PERFORMANCE EVALUATION OF VERTICAL EAST-WEST BIFACIAL PV MODULES COMPARED TO TILTED BIFACIAL AND MONOFACIAL MODULES IN COASTAL PERU

Summary

This study presents a one-year performance evaluation of a vertically bifacial module with an east-west orientation compared to tilted bifacial and monofacial modules in a low-latitude, coastal and desertic site. The vertical bifacial module achieved an annual yield (Ydc) of 2.82 kWh/kWp/day, lower than the tilted bifacial (3.80 kWh/kWp/day) and monofacial (3.56 kWh/kWp/day) modules. Bifaciality-related losses reduced the vertical module's Performance Ratio (PR) by 11.1%, while temperature caused a 3.7% reduction. In contrast, the tilted module showed 1.8% bifaciality-related losses and 5.2% from temperature. PR losses from partial shading by the module frame were quantified using Fill Factor corrections. Despite similar irradiance (Yref), the vertical module produced less power than the monofacial one, highlighting the impact of asymmetric irradiance and frame shading. This detailed performance comparison offers practical insights for the deployment of bifacial PV systems in space-constrained or building-integrated applications.

Keywords: bifacial modules, vertical east-west, performance losses, frame-induced shading

1. Introduction

With growing demand for renewable energy in space-constrained environments, optimizing bifacial photovoltaic (PV) systems has become increasingly relevant (Alam et al., 2023). This study investigates the long-term performance of vertically mounted, east-west facing bifacial PERC modules, which offer advantages in land use and architectural integration—particularly in Building-Integrated PV (BIPV) and agrivoltaic applications (Cho et al., 2020; Pike et al., 2021). A high-resolution dataset was collected over a full year in Lima, Peru—a low-latitude, coastal desert site with frequent fog and high diffuse irradiance in winter. Five-minute interval measurements of I-V curves, irradiance, and temperature were used to characterize seasonal system yield (Ydc), corrected performance ratios (PR), and losses due to temperature, bifaciality, and partial shading from the module frame. We compare the vertical configuration with standard tilted bifacial and monofacial modules, offering insights into real-world PV behavior under asymmetric irradiance conditions and informing optimization strategies for installations in space-limited or diffuse-rich environments.

2. Experimental details

The monitored vertical PV module is shown in Figure 1(a).

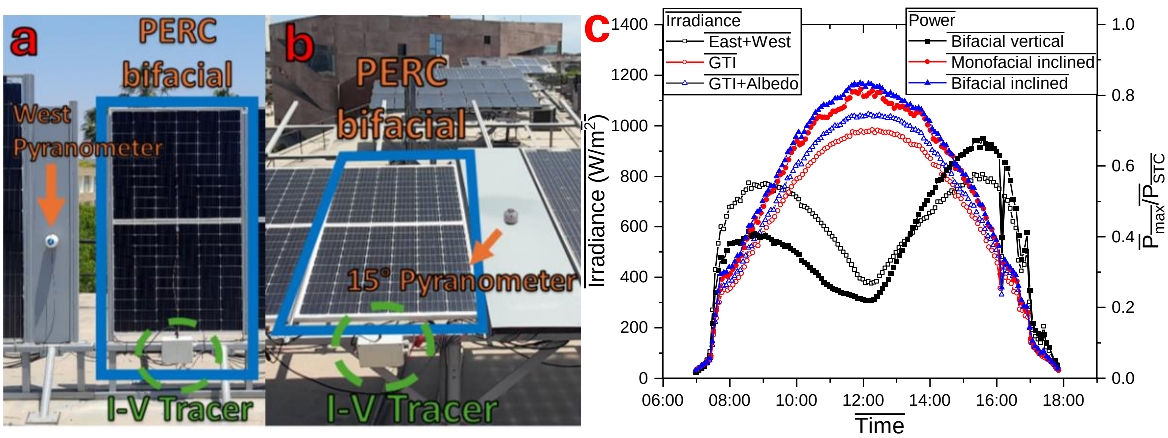

Fig. 1: PERC bifacial modules in (a) vertical east-west orientation and (b) tilted at 15°. (c) Measured power and irradiances of tilted and vertical modules on a sunny day.

This study uses monocrystalline PERC bifacial modules installed vertically with an east-west orientation. Each module has a nominal power of 320 W and a bifaciality factor of 70%, and is connected to an I-V curve tracer. Module temperatures are measured with Pt100 RTD sensors placed at the center of both the front and rear sides. Plane-of-array irradiance is recorded using EKO MS-80M pyranometers mounted on each incidence surface. I-V curves, temperatures, and irradiances were measured every five minutes. For comparison, identical measurements were performed on the same bifacial PERC module mounted at a 15° tilt (Figure 1(b)) and on a monocrystalline PERC monofacial module tilted at 20°. Figure 1(c) shows the irradiance and maximum power profiles for all three configurations on a clear-sky day.

3. Preliminary results and discussion

Figure 2(a) presents the monthly reference yield (Yref) for each incidence plane, calculated separately for the west and east orientations of the vertical bifacial module, and including both the 15° tilt plane and the ground-reflected irradiance on the rear side of the tilted bifacial module. The figure also includes Yref values for the horizontal plane and the combined east-west total. The 15° and 20° tilted planes show similar Yref values, allowing direct comparison between bifacial and monofacial tilted modules. On average, Yref on the west-facing plane is 18% higher than on the east-facing plane due to frequent morning fog at the site, which typically dissipates a few hours after sunrise. During the summer months (November to March), the horizontal plane records the highest Yref, while in winter, it aligns more closely with the 15°, 20°, and east-west planes due to Lima's high cloud cover and predominantly diffuse irradiance. On average, rear-side reflection contributes around 14% of the Yref measured on the 15° plane.

Figure 2(b) shows the monthly average temperatures of the PV modules and ambient air. The tilted bifacial modules consistently reach the highest temperatures, followed by the vertical bifacial, while monofacial modules remain the coolest.

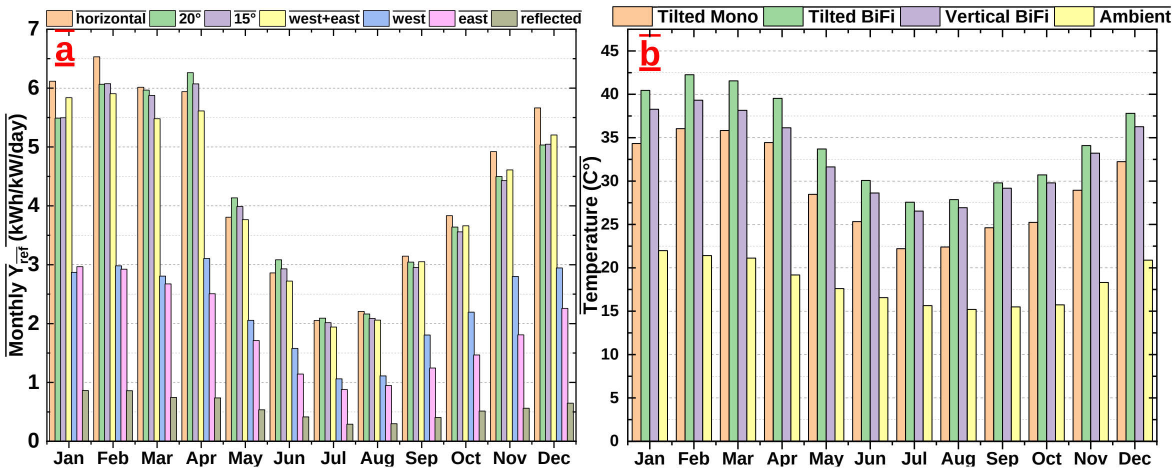

Fig. 2: (a) Monthly average Y_{ref} at different planes of incidence. (b) Monthly average temperature of the modules and ambient air.

Figure 3(a) shows the direct current yield (Ydc) of the evaluated modules. Annually, the tilted bifacial module delivers a Ydc about 6% higher than the monofacial module. However, during winter, both tend to converge due to the reduced ground-reflected irradiance, as noted in Figure 2(a). In contrast, the vertical bifacial module shows an annual Ydc approximately 21% lower than the monofacial one, even though its combined Yref (west and east planes) is comparable to the 20° tilted plane. This is mainly due to the unequal efficiency of both faces—a more pronounced limitation in vertical setups.

Figure 3(b) shows the direct current Performance Ratio (PRdc) for each configuration. For the monofacial module, PRdc was calculated using the irradiance on the 20° tilted plane. In the case of the tilted bifacial module, the PRdc includes both the irradiance on the 15° tilt and the rear-side ground-reflected component. For the vertical bifacial module, PRdc was based on the combined irradiance from the west- and east-facing planes. PR25° represents the PRdc corrected for temperature effects. Thus, the difference between PRdc and PR25°, shown in yellow, indicates the temperature-related losses for the monofacial module.

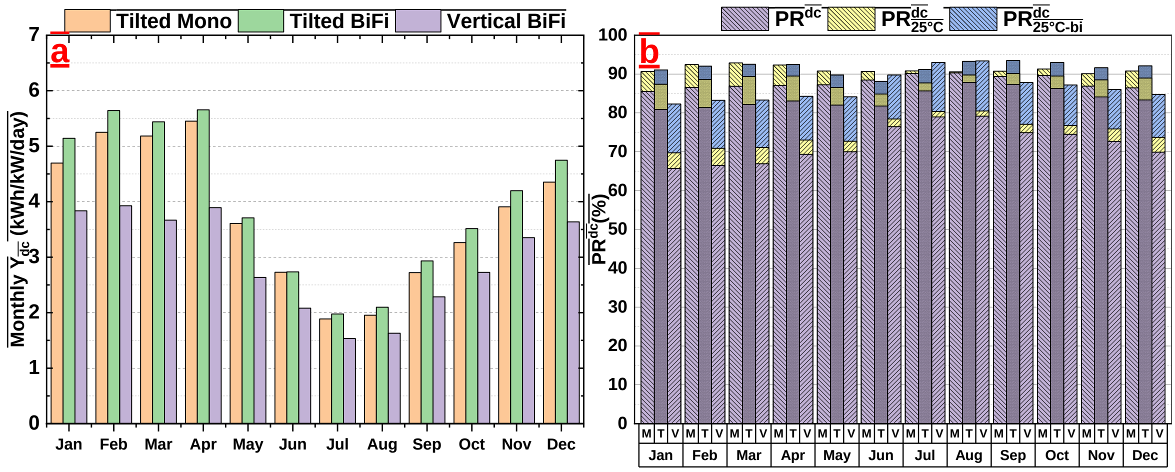

Figure 3: (a) Monthly Y_{dc} for each module. (b) Monthly PR_{dc} of the tilted monofacial (M), tilted bifacial (T), and vertical bifacial (V) modules. Corrections for bifaciality (PR_{bi}) and temperature ($PR_{25°\text{-}bi}$) are also indicated

For bifacial modules, the PRbi metric incorporates the bifaciality factor to estimate the effective irradiance received by the rear side, following the IEC 61724-1:2021 standard. The gap between PRdc and PRbi, highlighted in blue, reflects performance losses associated with the module's 70% bifaciality. Similarly, the difference between PRbi and PR25°-bi, shown in yellow, quantifies the temperature losses relative to the standard reference temperature of 25 °C.

Tab. 1: Annual Yield and Performance Ratio values, temperature, and bifaciality losses.

	Y_{ref} (kWh/kW/day)	Y_{DC} (kWh/kW$_p$/day)	PR (%)	$PR_{25°C}$ (%)	T_{loss} (%)	PR_{bi} (%)	$PR_{25°C\text{-}bi}$ (%)	BF_{loss} (%)
Monofacial	4.07	3.56	87.5	91.2	3.7	-	-	-
BiFi tilted	4.55	3.80	83.4	88.3	4.9	86.5	91.7	3.1
BiFi vertical	3.97	2.82	71.0	74.2	3.2	82.1	85.8	11.1

Table 1 summarizes the annual values of YDC, PR, PR25°, temperature losses (Tloss), PRbi, PR25°-bi, and bifaciality losses (BFloss). The tilted bifacial module shows the highest performance, with a Yref of 4.55 kWh/kW/day (including rear-side reflection) and a YDC of 3.80 kWh/kWp/day, followed by the monofacial and vertical bifacial modules. The PR analysis indicates that the tilted bifacial module also experiences the highest temperature-related losses, at 4.9%, while the vertical bifacial module shows the lowest, at 3.2%. Interestingly, the vertical bifacial module receives a total Yref of 3.97 kWh/kW/day—comparable to the monofacial tilted module's 4.07 kWh/kW/day. However, this irradiance translates into a 16.5% lower YDC, as reflected in their respective PR values: 71.0% for the vertical module vs. 87.5% for the monofacial module. This performance gap is primarily attributed to the limited energy contribution from the rear side due to the 70% bifaciality factor, as evidenced by the power asymmetry shown in Figure 1(c). Additionally, partial shading caused by the vertical module's frame further reduces output. These shading losses were quantified by estimating the vertical module's theoretical maximum power—using the measured Isc and Voc values—and correcting the Fill Factor (FF) accordingly.

4. References

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