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Study of the performance of the backside of bifacial photovoltaic panels for two similar snowy winter days with different levels of illumination

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Abstract. In times of energy crises, global pollution, and changing weather, the role of renewable energy sources in the green transition increases. Bifacial photovoltaic (PV) panels are becoming increasingly popular, but it is unclear how much the backside can improve their performance and under what conditions they are effectively applicable. This work investigates the maximum contribution of the back side for two similar snowy winter days with different illumination levels. The conclusion is that the backside significantly improves the performance of bifacial PV panels, if there is enough space behind them to reflect light. It contributed to the power generated by an average of 42.69 ± 6.32% for the sunny day and 53.36 ±7.9 % for the cloudy one. If the back side is with poor illumination, the performance degrades, and, in such cases, the bifacial PV panels should not be used. The difference in the energy generated by the studied models of BPV for the sunny and cloudy days reached values of 4.06 ±0.6 times, the average being 2.43 ± 0.36 times.

1 Introduction

The world is on the brink of a climate and energy crisis, and the photovoltaic (PV) panels are one of the key solutions, but they are not a perfect technology applicable in all cases, and such power plants must be optimized. There are different ways for PV system optimization, but the right solution depends on the specific case [1, 2].

The bifacial photovoltaic panels (BPV) are one of the innovations in the field, becoming increasingly popular as their manufacturing costs approach those of traditional monofacial modules [3], and their prices are very similar and rarely exceed 20 % [4]. The BPV performance in different situations must be well understood in order for their application to be appropriate, optimal, and the PV system to be safe and durable. The performance of bifacial PV modules depends on the irradiance at the rear side, which is strongly affected by

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the installation setup and environmental conditions [5]. Climatic conditions, mounting configuration, and system parameters influence the energy yield [6].

There are studies investigating the performance of bifacial PV modules, but they are done in different setups and climatic and environmental conditions. For example, a study assesses the performance of bifacial PV panels in a vertical east-west configuration in desert environments [7]. Another one is done for cloudy weather in Saudi Arabia and concludes that the energy efficiency of bifacial PV panels is from 3.5 % to 7 % better than that of monofacial ones [8]. Study analyzes bifacial photovoltaic systems under different snow-climatic conditions for regions of Turkey, and concludes that even in the absence of snow, the bifacial system provides approximately 26.4 % more energy, but with snow cover, the potential for energy production can be increased by approximately 7 %. The same study states that the snow does not have a fixed albedo value and it is influenced by numerous factors [9]. Another study investigates BPV performance, but for vertical mounting and in urban low-rise neighborhoods at high latitudes [10].

As already stated, there are studies of bifacial PV systems and modules, but their performance depends on the irradiance at the rear side, which is strongly affected by the installation setup and environmental conditions. The PV performance also depends on the type of soiling, which is influenced by location-based meteorological conditions like rainfall, wind speed, and humidity, tilt angle, the sources of soiling, and the texture of cover glasses [11-12].

All studies found are done in different ways, from different points of view, for different regions, under different system configurations and environmental conditions. There are a few studies for the winter, but they don't compare the BPV performance for two similar winter days with different levels of illumination, and this is what makes this work considerably different.

The work aims to find how much the back side could contribute to the power generation of BPV under winter conditions, and more specifically, for two similar winter days, but with different levels of illumination, which theoretically could represent real-world conditions close to STC. These sunny and snowy winter weather conditions are theoretically optimal and will allow conclusions to be drawn about the maximum energy that the studied BPV can produce, which is necessary in the process of designing a BPV system, for sizing strings and power inverters. This is a preliminary experimental case study for a Bifacial PV system under construction. It is done with a small data set and for only two winter days, but the analysis allows important preliminary conclusions to be drawn that will be used in the process of developing and completing the system. Future works based on more extensive measurements will aim to refine the results.

2 Materials and methods

A new bifacial PV (BPV) system is currently under construction on the campus of the University of Ruse. One of the strings was mounted before the winter, and it consists of 5 bifacial N-type TOPCon PV panels DAH solar DHN-72X16/DG, Figure 1. The investigation was done with the two PV panels installed side by side at the left end of the string, which are surrounded by snow. The back of the penultimate panel is covered entirely with black paper, which allows for comparison of one-sided and double-sided performance. The goal is to determine how much the backside contributes to the performance of bifacial PV panels in the specific snowy environment and at different levels of illumination. Their main parameters needed for this study are presented in Table 1. The parameters for different backside contributions for the NOCT testing conditions are calculated.

Fig. 1. Bifacial PV string on the campus of the University of Ruse.

Table 1. Specifications of DAH solar DHN-72X16/DG

Specification DAH solar DHN-72X16/DG	**STC**	**NOCT**
Peak Power P_{MAX} (Wp)	570	429
Module Efficiency η_m (%)	22.06	20.75
Peak Power for 5 % yield from the back side P_{D_MAX} (Wp)	598	450
Module Efficiency for 5 % yield from the back side η_m (%)	23.14	21.76
Peak Power for 15 % yield from the back side P_{D_MAX} (Wp)	654	493
Module Efficiency for 15 % yield from the back side η_m (%)	25.31	23.84
Peak Power for 25 % yield from the back side P_{D_MAX} (Wp)	713	536
Module Efficiency for 25 % yield from the back side η_m (%)	27.57	25.92
Temperature Coefficient of P_{MAX} (% / °C)	-0.30	-0.30

The radiation measurements are done with a CM11 pyranometer from KIPP & ZONEN. It is with a sensitivity of 4-6 μV/W/m^2 and directional error under ± 10 W/m^2 (beam 1000 W/m^2).

The PV panel energy production is measured with a specialized UNI-T device UT673PV. Its resolution is 0.1 W. It is with accuracy of ±(1.0 % + 10) for range 11W-500W and ±(1.5 % + 5) for range 501W-800W.

The temperature of the panels is measured by an infrared thermometer Parkside PTIA1, with measurement accuracy for T > 0 °C: ±1.5 °C or ±1.5%. The meteorological data were obtained from a Vantage Pro 2 meteorological station by Davis Instruments, located on the campus of the University of Ruse, in the immediate vicinity of the PV system site.

3 Climatic conditions for the two days of the study

3.1 Weather parameters

The weather forecasts for the 20th and 21st of January were practically the same, with the only difference being that the 20th was predicted to be sunny while the 21st was predominantly cloudy. The negative temperatures and present snow cover offered rarely occurring optimum conditions for peak PV panel performances and a chance for real-world comparison, based on the different levels of illumination for the two investigated days.

Even though the weather forecasts were identical, in reality, there were some differences. The temperatures for both days were negative, and there was no visible change in the snow cover, but there was a difference from 1.6 °C to 5.1 °C, being higher in the morning and lowest at noon, Figure 2. Such differences could be considered insignificant from the point of view of this study.

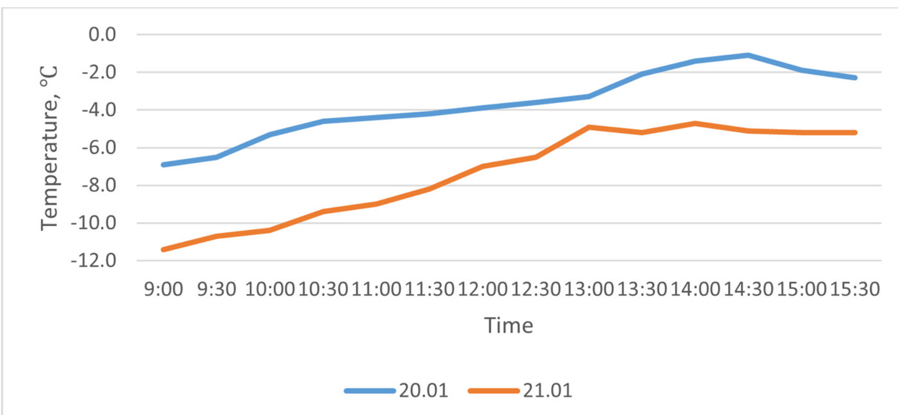


Fig. 2. Actual ambient temperature for the 20th and 21st of January.

The wind speeds are light for both days, and the difference is also insignificant. The average wind speed for the first day is 0.85 m/s, while for the second it is 0.38 m/s.

The average humidity for the measurement period on the 20th of January is 76 %, while for the 21st of January it is 84 %. The difference on average is about 8 %, which will slightly boost the PV panel cooling on the colder second measurement day.

3.2 Global and reflected radiation

The measurements for the Global Tilted Irradiance (GTI) at the front plane of the bifacial PV arrays and the Reflected Irradiance (RI) at the rear side of the bifacial PV panel are presented on Figure 3. For the sunny 20th of January, the measurements are done until 13:30, when the sun goes behind the nearest tall building and there is no direct sunshine on the PV panels. For the second day, the measurements were done for a longer period, until the light became comparatively scarce. All measurement values are with uncertainties of 10.05%, the relative one being 14.21 %.

On average, for the measurements from 10:00 to 13:30, the GTI for 20.01.2026 is 3.2 ±0.45 times more than that for 21.01.2026. On average for the measurements, the RI for 20.01.2026 is 1.3 ±0.18 times more than that for 21.01.2026. This means that for the sunny 20th of January, the directly falling sunlight on the PV panel surface was about 3.2 ±0.45

times more, while the reflected towards the backside one was only 1.3 ±0.18 times more in comparison to the predominantly cloudy 21st.

On average, for the measurements from 10:00 to 13:30 on 20.01.2026, the GTI is 4.1 ±0.58 times more than the RI. On average, for the measurements from 10:00 to 13:30 on 21.01.2026, the GTI is 1.9 ±0.27 times more than the RI, and for the whole measuring range from 10:00 to 15:30, it is 2 ±0.28 times more, which means that the GTI for the predominantly cloudy 21st is about 2 ±0.28 times higher than the RI. The conclusion is that in cloudy weather, the backside should contribute more to the total PV panel production. The average ratio RI/GTI, which could also be the maximum contribution of the backside being part of the total, for 20th of January is 24.64 ±3.5 %, for 21st from 10:00 to 13:30 it is 58 ± 8.24 %, and for the whole measurement period from 10:00 to 15:30 it is 55.2 ± 7.84 %.

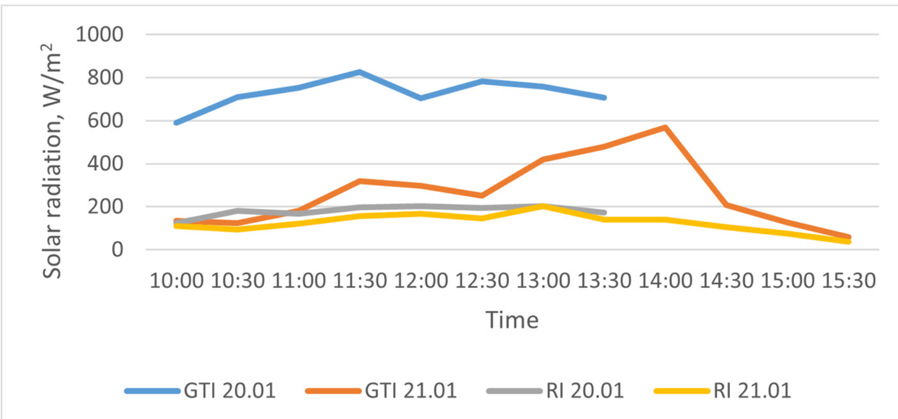


Fig. 3. Measured Global Tilted (GTI) and Reflected Irradiances (RI).

4 Comparison of the BPV panel performances for the two winter days

The comparison is done for two identical BPV panels placed next to each other, with the same orientation and tilt, but one of them has the back side covered. The one with a covered backside is called Reference (RBPV), and the one with an open backside, which contributes due to snow reflection, is called in short Snow (SBPV).

4.1 PV panel temperatures

The PV panel temperatures have been measured, but are about the same for both panels. On average, the SBPV could be a few degrees warmer at certain parts of the day. The maximum measured temperature difference is 6 °C, and for the PV panel temperature coefficient of P_{MAX} of -0.3 % / °C, the SBPV generated power could be 1.8% lower.

4.2 Uncertainty propagation analysis

The UNI-T UT673PV device has a maximum error for the measurement range U_U of 2.51 %. For the maximum measured temperature difference for the investigated PV panels of 6 °C, the power could change up to 1.8 %, which could be considered to be an error U_t.

Due to differences in the exact time of power measurement and the changing irradiation, it has been found that the measured power values could vary by a maximum of 10%, which is an error U_{IR}.

The uncertainty for each separate measurement U_P is calculated by:

$$U_P = \sqrt{{U_U}^2 + {U_t}^2 + {U_{IR}}^2} = 10.47\ \% \tag{1}$$

The percentage error of the ratio U_R, for the uncertainty of measurement for each PV panel U_{P1} and U_{P2}, is:

$$U_R = \sqrt{{U_{P1}}^2 + {U_{P2}}^2} = \sqrt{10.47^2 + 10.47^2} = 14.81\ \% \tag{2}$$

The result is that the ratio of the powers of the two panels has an uncertainty of 14.81 %.

4.3 Comparison of the instantaneous PV panel powers

The measured PV panel powers for both days are presented in Figure 4. The active power ratio for both days is presented in Figure 5. For this ratio, the power generated by RBPV is divided by the power generated by the SBPV for the same hour. This ratio represents what part of the total power is generated by the front side of the BPV, and the rest is the contribution of the backside. On average, for the measurements on the sunny 20th of January, the front side generated power is 57.31 % of the total with uncertainty of ±8.49 %. On average, for the measurements for the cloudy 21st of January, the front side generated power from 10:00 to 13:30 is 46.64 ±6.91 % of the total, and from 10:00 to 15:30 it is 49.66 ±7.36 %. The conclusion is that for the sunny and cold 20th of January, the front side might have contributed slightly more to the total power generation, but because of the uncertainty of ±8.49 %, this is not sure. For the cloudy and cold 21st, it might have contributed less or about the same. There is one noticeable reason for this effect, and it is the ice cover of the PV panels due to the cold weather, which differed for both days. Early in the morning on the sunny 20th of January, there was a thick ice cover on the top side of the PV panels, while the backside was less affected. The ice melted, and the panel surfaces dried between 10-10:30 o'clock, soon after the PV panels were directly illuminated by the sun. On the cloudy and cold 21st of January, the top ice cover wasn't so thick, but because of the lack of direct sunshine and the cold weather, it stayed on the surface for longer in the day, Figure 6. In the early afternoon, the weather on the 21st turned sunny and warmed up. The conclusion is that the winter ice cover could significantly degrade the PV panel performance.

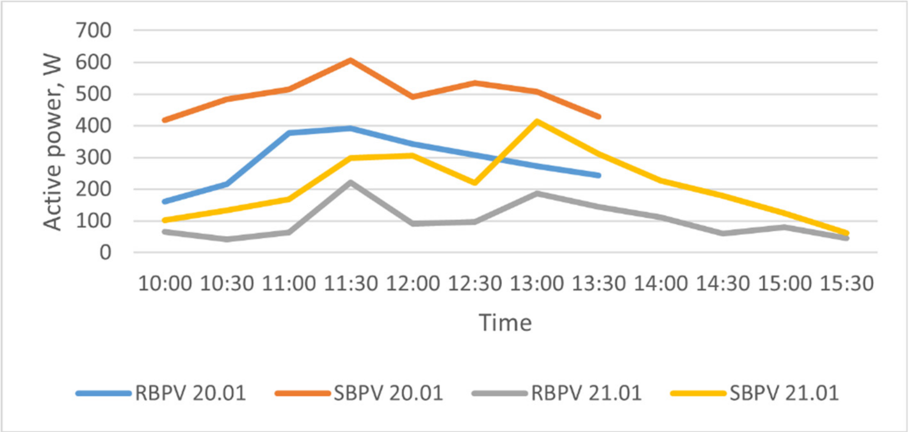


Fig. 4. Measured active PV panel powers for both days.

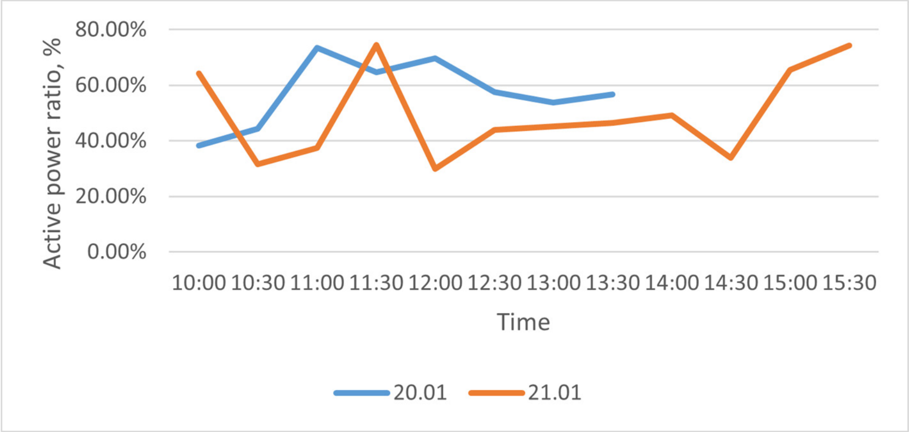
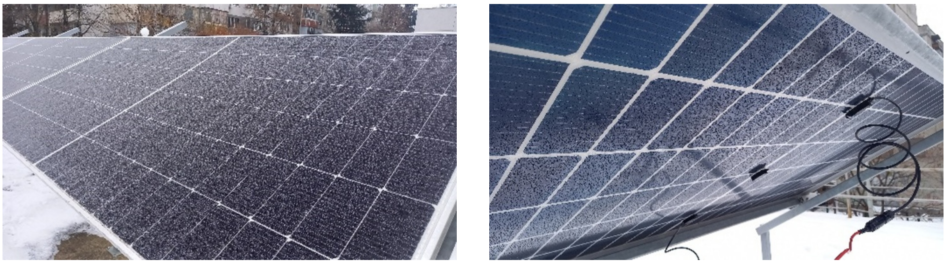


Fig. 5. Active power ratio comparing the performance of RBPV to that of SBPV for both days.



a) b)

Fig. 6. BPV surface condition on 21st of January – a) Slight ice cover at 10:00; b) Melted ice but water droplets present on the surfaces of the BPV panel at 11:30.

Figure 7 presents the active power ratios of RBPV and SBPV, which are achieved by division of the power of one of the PV panels at a certain hour for the first sunny day to the power of the same panel for the same hour for the second predominantly cloudy day. It allows conclusions to be drawn about how panels perform in sunny and cloudy weather.

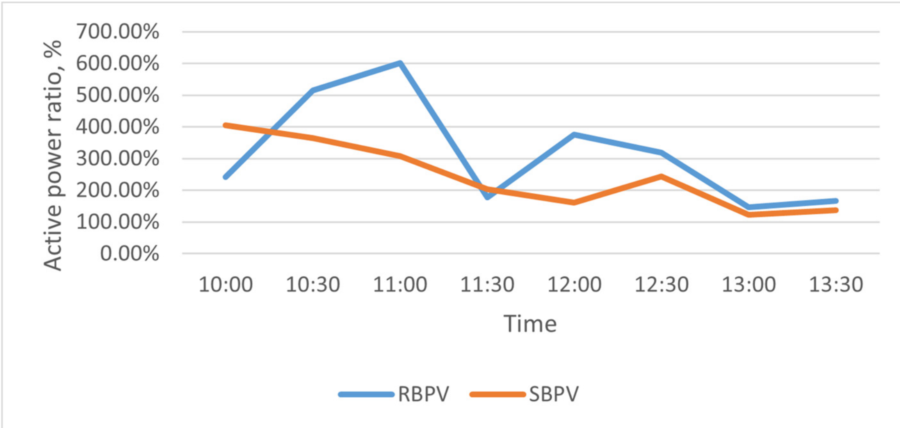


Fig. 7. Active power ratio comparing the performance of RBPV for the first day to that of the second, and the performance of SBPV for the first day to that of the second.

The RBPV curve varies a lot because of the changing amount of direct sunlight falling on the PV panel. The SBPV curve is steadier and more interesting in this case. While the weather on the 20th of January was completely sunny without clouds and fog, the weather on the 21st was cloudiest in the morning and with decreasing cloudiness until noon, when it started to get sunnier. The conclusion is that, on average, for the clear sunny day, the RBPV generated 3.18 ± 0.47 times more power than during the cloudy day. On average, the SBPV power ratio is 2.43 ± 0.36 times, being higher in the morning up to 4.06 ±0.6 times, when the sky is cloudy on the second day, and falling to 1.22 ± 0.18 when the weather turns predominantly sunny on the 21st, or the light conditions are approximately the same on both days at that time. The difference in the generated energy by the studied models of BPV for the sunny and cloudy days reached values of 4.06 ±0.6 times.

4.4 Comparison of the PV panel conversion efficiencies for both days

The average conversion efficiencies of the PV panels for both days have been calculated by:

$$Efficiency = \frac{P_{MAX}}{PV\ area \times (GTI + RI)} \times 100, [\%] \quad (3)$$

The RI for the RBPV calculations is zero. The PV area is 2.58 m2. The uncertainty of the result in this case is 14.51%.

The average efficiency for the sunny 20th of January is 21.22 ± 3.08 %, while for the cloudy 21st of the same period, from 10:00 to 13:30, it is slightly higher, 22.19 ±3.22 %. Although the back side is proven to have a high contribution to the total energy production, the average conversion efficiencies for both days are comparatively low. The one-sided efficiency by specification is 22.06 %. The conversion efficiency for the cloudy day is slightly higher, most likely due to the colder PV panels and the negative temperature coefficient, but the available sunlight on that day is lower, hence the generated power. The low conversion efficiencies might be due to the ice cover in the morning. Although winter temperatures are low and this improves the conversion efficiency of photovoltaic panels, ice and snow cover on photovoltaic surfaces has a negative impact on their performance. The conclusion is that positive temperatures close to zero could be most suitable for the highest average daily performance of photovoltaic panels, but on certain sunny winter days, ice may not be a problem, and they could reach top performance.

4.5 Comparison of the obtained PV panel parameters for the investigated winter days with those presented for STC and NOCT testing conditions

The maximum measured power for SBPV is 606 ± 63W at 11:30 on the sunny 20th of January, and based on our measurements in this case, the backside contributes approximately 35 ± 3.7 %. It is well known that the NOCT testing conditions are significantly closer to real conditions than STC. The NOCT peak power at 35 % backside contribution is 579 W, which is close. The conclusion is that the NOCT rating is the more realistic one for bifacial PV panels, but under certain conditions, it could be exceeded. For comparison, a study led under desert climate conditions concludes that the rear side contributes approximately 8–12 % of total energy yield [13]. Another work concludes that under optimum conditions, bifacial modules offer up to 30 % more energy than conventional modules [6], but in this case, we have achieved more.

During the bifacial PV system design process, for safety reasons, it is accepted that the backside contribution based on the parameters measured at STC conditions is to be taken between 15 and 25 %. In our case, the highest measured power of 606 W is equal to 7 % backside contribution based on the powers measured at STC. The weather conditions during the two winter days of study may not be the best, offering the best SBPV performance, and it is not advisable to load power inverters close to their maximum capacity, as this would shorten their life, although it may improve their efficiency a little. In this regard, we suggest that PV system oversizing based on 25 % backside contribution is better from the point of view of system durability and safety.

5 Conclusion

The main conclusion is that the BPV panel backside contribution could be significant in certain winter conditions and parts of the day, comparable to and even greater than the performance of the front one. On average, for the measurements from 10:00 to 13:30 on the sunny 20th of January, the front side generated power is 57.31 % of the total with uncertainty of ±8.49 %, and for the cloudy 21st of January, it is 46.64 ±6.91 %. This means that on average, the back side contributed 42.69 ± 6.32% for the sunny day and 53.36 ±7.9 % for the cloudy one. The conclusion is that for the sunny and cold 20th of January, the front side contributes slightly more to the total power generation, but for the cloudy and cold 21st, it contributes slightly less or about the same.

On average, the SBPV power ratio for both days is 2.43 ± 0.36 times, being higher in the morning up to 4.06 ±0.6 times, when the sky is cloudy on the second day, and falling to 1.22 ± 0.18 when the weather turns predominantly sunny on the 21st, or the light conditions are approximately the same on both days at that time. The difference in the generated energy by the studied models of BPV for the sunny and cloudy days reached values of 4.06 ±0.6 times.

Although winter temperatures are low and this improves the conversion efficiency of photovoltaic panels, ice and snow cover on photovoltaic surfaces have a negative impact on their performance. The winter ice cover could significantly degrade the PV panel power generation, and for this reason, positive temperatures close to zero could be most suitable for the highest average daily performance of photovoltaic panels, but on certain sunny winter days, ice may not be a problem, and they could reach top performance.

The maximum measured power for SBPV is 606 ± 63 W at 11:30 on the sunny 20th of January, and based on our measurements in this case, the backside contributes approximately 35 ± 3.7 %. The measured powers and conversion efficiencies are comparatively low, close to the ones for NOCT.

During the bifacial PV system design process, for safety reasons, it is accepted that the backside contribution based on STC is to be taken between 15 and 25 %. In our case, the highest measured power of 606 W is equal to 7 % backside contribution based on the powers measured at STC. In this regard, we suggest that PV system oversizing based on 25 % backside contribution is better from the point of view of system durability and safety.

This work is a preliminary experimental case and has many limitations. It is done with a small data set and for only two winter days, but the analysis allows important preliminary conclusions to be drawn for the PV system performance at this location. Future works based on more extensive measurements will aim to refine the results. More BPV performance studies are needed for other climatic conditions, but they are a matter of future work.

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