Solar Energy 137 (2016) 129–133

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Review

A study on electrical performance of N-type bifacial PV modules

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ARTICLE INFO

Article history:
Received 25 December 2015
Received in revised form 2 August 2016
Accepted 4 August 2016
Available online 11 August 2016

Keywords:
Bifacial PV modules
Solar cells
Transparent backsheet
N-type

ABSTRACT

Transparent backsheet is adopted to encapsulate PV modules to take the advantages of the potential of N-type monocrystalline bifacial solar cells. The energy output of bifacial modules is significantly higher than that of regular modules for micro inverter and string inverter PV system at different weather conditions. The monthly energy output of a bifacial module is averagely 4.03% higher than that of a regular module for micro inverter PV system after an outdoor test lasting for six months. The monthly energy output of bifacial modules is averagely 3.21% higher than that of the regular modules for string inverter PV system after an outdoor test lasting for one year. This indicates the advantages of the application of transparent backsheet on the N-type c-Si solar cells and shows good potential in application to rooftop and household photovoltaic systems in large scale. Besides, N-type bifacial PV modules with transparent backsheet is especially suitable to those areas with good irradiance and low temperature.

Contents

1. Introduction

N-type monocrystalline silicon solar cell is a high efficiency and low cost photovoltaic technology. It is competitive in commercialization and has a good potential in application. Compared with P-type solar cell, N-type solar cell has higher Isc, Voc and filling factor (FF). The phosphorus-doped back surface field (BSF) enables a symmetrical bifacial grid design. Besides Yingli, other solar modules manufacturers like Sanyo and Bsolar also provide bifacial PV modules (Song and Xiong, 2013). Sanyo's bifacial hetero-junction with intrinsic thin-layer (HIT) solar cell deposits ultra-thin amorphous silicon stack layers on c-Si wafer to form PN junction (Joge et al., 2003), while the bifacial modules by Bsolar utilizes the reflected lights from ground and its overall performance is equivalent to regular modules with efficiency up to 21–24% at solar cell level (Wang et al., 2008).

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http://dx.doi.org/10.1016/j.solener.2016.08.011
0038-092X/

2. The structure and advantages of N-type bifacial solar cells

2.1. The structure of N-type bifacial c-Si solar cells

The solar cells in this work use a phosphorus-doped N-type wafer (1–2 Ω cm) as substrate. Compared to the standard P-type (boron-doped) silicon solar cells, N-type silicon solar cells feature two key advantages. First, they do not suffer from light induced degradation (LID) caused by the simultaneous presence of boron and oxygen in the wafers, a phenomenon that in the standard P-type silicon solar cells leads to reduction of the module's electricity output by usually two to three percent within the first few days of installation. Second, N-type silicon wafers are less sensitive to impurities that are usually present in silicon feedstock. Consequently, less efforts are needed to be made to obtain N-type silicon wafers with a high carrier lifetime (Uematsu et al., 2003). The structure of N-type bifacial solar cells is illustrated in Fig. 1.

2.2. The advantage of N-type bifacial PV modules

The efficiency of N-type PV modules can be higher than conventional P-type modules. The majority of metal impurities in N-type silicon are inactive for mobile carriers. The specialized rear passivation enhances the quantum efficiency of infrared light (Hezel, 2003). The N-type PV modules show an extremely low initial degradation. The N-type solar cells also show a higher electricity output in low irradiance condition like in the morning and evening. Compared with P-type modules, the temperature coefficient of N-type modules is lower. Hence a higher energy output can be expected in warm and sunny days. The measurement of N-type modules with 60 N type solar cells during the first week after fabrication found no efficiency degradation due to any interference of B-O complex (Joge et al., 2004).

The *I-V* curves from both sides of N-type solar cells with N type wafer of 200 μm thickness and 2 Ω cm resistivity are illustrated in Fig. 2.

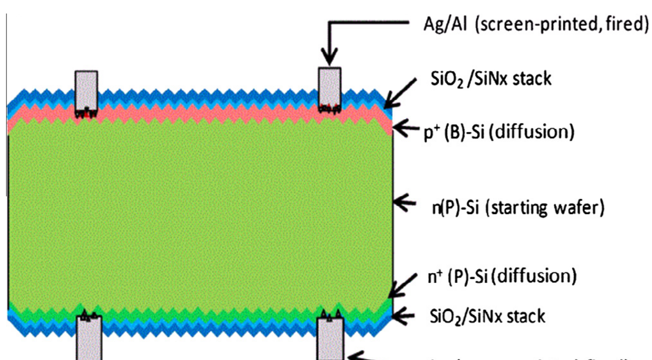

Fig. 1. A cross section of a N-type bifacial solar cell.

3. Bifacial PV modules

3.1. Properties of bifacial PV modules

Bifacial modules with transparent backsheet which is light transmittance above 80% with excellent transparency. Regular modules with a white reflective backsheet which is light transmittance nearly zero. Bifacial modules and regular modules are used the same material including bifacial cells, EVA, and tempered glass except backsheet. Transparent backsheet was developed under the impetus of the emerging building integrated photovoltaics (BIPV) and bifacial solar cells. The advantage of this material is its low density and transparency. Expensive polyvinyl Butyral (PVB) is used as encapsulating materials in the application of BIPV (Sánchez-friera et al., 2007). Cheaper materials like ethylene vinyl acetate (EVA) and polyolefin are used in other applications. For bifacial solar cells, the IR lights are susceptible to the reflection from the ground, and are accepted from the rear side of the solar cells and the electricity output is therefore enhanced (Robles-Ocampo et al., 2007). Several research institutes indicated that an improvement up to 30% can be expected (Kreinin et al., 2010). Besides, conventional laminating machines suffice to process transparent backsheet and it's not necessary to purchase excess equipments like autoclaves.

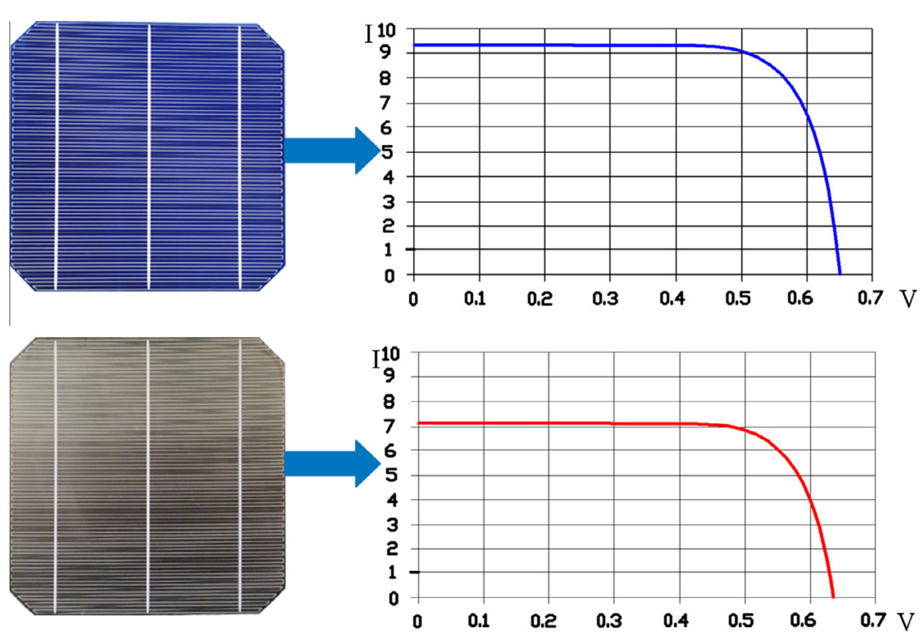

Fig. 2. *I-V* characteristic of N-type solar cells (156 × 156) from the front and rear sides (front efficiency 18–20%, rear efficiency 13–16%).

3.2. Bifacial PV modules application design

We investigated the electricity output characteristics of bifacial PV modules and an outdoor comparison system including micro inverter and string inverter system was constructed. The comparison of actual energy output between the regular modules and the bifacial modules were made and all electrical parameters were collected. The superiority of the bifacial modules is demonstrated in the following sections.

In the application of bifacial modules, part of sunlight illuminates the front side of the module, meanwhile partial sunlight reflected from the ground surface reaches the module from the rear side. Compared with the regular PV modules, the energy output is hence enhanced. Moreover, infrared lights in the spectrum is transmitted by the transparent backsheet. Therefore, the temperature of the bifacial PV module is lower than that of the regular modules at a given condition (Kreinin et al., 2011). This also contributes to bifacial modules' higher energy output.

Fig. 3. The outdoor testing ground.

4. Outdoor testing

4.1. Comparison of energy output for micro inverter PV system

A bifacial PV module (285 Wp) was connected to a micro inverter (300 W) which was connected to the public grid and a regular PV module (285 Wp) was connected to another micro inverter (300 W) which was also connected to the public grid in Yard No. 3 Experimental Field at Yingli Company and a comparison of their electricity yields was made. The energy output of the two modules is measured by an automatic inspection system once per hour. The two modules were installed facing south with a tilt angle of 45°. Fig. 3 shows the experimental field (Han et al., 2013).

Table 1
Energy output measurement data in year 2014.

Month	Bifacial module (kW h/kWp)	Regular module (kW h/kWp)	Relative difference of energy output (%)
6	118.21	112.04	5.22
7	95.44	89.40	6.32
8	116.04	110.95	4.38
9	115.79	112.21	3.09
10	80.63	78.49	2.65
11	85.68	83.51	2.54
Average	101.97	97.77	4.03

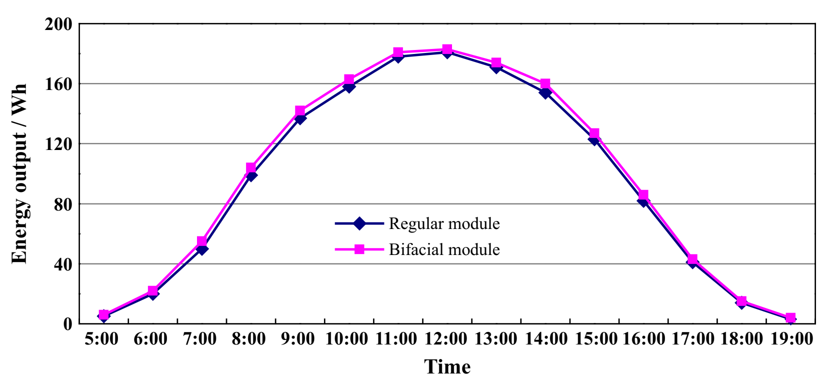

Fig. 4. Comparison of energy output between a bifacial module and a regular module in a sunny day.

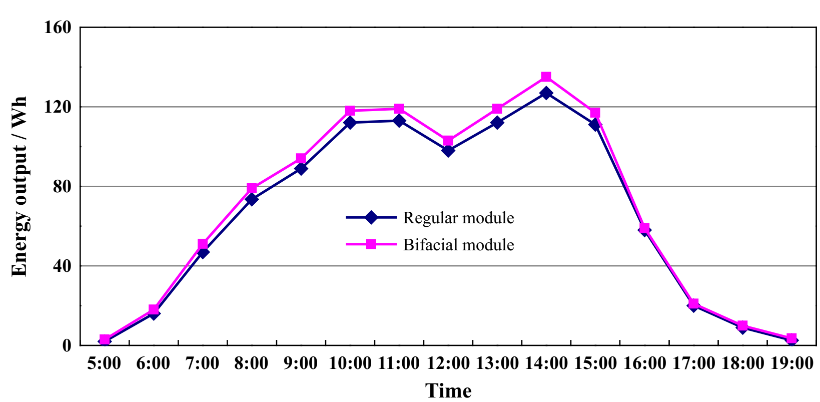

Fig. 5. Comparison of energy output between a bifacial module and a regular module in a cloudy day.

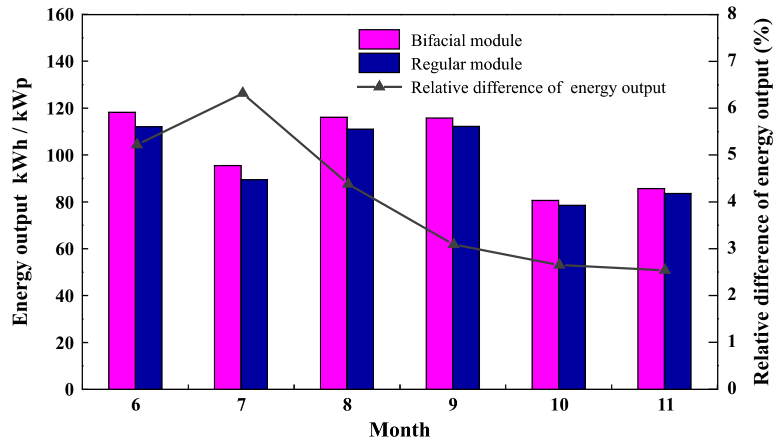

Fig. 6. A comparison of monthly energy output in year 2014.

4.1.1. Comparison of energy output

4.1.1.1. Daily energy output. The data acquisition in this work is based on energy output in the field for six months. The comparisons of daily energy output between a bifacial module and a regular module for a sunny weather and a cloudy weather conditions are shown in Figs. 4 and 5. It shows that the enhancement of daily energy output of bifacial PV modules in sunny days is lower than that in cloudy days. The main reason is that solar irradiance is affected by fluctuations of cloud amount, cloud geometry and its optical properties. When the cloud amount is large and obscures the direct irradiance, the diffusion irradiance from the cloud enhances the reflectance of the ground and counter-intuitively results in a higher irradiance than even in sunny days.

4.1.1.2. Monthly energy output. The energy output of year 2014 was tracked and recorded using an automatic tracking system. The recorded data is shown in Table 1 and Fig. 6. Through a data statistics lasting for 6 months, it shows that the monthly energy output of a bifacial module is significantly higher than that of a regular module. Especially July is the month of the most significant increasing as high as 6.3% due to high reflectance from rear side during this period. Comparing with the changes of energy output improvement and considering ground reflection situation in different weather conditions, we found that the bifacial modules was suitable for installation in places with abundant sunshine and more diffuse reflectance. With rapid decreasing in the cost of PV electricity, the bifacial modules will have great potential to improve its overall economic performance.

Table 2
Energy output measurement in year 2014.

Month	Bifacial modules (kW h/kWp)	Regular modules (kW h/kWp)	Relative difference of energy output (%)
1	65.33	62.07	5.00
2	81.58	78.07	4.30
3	77.68	75.96	2.21
4	107.75	105.05	2.51
5	106.67	102.39	4.01
6	109.96	105.86	3.73
7	88.77	84.77	4.51
8	107.93	104.60	3.09
9	107.72	105.47	2.08
10	75.02	73.86	1.54
11	79.72	78.77	1.19
12	60.42	57.79	4.36
Average	89.05	86.22	3.21

4.2. Comparison of energy output for string inverter PV System

Transparent backsheet was adopted to encapsulate PV modules considering the advantages of N-type monocrystalline silicon bifacial solar cell. In this work, we used a PV array (with 8 modules) to conduct an outdoor comparison experiment. In order to study the advantages of the transparent backsheet modules, 8 bifacial modules (2280 Wp) were connected to one inverter (2300 W) which were connected to the public grid and 8 regular modules (2280 Wp) were connected to another inverter (2300 W) which

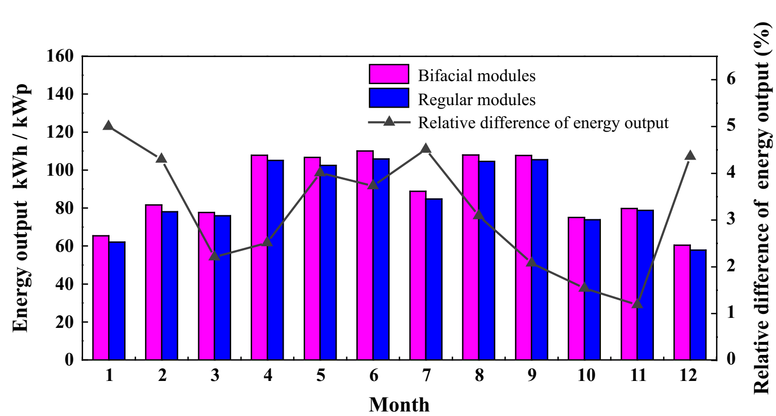

Fig. 7. Outdoor testing results (year 2014).

were also connected to the public grid in Yard No. 3 Experimental Field at Yingli Company. The recorded data is shown in Table 2 and Fig. 7.

After one year outdoor testing in year 2014, it shows that the average daily electricity output of bifacial PV modules is averagely 3.21% higher than that of the regular ones. The energy output increasing is much higher in cloudy days and in low light intensity. The main reason is that an enhanced ground reflectance due to the diffuse radiation from the clouds (Joge et al., 2004). At the same time, the average temperature of modules with transparent backsheet is about 3 °C lower than that of the regular modules with Infrared (IR) camera measurement at the same location. This is one of the factors that the modules with transparent backsheet have more energy output. The influence of the temperature on the performance of bifacial modules needs further study (Mason and Bruton, 2000).

5. Conclusions

We made a comparison study of electricity output between the bifacial PV modules and the regular PV modules for micro inverter and string inverter PV system. During six months outdoor testing, it shows that the average daily electricity output of a bifacial PV modules is averagely 4.03% higher than that of a regular one for micro inverter PV system. After one year outdoor testing in year 2014, it shows that the average daily energy output of the bifacial PV modules is averagely 3.21% higher than that of the regular ones for string inverter PV system. The energy output increasing is much higher in cloudy days and in low light intensity. The main reason is an enhanced ground reflectance due to the diffuse radiation from the clouds. At the same time, the average temperature of modules with transparent backsheet is about 3 °C lower than that of the regular modules at the same location. This is one of the factors that the PV modules with transparent backsheet have more energy output.

Acknowledgements

This research work is supported by the 2013 Electronic Information Industry Development fund under the program of "Development and Industrialization of Home-Use Photovoltaic System". Appreciation is attributed to Associate Professor Zaoyang Li of Xi'an Jiaotong University, China, who kindly reviewed and helped in revising the manuscript.

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