Solar World Congress 2025

ENERGY YIELD ENHANCEMENT OF VERTICAL BIFACIAL PHOTOVOLTAIC MODULES THROUGH REFLECTORS

Summary

Bifacial photovoltaic (PV) modules enable novel installation configurations by capturing additional irradiance from the rear side, thereby increasing energy yield. This study investigates the influence of fixed reflectors on the performance of vertically mounted bifacial PV modules with an east-west orientation in the low-latitude region of Lima, Peru. Two bifacial technologies are evaluated: PERC with an aluminum frame and frameless HJT. Current-voltage (I-V) characteristics were measured under sunny and cloudy conditions, with and without reflectors. Key performance indicators are calculated and compared across various setups. The analysis quantifies performance losses attributed to module temperature, bifaciality, and partial rear-side shading caused by the frame. Performance metrics for the vertical modules are compared against standard configurations of both bifacial and monofacial modules. The findings provide practical guidance on selecting appropriate technologies and configurations for vertical bifacial PV installations.

Keywords: PV modules, bifacial, vertical setup, reflectors, performance, energy yield,

1. Introduction

The main advantage of bifacial (BF) photovoltaic (PV) modules is that their backside can receive additional solar energy, such as the one reflected by the ground (Sun, 2018). One novel configuration is vertically mounted bifacial (VBF) PV modules, benefitting new implementations such as agrivoltaics and highway PV. However, the potential increment in yield of VBF compared to commonly inclined BF or monofacial (MF) modules varies greatly depending on the latitude of the location, the albedo, and the sky conditions (Reagan and Kurz, 2022). So far, very few studies have explored the influence of ground geometry on the energy yield of VBFs. One work by Khan et al. (2019) presents the viability of ground sculpting around a VBF multi-array system. Their model suggests that ground-sculpted VBF works best at higher latitudes, claiming that a conventional MF array below 20° of latitude tends to yield better than VBF configurations. More recently, Zahid et al. (2023) used two adjustable mirrors to enhance the yield of a VBF module, enhancing the power generation of the array by up to 51% for the entire year. The present work explores this field by designing and implementing fixed reflectors and mounting them in a VBF configuration (rVBF). We analyze their impact on the energy yield of a rVBF and compare it to a VBF without reflectors, tilted BF, and MF modules.

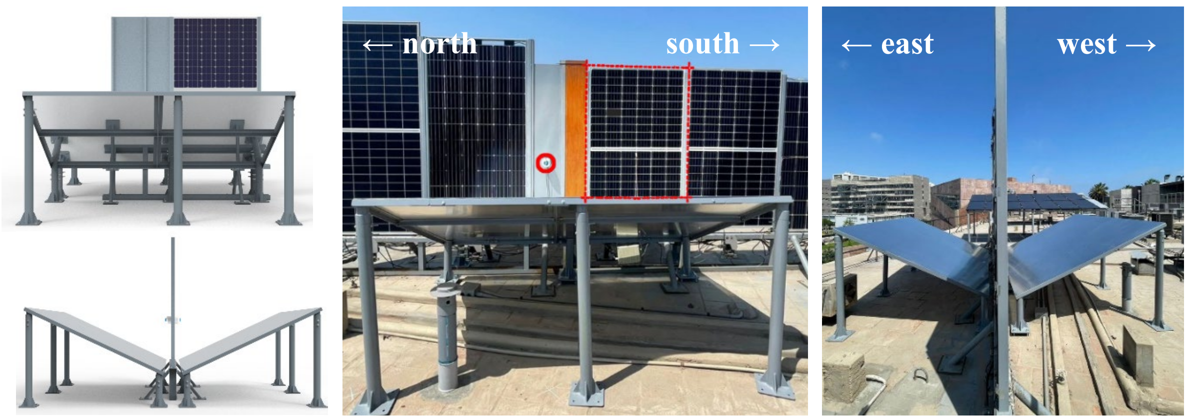

Fig 1: Design (left) and implemented experimental setup (center and right) of a vertical bifacial PV module (marked by red rectangle) with the front facing west. One of the two pyranometers is marked by a red circle.

2. Experimental setup

First, to assist in designing the reflectors and the simulation of their irradiance yield impact, the solar concentrator and ray tracing software Tonatiuh and the bifacial_radiance NREL software for bifacial systems were used, respectively. Tonatiuh helped determine the geometrical dimensions of the reflectors, while bifacial_radiance helped determine the optimum tilt of the reflectors for maximum yield. Spectral reflectance measurements of different reflector materials identified aluminum as a suitable material. For the experimental design in Fig. 1, we used one commercial BF module installed vertically with its front facing west. One PV module is a monocrystalline bifacial Passivated Emitter Rear Cell (PERC) with half-cut cells, a maximum power of 320 W at standard test conditions (STC), and a power bifaciality of (73±5) %, according to the manufacturer's datasheet. The other bifacial module is of Heterojunction Technology (HJT), frameless, with 325 W and a bifaciality of 90 %. The current and voltage (I-V) curves were measured at five-minute intervals, and the power at the maximum power point (MPP) was extracted. Two pyranometers measured the incident irradiance on the west-oriented front and the east-oriented back side. Global horizontal irradiance (GHI), global tilted irradiance (GTI), module temperatures, along with the I-V curves of MF and BF tilted, north-oriented PV modules were measured for comparison.

3. Results and discussion

Fig. 2(a) shows the design of the reflector to illuminate the PV module areas fully throughout the year, as evidenced by the homogenous incident flux distribution in Fig. 2(b). With this design and considering the measured total reflectivity R = 0.65 of the selected aluminum, we simulated the corresponding daily reference yield (Y_r), to be perceived by the VBF module, denoted as rVBF in Fig. 2(c). For comparison, the simulated Y_r is also shown for different PV module configurations: 15° inclined north-oriented MF and BF modules, VBF and rVBF facing east-west with different heights (h) and reflectivities (R) of the reflector material. For the implemented rVBF design (h=0.4m, R=0.65), we expect an irradiation gain of 34% with regard to the MF configuration and 30% to the VBF without reflectors.

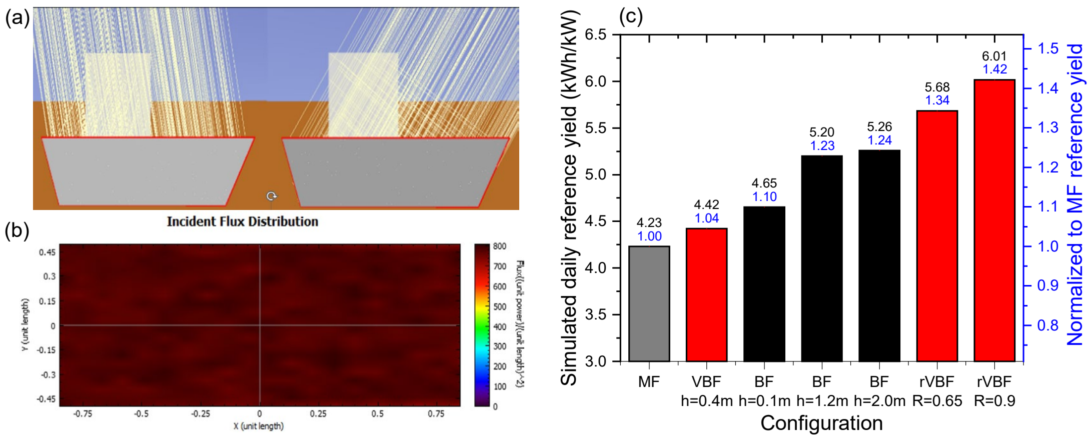

Fig 2: (a) Design with the sun at its highest elevation during summer and winter solstice in Lima, Peru. (b) Incident flux density on module. (c) Simulated reference yield for different PV module configurations.

In Fig.3, the maximum power of the PERC bifacial module is contrasted with the sum of the east- and west-irradiances. For the clear sky day in Fig. 3(a), the symmetry in the irradiance is not reproduced in the power, mainly when the backside receives the direct irradiance before noon. This loss can be attributed to the power bifaciality and partial shadowing of the backside by the module frame, as evidenced by a detailed analysis of the I-V curve shapes. During the cloudy sky day in Fig. 3(b), no impact of the bifaciality is observed, and the power follows the evolution of the total irradiance. Also, the I-V curves show no artifacts due to partial shading, indicating that diffuse irradiance is the dominating component for power conversion.

Table 1 summarizes the VBF yield indicators. On a clear sky day, the reflectors enhance the captured irradiance by 59%, and the module yield (Y_{DC}) by 39%. On a cloudy day, irradiance and module yield enhancements are 32% and 22%, respectively.

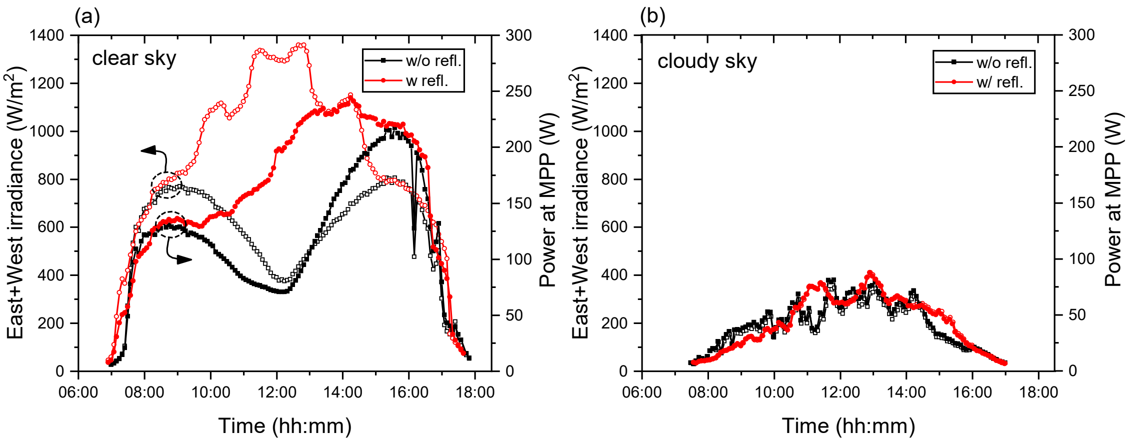

Fig 3: Sum of irradiances measured by the east and west pyranometers, compared with the measured maximum power of the VBF module without and with reflector for (a) a clear sky day and (b) a cloudy day.

Tab. 1: Yields of VBF modules for clear and cloudy sky days without and with reflectors.

Conditions	Y_r^{GHI} **(kWh/kW)**	$Y_r^{East+West}$ **(kWh/kW)**	Y_{DC} **(kWh/kW)**	**Reflector** Y_r **Gain**	**Reflector** Y_{DC} **Gain**
Clear sky w/o refl.	6.57	6.11	3.98	-	-
Clear sky w/ refl.	6.46	9.54	5.41	+ 59%	+ 39%
Cloudy sky w/o refl.	1.91	1.75	1.26	-	-
Cloudy sky w/ refl.	1.62	1.96	1.30	+ 32%	+ 22%

Table 2 compares the yields between different configurations. The reflectors can considerably enhance the energy yield of the rVBF PERC module, but it cannot surpass the yield of the inclined MF and BF modules. A detailed analysis of the I-V curves and performance ratios indicates that its low bifaciality and partial shading by the backside frame hinder the rVBF PERC module from fully using the additionally reflected irradiance.

Tab. 2: Yield comparison between MF, BF, VBF, and rVBF modules for clear and cloudy sky days.

	Y_r **Gain**	Y_{DC} **Gain**	Y_r **Gain**	Y_{DC} **Gain**
	Clear sky		Cloudy sky	
BF vs MF	+ 7%	+ 5%	+ 5%	+ 7%
VBF vs MF	- 10%	- 28%	- 2%	- 21%
rVBF vs MF	+ 37%	- 6%	+ 31 %	- 3%

We further investigate the reflector gains obtained by the vertical HJT bifacial module. Its frameless design and higher bifaciality make it less prone to the losses observed in the PERC bifacial module and, thus, can potentially surpass the energy yields of inclined MF and BF modules.

4. References

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