FIELD PERFORMANCE OF BIFACIAL MODULES IN SOUTH AFRICA

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ABSTRACT: This study presents the initial results of field performance analysis conducted on bi-facial modules installed on a fixed tilt rack and dual axis tracker system in Pretoria, South Africa. Bifacial modules produce better energy yield compared to monofacial modules depending on the geographical location, albedo of the back surface, height of a module from the surface and tilt angle. Currently multiple standards are under development to predict the bifacial gains and the field performance data is required to validate the models. This paper presents the bifacial gains over the monofacials without a high albedo back surface in a fixed tilt system, inter-comparison of the grass cover, unpainted and white painted pavement and overall bifacial gain over the monofacials in dual axis tracker system. The bifaciality factor and efficiency curve of two bifacial types measured on indoor sun simulator is presented.

Keywords: solar PV, bifacial, monofacial, specific yield, performance ratio

1 INTRODUCTION

The solar PV market is growing rapidly with the declining module prices globally; the industry is also striving to reduce the levelized cost of electricity (LCoE) by moving to 72 cells from 62 cells or from 1000 volts to 1500 volts. The industry has also adopted the changed cell layout such as half-cell, bifacial and shingle configurations. Bifacial modules convert the light from both front and rear sides in contrast with the monofacial modules which convert light only from the front side. This means bifacial modules produce more power than monofacial modules under same conditions enhancing power density (power per unit area) further leading to reduction in the related costs such as land, wiring, mounting assemblies etc. The current challenge for the bifacial module growth is the lack of standards for testing and rating the rear-side performance of the module. The performance from the back side can vary from 5% to 30% and can impact the bankability of projects using bifacial modules. It is challenging to model the performance of a bifacial module for developers or financial institutions since it is strongly influenced by the installation method and location. Experimental studies have shown that use of bifacial modules can potentially increase system yield by at least 10% over a fixed latitude tilt monofacial modules, and increased yield can be much higher under certain conditions. The benefit from the bifacial modules varies depending on tilt angle, height of module from the surface, reflectivity (albedo) of the surface, and other factors that influence the total amount of light reaching both sides of the PV cells. However, the sensitivity to these parameters is complex and as system size and ground coverage ratio increases, bifacial gains suffer as the array increasingly covers the ground with shadows and less light is available to the back of the modules [1]. A performance gain of close to 10% compared to the monofacial modules is easily achieved without modifying the rooftop (reflectivity < 20%) and the experimental results also showed that bifacial modules perform better when the diffuse content in the global irradiance is high [2]. There are significant efforts underway by the International Electro technical Commission (IEC) to develop industry standards for the bifacial module certifications. IHS Markit expects bifacial to increase steadily over the next three years and as per PV Info Link projects, the bifacial modules will see rapid growth in the coming years and comprise 22% of market share in 2022 [3, 4]. South Africa is known for high degree of sunshine with on average at least 8 to 9 hours per day and, in Pretoria, the summer period will be a combination of clear and cloudy sky conditions with periods of heavy rain, whereas winter period is mostly with clear sky conditions. Hence, to know the performance and behaviour of emerging bifacial modules with respect to local climatic conditions, it is necessary to assess the field performance of these bifacial modules. This field performance data can assist the local industry to optimise the bifacial PV modules performance and the PV installations in the country. CSIR Energy Centre has a fully operational outdoor solar PV testing facility and a 202.3 kWp dual axis tracker grid connected solar PV system which houses the bifacial modules in both of these PV infrastructure.

Outdoor solar PV testing facility

The outdoor solar PV testing facility consists energy yield racks for maximum peak power (MPP) and current voltage (IV) characterization, grid connected PV systems with and without battery storage and an in-line power quality analyser. A fully integrated meteorological station consisting of secondary class pyranometers and pyrheliometers, spectroradiometer, UV radiometer, temperature and humidity sensor, wind speed and direction sensors rain gauge complements the outdoor solar PV testing facility. The modules under the test include bi-facial and mono facial types and two (2) modules of each type are under surveillance. The modules are installed at 25° tilt angle on a fixed rack and are oriented towards true north. The height of the lower part of the module from the roof surface is 1 meter. Presently, n-type c-Si (270 Wp) and mono-PERC (280 Wp) type of bifacial modules and the monofacials include mono crystalline silicon (mc-Si) (275 Wp), poly crystalline silicon (pc-Si) (315 Wp) and heterojunction (HIT) (360 Wp) are installed to analyse the performance of different technologies under same conditions. The roof surface has a very low albedo dull matt black paint with possible opportunities to prepare a high albedo surface in the future. Figure 1 presents the CSIR's outdoor solar PV testing facility with fully integrated meteorology station.

Figure 1: CSIR Outdoor solar PV testing facility

The global horizontal irradiance (GHI) and diffuse horizontal irradiance (DHI) is measured by CMP21 pyranometers on Solys 2 sun tracker and the Plane of Array (PoA) irradiance in front and rear side is measured using SMP10 pyranometers which are mounted next to PV modules on the same rack. The electronic loads connected to each module allows tracking of maximum peak power point (MPPT) and perform IV characterization for all the modules at 10 minute interval and MPP measurements are carried out at every 1 minute interval simultaneously. The building roof has dull matt black roof paint, which is a generic paint used for flat roofs in South Africa and possesses a very low albedo. The measured data is stored at centralized database and further processing is carried using respective software tools.

Dual axis tracker PV systems

The ground-mounted dual axis tracker plant has fifteen (15) tracker units of monofacial with an installed capacity of 179.5 kWp and two (2) tracker units houses 11.3 kWp of bifacial modules on each tracker unit. The bifacials include mono-PERC (270Wp) type of modules and the monofacials include mc-Si (285Wp) type of modules. Each of the tracker unit has 2 strings of 21 modules in series and is connected to an individual string inverter on the tracker mast. One of the bifacial trackers has a grass surface and the other one had an un-painted pavement surface with dull grey coloured bricks. This pavement was painted with white paint after a period of 1 year since its inception to study the effects from the higher albedo back surface. A grass land or crop land, dark coloured soil surface and a fresh or deep snow has an approximate albedo of 0.1 to 0.25, 0.1 to 0.2 and 0.9 respectively [5]. The albedo of white paint painted underneath bifacial tracker is expected to be on the higher side similar to the albedo of snow. The generation data of the bifacial and monofacial modules is monitored through a web accessed portal on hourly basis. Figure 2 presents the CSIR's dual axis tracker system consisting bifacial and monofacial modules at the CSIR Pretoria campus.

Figure 2: CSIR Dual axis tracker system

Indoor solar PV testing facility

The indoor research facility includes a HALM A+A+A+ sun simulator for performance measurements at multiple irradiance and temperature levels as per IEC 61853-1: Energy Rating standard for PV modules. The research lab also includes environmental chambers, and mechanical load tester for conducting accelerated stress tests for pre-qualification and extended reliability research. The lab also houses equipment to conduct high potential safety tests (wet and dry insulation resistance), electroluminescence and infrared imaging. Figure 3 presents the CSIR's indoor solar simulator capable of measuring monofacial and bifacial modules at its Pretoria campus.

Figure 3: CSIR Indoor Solar Simulator

2 METHODOLOGY

In this study, the power produced by bifacial and monofacial modules on fixed tilt energy yield rack dual axis tracker system is analyzed. The indoor current-voltage (IV) characterization of bifacial modules at different irradiance levels is also performed. The specific yield of the bifacial and monofacial modules installed on the fixed tilt rack is calculated from the generated power by normalizing to the manufacturer rated output power at STC conditions. Further, the DC Performance Ratio (PR) is calculated from the measured Plane of Array (POA) irradiance at the same plane as per the standard IEC 61724: Photovoltaic system performance - Part 1: Monitoring. For dual axis tracker system, the POA irradiance is modelled using SAM software from the measured global horizontal, direct normal and diffuse horizontal irradiance at the campus. For both the systems, the irradiance available on the back side of the bifacials (albedo) is not considered and only the front side irradiance is used to determine the effective bifacial gain over the monofacial modules in the normal operating conditions. The AC PR of the 179.5 kWp with monofacial modules and 11.3 kWp with bifacial modules on dual axis tracker with two (2) different surfaces is calculated and inter-compared. The daily PR gain of bifacial modules with respect to grass, painted and un-painted back surface over monofacial modules is presented. In indoor solar PV laboratory, mono PERC (280Wp) and n-type c-Si (270Wp) bifacial type of modules were characterized for I-V curve at 1000, 800, 600, 400 and 200W/m^2 irradiance levels on sun simulator. The back side of each PV module was covered with opaque black sheet to evade any power generation from the active back surface. Further, the bifaciality factor and the normalized efficiency were calculated and are the results are presented in this paper. The bifaciality factor is the commonly used term for defining the bifacial module performance. It is calculated by dividing power measured on back side by the power measured on front side for the irradiance ranging from 200W/m^2 to 1000W/m^2.

3 RESULTS AND ANALYSIS

Bifacial module performance on fixed tilt rack

The bifacial and monofacial modules performance on a fixed tilt rack is presented in this section. Figure 4 presents the electrical performance of five (5) different sets of modules on an IV curve. The outdoor IV scans of all the modules was carried out on a clear sky day at 12:00 HRS. During the scan, the measured peak powers of two (2) modules in each set matched closely with one another.

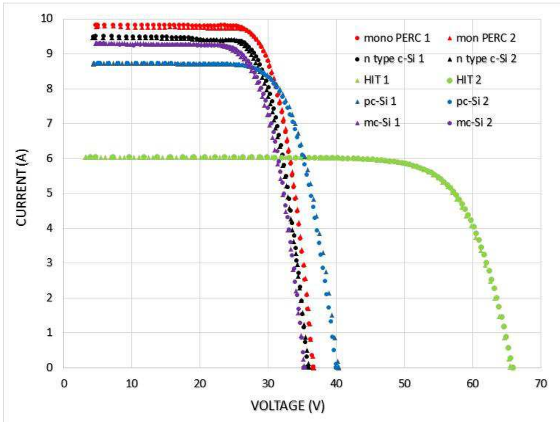

Figure 4: IV scans of bi-facial (mono PERC and n type c-Si) and mono-facial modules (mc-Si, pc-Si and Heterojunction)

The calculated DC PR of bifacials and monofacial modules is presented in Figure 5. In this study, the DC PR of mono-PERC and n type c-Si bifacial modules hovered around 95% while the monofacials including HIT, mc-Si and pc-Si modules were around 89%, 87% and 81% respectively during Feb'18 to Jul'19.

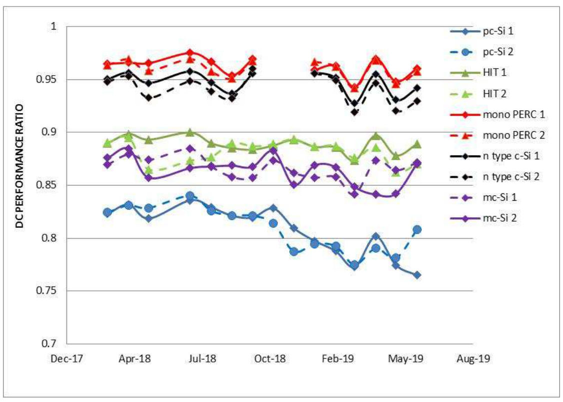

Figure 5: DC PR of bifacials and monofacial modules

A PR gain of 6%, 8% and 16% is achieved by bifacials over different sets of monofacials under the study. The relative energy generation from the bifacials is expected to be much higher than the PR gain. The drop in the PR of pc-Si module might be a temperature effect; most common in the summer months and will be subjected for further analysis during the forthcoming summer season.

Bifacial modules performance on dual axis tracker

The analyzed outcome of bifacial and monofacial modules on a dual axis tracker system in terms of PR is presented in this section. A two (2) years period of data is analyzed and the bifacial performance with respect to three (3) different types of back surfaces is also presented. Figure 6 presents the measured monthly AC PR of monofacials and bifacials with grass cover, un-painted pavement and white painted back surface and Figure 7 presents the daily bifacial gain over monofacial modules in respect to different back surfaces.

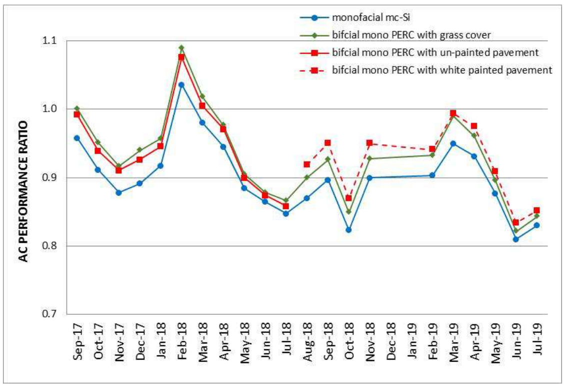

Figure 6: AC PR of bifacial and mono facial modules on the dual axis tracker

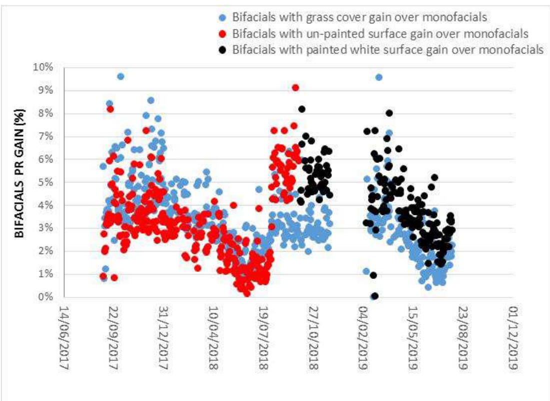

Figure 7: PR Gain of bifacial modules over monofacial modules

In this analysis, the PR achieved for the 15 trackers with mono-facial modules is used as a baseline to compare the relative gains in PR for the trackers with bifacial modules. The one (1) tracker with bifacial modules over grass cover measured an average 3% higher PR over the baseline during the period Sep'17 to July'17. The other tracker with bifacial modules on the un-painted pavement measured an average 2% higher PR over the baseline for the period Sep'17 to Jul'18. Post refurbishments of un-painted pavement with white painting, the same tracker produced an average 5% higher PR over the baseline for the period Aug'18 to Jul'19. The gain from the white painted back surface over the unpainted pavement or grass cover is not significant as the bifacial modules on the dual axis tracker are optimally inclined towards the sun at any point of time and the type of back surface hardly matters. The measured data also indicate that bifacials gain over monofacials depends on the season. A higher gain from the bifacials is observed during summer months irrespective of grass, un-painted or painted surfaces. In summer months, the higher sun elevation during peak production hours may result in more reflected light to the back side of bifacials compared to winter. In winter months, the lower sun elevation may result in more of the reflected light passing beyond the array and less reflected light on to the back of the module.

Bifacial modules indoor characterization

The indoor characterization on the n type c-Si and mono PERC bifacial modules was carried out at different irradiance levels with the back side of module completely covered with opaque material. The sun simulator is set to ensure the repeatability of measurements before the start of the characterization. Table 1 presents the calculated bifaciality factor of n type c-Si and mono PERC modules from the measured power of front and back surface at different irradiance levels.

Bifacial type	**Irradiance**				
	200	**400**	**600**	**800**	**1000**
n type c-Si 1	83%	82%	82%	81%	81%
n type c-Si 2	82%	82%	82%	81%	82%
mono PERC 1	54%	53%	53%	52%	51%
mono PERC 2	45%	55%	55%	54%	53%
mono PERC 3	54%	56%	56%	55%	54%

Table 1: Bifaciality factor of n type c-Si and mono PERC modules

The back side of bifacials perform mostly in low light conditions in the real world platform and understanding the behaviour during low light conditions is quite important to predict the bifacial PV plants performance.

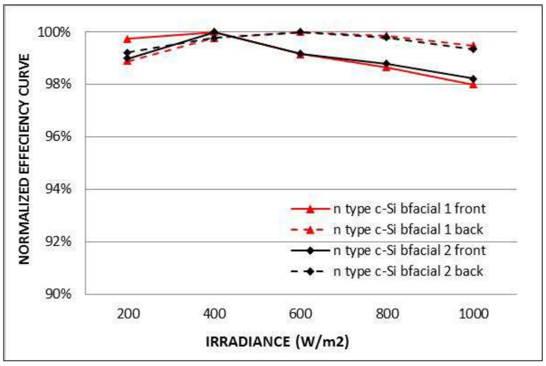

Figure 5: Normalized efficiency curve of the n type c-Si bifacials

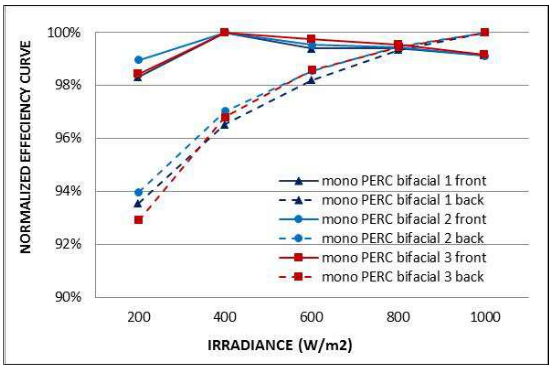

Figure 6: Normalized efficiency curve of mono PERC bifacials

Figure 5 and 6 presents the behaviour of both the sides in the bifacial modules at different irradiance levels. The n type c-Si bifacial modules did not exhibit greater dependency on the irradiance whereas the mono PERC modules exhibit dependency. The efficiency of back side in mono PERC modules dropped up to 7% at lower irradiance whereas the n type c-Si modules dropped only by 1%. The efficiency of front side in both the technologies did not vary significantly and was under 2% at low light conditions.

4 CONCLUSIONS

The bifacial module performance gain over the monofacial modules on a fixed tilt rack and dual axis tracker system is analyzed. The DC PR of bifacial modules on a fixed tilt rooftop system averaged 95% compared to 89% for HIT, 87 % for mc-Si and 81% for pc-Si modules. On a dual axis tracker system, the bifacial modules averaged 3% higher PR than the average of 15 trackers with mono-facial modules over grass surface. The tracker with bifacial modules over an un-painted paved surface averaged 2% higher than the monofacials and that increased to 5% when the pavement was white painted. The bifacial modules were also characterized in indoor sun simulator and the bifaciality factor for n type c-Si and mono PERC were at 82% and 53% respectively. The mono PERC module efficiency decreased by 6% at 200 W/m^2 compared to 1000 W/m^2.

5 OUTLOOK

This paper has focussed on understanding the performance of bifacials in fixed tilt and dual axis tracker system. The effectiveness of the white painted surface in the fixed tilt system on a rooftop will be explored by preparing the high reflective white surface underneath the rack and the performance will be compared against the monofacials. The bifacial gain from the white painted fixed tilt rack and dual axis bifacial modules will be assessed.

6 REFERENCES

[1] Joshua S. Stein[1], Daniel Riley[1], Matthew Lave[1], Clifford Hansen[1], Chris Deline[2], Fatima Toor[3]. Outdoor Field Performance from Bifacial Photovoltaic Modules and Systems

[2] Jai Prakash SINGH [a, b, #], Timothy M. WALSH [a], Armin G. ABERLE [a, b.] Performance investigation of the bifacial modules in the tropics

[3] The sun rises on the bifacial module market https://www.pv-magazine.com/2019/06/10/the-sun-rises-on-the-bifacial-module-market/ Accessed on 20 Aug 2019.

[4] https://www.pv-magazine.com/2019/05/27/bifacial-module-demand-continues-to-grow/ Accessed on 20 Aug 2019.

[5]http://www.uni-miskolc.hu/~ecodobos/14334.pdf. Accessed on 25 Aug 2019