Strings	Nominal Power/String [kWp]
1	6.12	3	2.04
2	6.56	4	1.64
3	6.56	4	1.64
4	6.56	4	1.64
5	6.56	4	1.64
6	6.56	4	1.64
7	6.56	4	1.64
8	6.56	4	1.64
9	6.56	4	1.64
10	6.56	4	1.64
11	4.92	3	1.64
12	4.92	3	1.64
Total	75.00	45	–

further enhanced by the fact that the system is installed on top of a skyscraper at ∼250 m height. All modules face the same orientation (South-West) with the same tilt angle (19°). The PV generator is divided into 12 subsystems (12 inverters). Table 1 shows the subsystems configuration.

The energy generation for each subsystem of the BIPV system has been monitored by the Solar Energy Research Institute of Singapore (SERIS) since the system's commissioning date in March 2011, with data acquisition at five-minute intervals. In November 2013, additional monitoring equipment was installed by SERIS, as shown in Fig. 3, containing one global horizontal irradiation sensor and one ambient temperature sensor central to the system (location F), and five global tilted irradiation (19°), and module temperature sensors (A-E, using PT100s, Class B), all parameters also being recorded at five-minute intervals. The temperature probes are placed at the center of the PV module closest to the irraditation sensors, attached to its backsheet. A thermal tape is used to promote more stable readings and to prevent the probe from falling after a period of time exposed to the elements due to loss of adhesion. The silicon sensors for irradiation measures carry a laboratory accuracy of ±2% and were calibrated before installation.

The present study is based on a one-year period of analyses spanning from January to December 2014.

Next, shading masks were calculated and annual shading percentages derived for each sensor location using the software Ecotect (from Autodesk) in order to conduct a shading analysis for the site. The five irradiance sensors and temperature probes attached behind the modules provided readings for the validation of this work.