sustainability

MDPI

Article

Outdoor Performance Test of Bifacial n-Type Silicon Photovoltaic Modules

Hyeonwook Park [1], Sungho Chang [2,*], Sanghwan Park [1,2] and Woo Kyoung Kim [1,*]

1 School of Chemical Engineering, Yeungnam University, 280 Daehak-ro, Gyeongsan 38541, Korea; greatekal@naver.com (H.P.); sanghwan.park@lge.com (S.P.)
2 Solar research and development lab, LG Electronics, Gumi-si 39381, Korea
* Correspondence: sungho.chang@lge.com (S.C.); wkim@ynu.ac.kr (W.K.K.)

Received: 3 October 2019; Accepted: 4 November 2019; Published: 7 November 2019

check for updates

Abstract: The outdoor performance of n-type bifacial Si photovoltaic (PV) modules and string systems was evaluated for two different albedo (ground reflection) conditions, i.e., 21% and 79%. Both monofacial and bifacial silicon PV modules were prepared using n-type bifacial Si passivated emitter rear totally diffused cells with multi-wire busbar incorporated with a white and transparent back-sheet, respectively. In the first set of tests, the power production of the bifacial PV string system was compared with the monofacial PV string system installed on a grey concrete floor with an albedo of ~21% for approximately one year (June 2016–May 2017). In the second test, the gain of the bifacial PV string system installed on the white membrane floor with an albedo of ~79% was evaluated for approximately ten months (November 2016–August 2017). During the second test, the power production by an equivalent monofacial module installed on a horizontal solar tracker was also monitored. The gain was estimated by comparing the energy yield of the bifacial PV module with that of the monofacial module. For the 1.5 kW PV string systems with a 30° tilt angle to the south and 21% ground albedo, the year-wide average bifacial gain was determined to be 10.5%. An increase of the ground albedo to 79% improved the bifacial gain to 33.3%. During the same period, the horizontal single-axis tracker yielded an energy gain of 15.8%.

Keywords: bifacial solar cell; n-PERT; silicon; albedo; bifacial gain; bifaciality

1. Introduction

The enhancement of power production by utilizing bifacial photovoltaic (PV) modules and systems is known to be one of the most promising approaches, and their market is expected to expand tremendously [1]. Unlike conventional monofacial silicon PV modules, bifacial silicon PV modules are designed to absorb sunlight incident on both the front and back surfaces of cells by adopting grid-type metal contacts for both surfaces. Furthermore, in the configuration of these modules, opaque back-sheets are replaced with transparent back-sheets or glass. A global analysis and optimization of various bifacial module configurations using opto-electro-thermal simulations suggest that a bifacial gain of nearly 30% (defined as the ratio of the additional power yield of the bifacial PV module to the power yield of a monofacial PV module) can be achieved under the conditions of a module height of 1 m and an albedo of 50% [2]. The results of outdoor tests indicate a bifacial gain in excess of 20% for a bifacial module (72-solar cells) that is south-oriented at an installation angle of 30° and ground albedo of ~50% [3]. Even though bifacial PV modules are slightly more expensive than monofacial PV modules, bifacial PV modules can produce more power and are more suitable in snowy areas and desert climates compared to monofacial PV modules [4].

In this regard, it is believed that the replacement of conventional monofacial silicon PV modules with bifacial silicon PV modules can reduce the number of modules required for power production systems and the overall installation cost including ground area, materials, labor costs, and construction period. Further, the bifacial PV modules absorb sunlight reflected from the ground and they can generate a maximum of 30% additional electricity simply by optimizing the installation conditions (e.g., height, angle, and direction) and the reflectivity of the ground without investing in additional equipment and systems [5–8]. In the 2019 International Technology Roadmap for Photovoltaic (ITRPV) report, it is predicted that the worldwide market share of bifacial crystalline silicon PV cells used in both conventional monofacial and bifacial modules will dramatically increase from 10% (2018) to 60% (2029) in ten years, and furthermore, 50% of bifacial cells will be used in true bifacial modules in 2029. For the crystalline silicon PV market in 2018, the market shares of p-type and n-type silicon cells are approximately 95% and 5%, respectively. However, in 2029, the n-type silicon cell is expected to have a market share of approximately 45%.

N-type single crystalline silicon PV cells are known to have higher short-circuit current (I_{SC}), open-circuit voltage (V_{OC}), and fill factor (FF) compared to p-type cells, and thus have advantages in terms of the commercialization of high-performance PV cells and modules. In addition, they are relatively stable against light-induced degradation (LID) and are less sensitive to impurities within the silicon materials [9]. Moreover, n-type silicon cells exhibit low recombination losses compared to p-type silicon cells, such that the former is more suitable for use in a bifacial cell configuration than the latter. Multi-wire busbar technology is attracting more attention due to the reduced resistance and enhanced light absorption associated with this approach due to increased light scattering [10]. Recently, our research group reported outdoor field test results indicating a bifacial gain in excess of 30% from a 60-cell n-type silicon bifacial module oriented to the south at an installation angle of 30° [11], and a bifacial gain of 14.5% from a 1.8 kW bifacial PV system [12].

In this study, n-type bifacial silicon cells with multi-wire busbar and their modules were utilized to evaluate the gain of bifacial modules and 1.5 kW PV string systems installed under different ground reflection conditions. In addition, the bifacial PV gain was compared to that of a horizontal single-axis tracker.

2. Materials and Methods

Three types of one-cell mini-modules were prepared using a 156 mm × 156 mm (6 inches) n-type passivated emitter rear totally diffused (n-PERT) bifacial silicon cells (Model: Neon2, LG Electronics) and three different back-sheet materials, i.e., white, black, and transparent back-sheets that have different optical properties. Their current-voltage (I-V) characteristics were measured using a solar simulator (SINUS-220, Wavelabs) at standard conditions (STC) of 25 °C and 1000 W/m^2. For the one-cell mini-module with transparent back-sheet, I-V characteristics of the rear side were also evaluated. Both monofacial and bifacial silicon PV modules were prepared by a series connection of n-PERT bifacial silicon cells with multi-wire busbar. Conventional monofacial PV modules employ an opaque white polymer back-sheet while bifacial PV modules adopt a transparent back-sheet. Outdoor field tests of these modules were performed at Gumi-Si, South Korea (latitude 36.11°N, longitude 128.38°E) by installing the PV modules on the rooftop of the LG Electronics building at a fixed angle of 30 degrees to the south and a height of 1 m, and the power production was monitored.

In the first set of tests, the power production of the monofacial PV string system (five monofacial PV modules) was compared to that of the bifacial PV string system (five bifacial PV modules) installed on the concrete floor with an albedo (ratio of reflected irradiance to surface irradiance) of ~21% for approximately one year (June 2016–May 2017). Each string system was composed of five 60-cell modules as shown in Figure 1. Both the monofacial and bifacial PV modules were prepared using the equivalent solar cells produced in the same batch of the production line. However, their nameplate powers (front powers) in Table 1 are slightly different due to the use of different back-sheets, i.e., white and transparent back-sheets.

Figure 1. Monofacial and bifacial photovoltaic (PV) systems monitored for the period of June 2016–May 2017.

Table 1. The nameplate specification of the PV modules used in this study.

		Test 1		Test 2	
Module Type		**Monofacial**	**Bifacial**	**Monofacial**	**Bifacial**
Module size	(mm^2)	1640 × 1000		1960 × 1000	
Number of cells	-	60	60	72	72
Cell type	-	n-type	n-type	n-type	n-type
P_{max}	(W)	315	300	370	370
V_m	(V)	33.2	32.9	39.2	39.2
I_m	(A)	9.50	9.15	9.44	9.44
V_{OC}	(V)	40.6	40.1	48.0	48.0
I_{SC}	(A)	10.0	9.65	9.98	9.98

In the second set of tests (Figure 2), the power production performance of 72-cell monofacial and bifacial PV modules installed on a white membrane floor with an albedo of ~79% was evaluated for approximately ten months (November 2016–August 2017). During the same period (November 2016–August 2017), another monofacial PV string system with two 72-cell modules was monitored using a horizontal solar tracker; their installation height was 1 m. As summarized in Table 1, the nameplate powers of both the 72-cell monofacial and bifacial modules were intentionally set to be approximately 370 W by selecting slightly larger PV cells for the bifacial module to compensate for any losses due to the use of the transparent back-sheet.

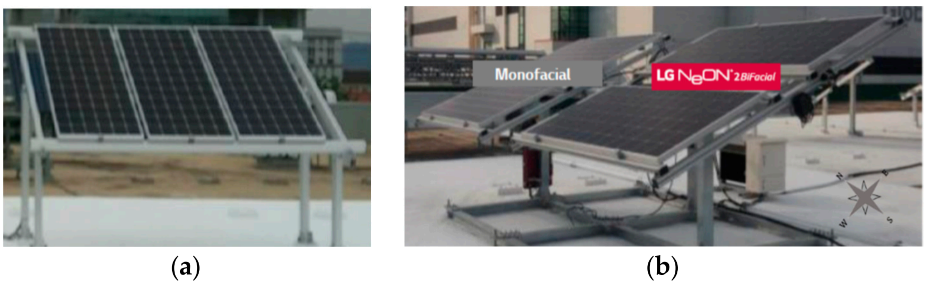

Figure 2. The 3-module bifacial PV system (**a**) and two monofacial (fixed and tracked) PV systems (**b**) monitored for the period of November 2016–August 2017.

Based on the collected data sets, the monthly power yield was calculated by

$$\text{Power yield} = \frac{total\ power\ production\ for\ a\ month}{total\ nominal\ power\ of\ PV\ system} \quad (1)$$

where the nominal power represents the nameplate capacity of the PV module measured at indoor STC. In addition, the bifacial gain was estimated for each month.

3. Results and Discussion

3.1. Characteristics of Bifacial One-Cell Mini-Modules

The effect of back-sheet nature (white, black, and transparent) on the performance of one-cell mini-modules was studied. The I-V characteristics of three one-cell mini-modules with different back-sheets are shown in Figure 3, and their device performance parameters are listed in Table 2. As shown in Figure 3 and Table 2, the short-circuit current (I_{SC}) values of the three one-cell mini-modules are apparently different (I_{SC} = 9.78–10.5 A), while their open-circuit voltages (V_{OC}) are nearly identical to each other (V_{OC} = 0.67–0.68 V). The highest I_{SC} value of 10.5 A was achieved for the module with a white back-sheet, which is due to the increased light absorption by the reflection of transmitted light from the white back-sheet. The nearly non-reflective black back-sheet yielded the lowest I_{SC} value of 9.78 A. The bifaciality of the bifacial one-cell mini-module is defined as the ratio of the rear side power (or I_{SC}) to the front side power (or I_{SC}) under standard conditions [13]. This was estimated to be 90.4% and 91.5% from I_{SC} and the maximum power, respectively.

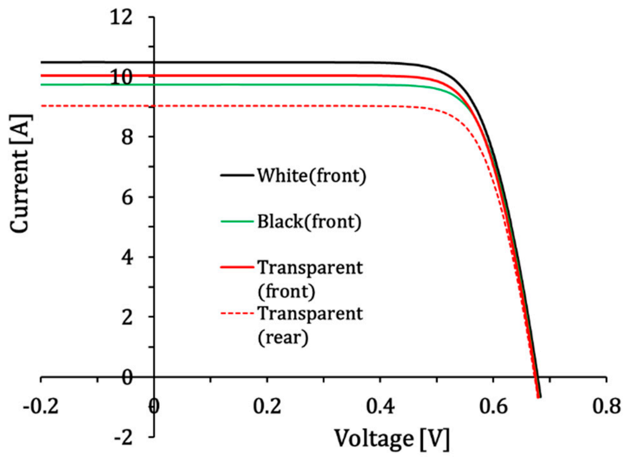

Figure 3. Current-voltage characteristics of one-cell mini-modules with three different back-sheet materials.

Table 2. The device performance parameters of one-cell mini-modules with different back-sheets.

Back-Sheet (Illumination)		White (Front)	Black (Front)	Transparent (Front)	Transparent (Rear)
I_{SC}	(A)	10.5	9.78	10.0	9.04
V_{OC}	(V)	0.68	0.68	0.67	0.67
FF	(%)	74.0	75.7	74.9	75.8
Efficiency	(%)	21.6	20.6	21.6	18.9
Bifaciality (I_{SC})	(%)	-	-	90.4	
Bifaciality (Power)	(%)	-	-	91.5	

3.2. Comparison of Annual Power Production of Monofacial and Bifacial PV String Systems with Low Albedo Ground

It should be noted that the nameplate powers of the 60-cell monofacial and bifacial PV modules used in this experiment were 315 W and 300 W, respectively. The similar performance bifacial cells produced from the same batch of the cell production line were used to fabricate the monofacial and bifacial PV modules. The only difference between the 60-cell monofacial and bifacial PV modules was the back-sheet material, i.e., white back-sheet for monofacial PV modules and transparent back-sheet for bifacial PV modules. As shown in Table 1, the nominal power of the 60-cell monofacial PV module measured via front illumination is slightly larger (~5%) than that of the 60-cell bifacial PV module due to the reflected light from the white back-sheet, but not from the transparent back-sheet. At present, the nominal power and test procedure of the 60-cell bifacial PV module considering rear side power production has not been established as yet by the International Electrotechnical Commission (IEC).

As shown in Figure 4, the monthly power production and thus the power yield of the 60-cell bifacial PV string system measured for an outdoor field is consistently larger than that of the monofacial PV string system over the entire year. In South Korea, there are four distinct seasons. Generally, during the spring-to-fall season (February to September), relatively high irradiance is observed compared to the fall-to-winter season, resulting in higher solar power production. For the test period of June 2016 to May 2017 at an outdoor testing site, the monthly front and back irradiance and the corresponding back-to-front irradiation ratios measured at a height of 1.7 m using an albedometer are summarized in Figure 5.

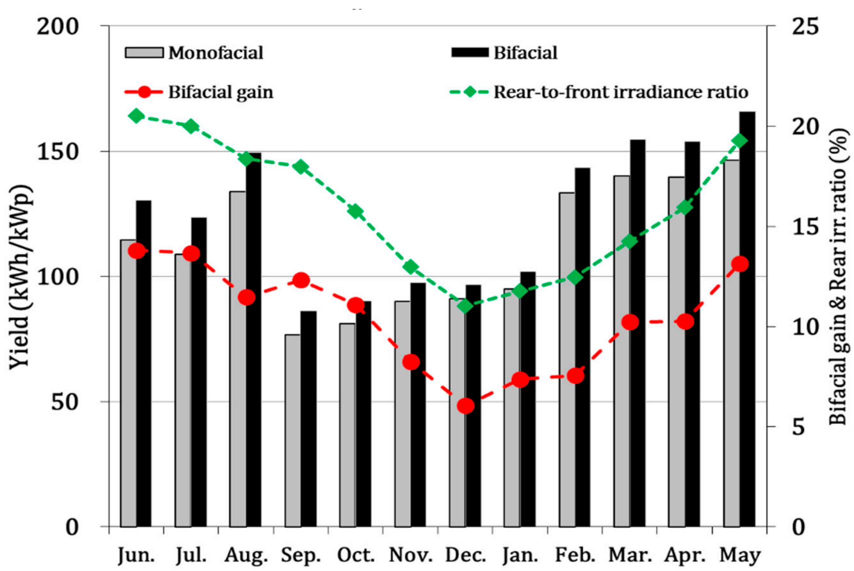

Figure 4. Monthly power yield (**left**) of monofacial and bifacial PV string systems and the resulting bifacial gains and back irradiation ratios (**right**) between June 2016 and May 2017 (12 months).

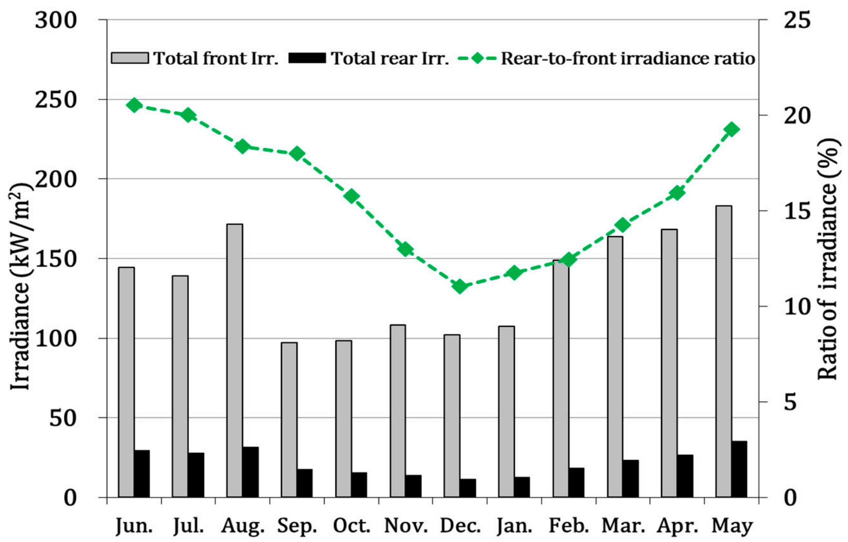

Figure 5. Monthly front and back irradiance (**left**) and corresponding back-to-front irradiation ratios (**right**) between June 2016 and May 2017 (12 months).

This result clearly demonstrates the strong correlation between the front irradiance and power production for the 60-cell monofacial and bifacial PV string systems. The annual trend of bifacial gain was also coincident with that of the back-to-front irradiation ratio, but not with the front irradiance. It was determined that the highest and lowest bifacial gains were obtained in June and December, respectively. From January to June, the bifacial gain monotonically increased and reached a maximum value in June. Then, from June to December, the bifacial gain decreased to the lowest value in December. Based on Figures 4 and 5, the bifacial gain highly depends on the back-to-front irradiation ratio, which is also affected by the meridian transit altitude of the Sun. In South Korea, with a north latitude of ~37°, the meridian transit altitude is the highest in the summer season (~76.5°) and the lowest in the winter season (~29.5°). It is believed that the higher meridian transit altitude of the Sun results in better back reflection and thus a higher bifacial gain [14,15]. The annual average bifacial gain and back-to-front irradiation ratio were estimated to be 10.5% and 16.2%, respectively. The highest monthly bifacial gain was obtained in June as 13.8% and at least approximately 5% of the bifacial gain was obtained in December. The annual daily average power generation hour was calculated to be 3.70 h for the monofacial PV module and 4.09 h for the bifacial PV module. This represents an improved performance of approximately 10% for the bifacial PV string systems compared to the monofacial modules. Finally, it should also be noted that the abrupt decrease of the irradiance from August to September is mainly due to the poor weather conditions (e.g., rainy and cloudy) that were encountered particularly in September 2017. Therefore, careful consideration should be exercised in attempting to generalize these results.

3.3. Comparison of Power Production of Monofacial and Bifacial PV String Systems with High Albedo Ground

In the second set of outdoor tests, a higher albedo (~79%) ground using a white membrane was utilized in the testing facility, where the monthly power production of the monofacial and the bifacial PV string systems consisting of three 72-cell modules was monitored for 8–10 months. The nominal power of the 72-cell Si monofacial and bifacial PV modules was measured to be 368 W and 366 W, respectively. Unlike the 60-cell modules that were previously used, the nominal powers of both the monofacial and the bifacial PV modules were intentionally set to be nearly identical to quantitatively investigate the bifacial gain. Therefore, slightly higher performance cells were used to fabricate the bifacial modules to compensate for the loss of nominal power caused by the replacement of the white back-sheet (monofacial module) with the transparent back-sheet (bifacial module).

Front and back irradiances were monitored using an albedometer installed at 1.7 m, and the corresponding rear-to-front irradiance ratio is presented in Figure 6. Compared to the previous test under the low albedo conditions, the average monthly albedo (i.e., rear-to-front irradiance ratio) over the entire test period was approximately 35.3% (± 3.9%) with a maximum value of 41.4%. The total irradiance increased from December to April and was saturated until August, except for the outlier of July (often cloudy and rainy). However, the rear-to-front irradiance ratio gradually increased from January to July, which is coincident with the previous results for the low albedo ground. Therefore, it can be concluded that this ratio is most probably affected by the change of the meridian transit altitude of the Sun with the season [14,15].

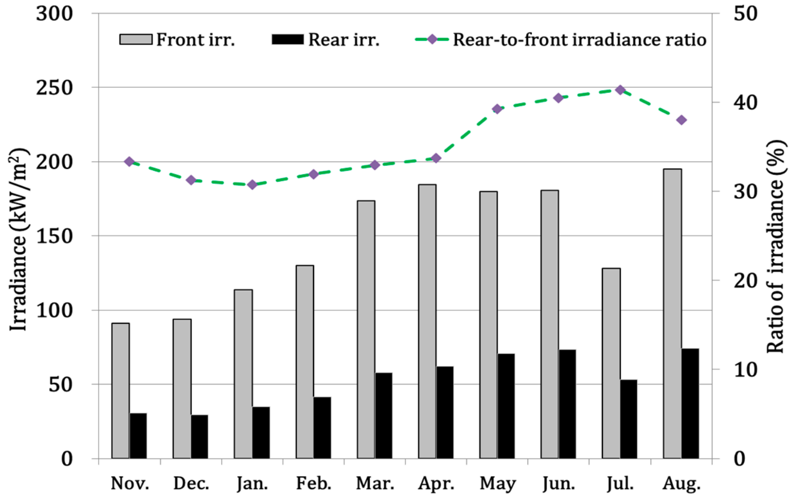

Figure 6. Trends of monthly front and back irradiance (**left**) and back-to-front irradiation ratios (**right**) between November 2016 and August 2017 (10 months).

In Figure 7, the monthly power yield of the monofacial and bifacial 72-cell PV modules and the corresponding bifacial gains and rear-to-front irradiation ratios (right) for 10 months are shown. The overall trends for the power yield of both the monofacial and bifacial PV modules were similar to that of the irradiance, showing a monotonic increase from November to April followed by saturation until June. Similar to Figure 6, the unexpectedly low power yield in June 2017 is attributed to the abnormally cloudy and rainy weather conditions and is thus considered an outlier. In addition, the change of the bifacial gain also followed that of the rear-to-front irradiance and presumably was affected by the meridian transit altitude of the Sun. For the test period of 10 months, the average rear-to-front irradiance and bifacial gain were calculated to be 35.9% and 33.3%, which are superior to the values of 16.2% and 10.5% for the 60-cell PV system with a lower albedo that was reported in the previous section. Furthermore, the daily average power generation hour was calculated to be 4.17 h for the monofacial PV module and 5.56 h for the bifacial PV module. This represents an improved performance of approximately 33% for the bifacial PV modules compared to the monofacial modules. It should be noted that the bifacial gain of the power generation hour for the 60-cell module PV system with a low albedo ground (~21%) was approximately 10% in the previous section.

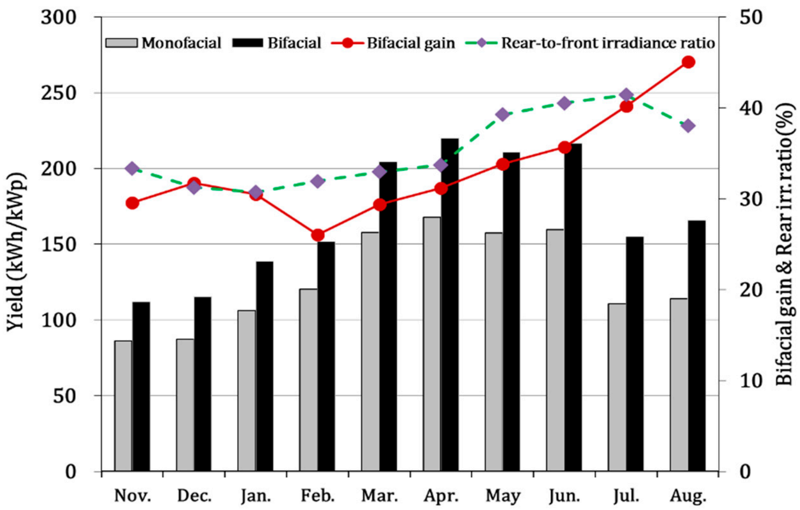

Figure 7. Monthly power yield (**left**) for the monofacial and bifacial PV modules, and the resulting bifacial gains and back irradiation ratios (**right**) between November 2016 and August 2017 (10 months).

3.4. Comparison of Power Production of Tracked Monofacial and Bifacial Modules with High Albedo Ground

In the final set of field tests, the monthly power production yield of the monofacial 72-cell PV module with a horizontal single-axis solar tracker (i.e., installation angle of 0° and tracking from east to west) and the bifacial 72-cell PV module on the white membrane (albedo ~79%) were monitored for approximately eight months and compared to that of the monofacial 72-cell module with a fixed tilt angle of 30 degrees to the South. As shown in Figure 8, it was determined that the overall power production yield of three different module setups exhibited similar trends to Figure 7. For the entire period of January to August, the bifacial gain (28–41%) was observed to be higher than the tracker gain (−13–32%: calculated using an additional power generation by a single-axis tracker).

The power production gain obtained by attaching a horizontal single-axis solar tracker seems to be related to the monthly power production yield or average irradiance according to the season, i.e., a greater tracker gain was obtained during the summer compared to the winter season. However, during January and February, the average values of the horizontal tracker gain were negative, indicating that the power production via a horizontal single-axis solar tracker is smaller than that produced by the monofacial module fixed at 30°. This is presumably due to the low height of the Sun during the winter period (January and February). There is a published report that suggests that the seasonal optimum tilt angle of the module near 35°N (similar to our study) is approximately 5° and 65° for the summer and winter solstice, respectively [7]. In summary, adopting a bifacial PV module on high albedo ground is more beneficial than attaching a horizontal single-axis tracker to a monofacial PV module in terms of the average production yield, consistency of gain with the season, required area for installation, and potentially the installation cost.

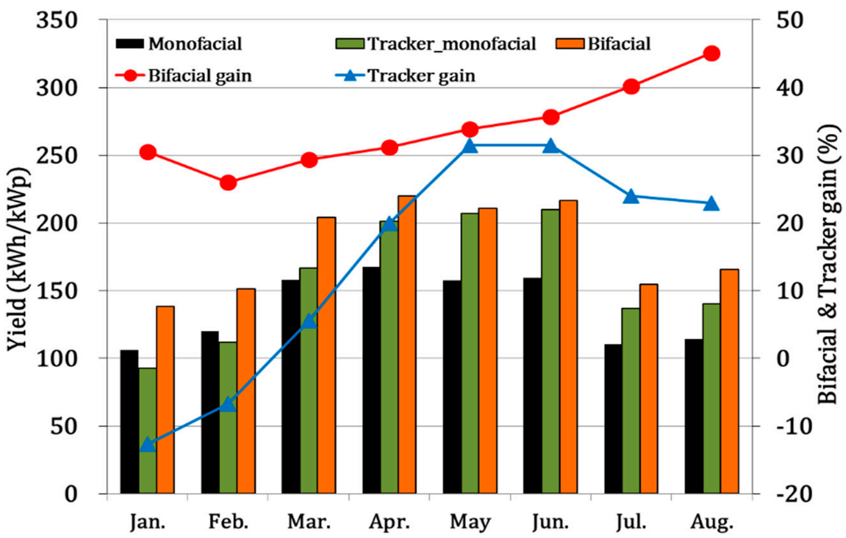

Figure 8. Monthly power yield (**left**) of monofacial, tracked monofacial, and bifacial PV modules, and the resulting bifacial gains and tracker gains (**right**) between January 2017 and August 2017 (8 months).

4. Conclusions

The extra power generation of n-type bifacial silicon modules and their 1.5 kW string systems was reproducibly demonstrated via long-term (8–12 months) outdoor tests under different ground reflection conditions, e.g., 21% and 79% albedo. The average bifacial gain was estimated by comparing the energy yield of the bifacial PV module and the string system to that of the monofacial module and the system. For the 1.5 kW PV string systems (five 60-cell modules) with a 30° tilt angle to the south and a 21% ground albedo, the year-wide average bifacial gain was determined to be 10.5%. Moreover, a significant enhancement of the bifacial gain to 33.3% was clearly demonstrated from the 72-cell module installed with a 30° tilt angle to the south and 79% ground albedo. It was also determined that the parallel test using the equivalent 72-cell monofacial module equipped with a horizontal single-axis tracker yielded an extra energy production (gain) of 15.8%, as summarized in Table 3.

Table 3. Summary of outdoor field test results performed in this study.

Period	2016.06–2017.05	2016.11–2017.08	2017.01–2017.08
Ground Albedo (%)	Grey concrete 21	White membrane 79	White membrane 79
Number of modules	String (5 modules)	Single module	Single module
Orientation	South facing (30° tilted)	South facing (30° tilted)	Horizontal single axis tracking
Height (m)	1	1	1
Module type	Monofacial & Bifacial strings	Monofacial & Bifacial modules	Monofacial modules with/without tracker
Accumulated production yield (kWh/kWp)	1351 (Mono) 1493 (Bi)	1267 (Mono) 1689 (Bi)	1094 (Mono) 1267 (Mono_tracker)
Gain (%) by bifacial or tracker	10.5	33.3	15.8

The bifacial gain was highly affected by the rear-to-front irradiance ratio of the module and thus, the seasonal meridian transit altitude of the Sun. For a 1.5 kW system with 21% ground albedo, the monthly average bifacial gain varied from 6.1% (December) to 13.8% (June). For the module with 79% albedo, the gain varied from 26.0% (February) to 45.1% (August). Surprisingly, the tracker gain changed significantly from −12.7% (January) to 31.5% (May and June).

Author Contributions: Conceptualization, S.C. and W.K.K.; data curation, H.P. and S.P. and W.K.K.; formal analysis, H.P. and S.P.; funding acquisition, S.C. and W.K.K..; investigation, H.P. and W.K.K.; methodology, S.C. and S.P.; supervision, W.K.K.; writing–original draft, H.P. and W.K.K.

Funding: This work was funded by the International Cooperative R&D Program (EUREKA), funded by the Korea Institute for Advancement of Technology (KIAT) (Grant no. N0002097) and the Priority Research Center Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (Grant no. 2014R1A6A1031189).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Rodríguez-Gallegos, C.D.; Bieri, M.; Gandhi, O.; Singh, J.P.; Reindl, T.; Panda, S.K. Monofacial vs bifacial Si-based PV modules: Which one is more cost-effective. *Sol. Energy* **2018**, *176*, 412–438. [CrossRef]
2. Sun, X.; Khan, M.R.; Deline, C.; Alam, M.A. Optimization and performance of bifacial solar modules: A global perspective. *Appl. Energy* **2018**, *212*, 1601–1610. [CrossRef]
3. Kreinin, L.; Bordin, N.; Karsenty, A.; Drori, A.; Eisenberg, N. Outdoor evaluation of power output improvement of the bifacial module. In Proceedings of the 37th IEEE Photovoltaic Specialists Conference, Seattle, WA, USA, 19–24 June 2011; pp. 1827–1831.
4. Russell, T.C.R.; Saive, R.; Augusto, A.; Bowden, S.G.; Atwater, H.A. The Influence of Spectral Albedo on Bifacial Solar Cells: A Theoretical and Experimental Study. *IEEE J. Photovol.* **2017**, *7*, 1611–1618. [CrossRef]
5. Joge, T.; Eguchi, Y.; Imazu, Y.; Araki, I.; Uematsu, T.; Matsukuma, K. Basic application technologies of bifacial photovoltaic solar modules. *Electr. Eng. Jpn.* **2004**, *149*, 32–42. [CrossRef]
6. Yusufoglu, U.A.; Pletzer, T.M.; Koduvelikulathu, L.J.; Comparotto, C.; Kopecek, R.; Kurz, H. Analysis of the annual performance of bifacial modules and optimization methods. *IEEE J. Photovolt.* **2015**, *5*, 320–328. [CrossRef]
7. Asgharzadeh, A.; Marion, B.; Deline, C.; Hansen, C.; Stein, J.S.; Toor, F. A sensitivity study of the impact of installation parameters and system configuration on the performance of bifacial PV arrays. *IEEE J. Photovol.* **2018**, *8*, 798–805. [CrossRef]

8. Kreinin, L.; Karsenty, A.; Grobgeld, D.; Eisenberg, N. Bifacial Modules: Indoor and Outdoor Measurements and Some Requirements for Correct Simulation of Energy Generation. In Proceedings of the 7th World Conference on Photovoltaic Energy Conversion (WCPEC), Waikoloa Village, HI, USA, 10–15 June 2018; pp. 582–585.
9. Yu, B.; Song, D.Y.; Sun, Z.G.; Liu, K.; Zhang, Y.; Rong, D.D.; Liu, L.J. A study on electrical performance of N-type bifacial PV modules. *Sol. Energy* **2016**, *137*, 129–133. [CrossRef]
10. Dullweber, T.; Schulte-Huxel, H.; Blankemeyer, S.; Hannebauer, H.; Schimanke, S.; Baumann, U.; Witteck, R.; Peibst, R.; Köntges, M.; Brendel, R. Present status and future perspectives of bifacial PERC+solar cells and modules. *Jpn. J. Appl. Phys.* **2018**, *57*, 08RA01. [CrossRef]
11. Yoo, Y.; Seo, Y.; Park, D.; Kim, M.; Jang, H.; Kwon, Y.H.; Hwangbo, C.; Kim, W.K.; Chang, S. Evaluation of Power Generation Performance for Bifacial Si Photovoltaic Modules installed on Different Artificial Grass Floors. *J. Energy Eng.* **2018**, *27*, 1–9.
12. Seo, Y.; Park, H.; Yoo, Y.; Kim, M.; Oh, S.-Y.; Alhammadi, S.; Chang, S.; Park, S.-H.; Lee, J.; Mun, S.; et al. Effect of front irradiance and albedo on bifacial gain in 1.8 kW bifacial silicon photovoltaic system. In Proceedings of the 46th IEEE Photovoltaic Specialists Conference, Chicago, IL, USA, 16–21 June 2019.
13. Newman, B.K.; Carr, A.J.; Jansen, M.J.; Goma, E.G.; Kloos, M.J.H.; De Groot, K.M.; Van Aken, B.B. Comparison of Bifacial Module Measurement Methods with Optically Optimized Bifacial Modules. In Proceedings of the 7th World Conference on Photovoltaic Energy Conversion (WCPEC), Waikoloa Village, HI, USA, 10–15 June 2018; pp. 3593–3597.
14. Razongles, G.; Sicot, L.; Joanny, M.; Gerritsen, E.; Lefillastre, P.; Schroder, S.; Lay, P. Bifacial photovoltaic modules: Measurement challenges. *Energy Procedia* **2016**, *92*, 188–198. [CrossRef]
15. Kreinin, L.; Bordin, N.; Karsenty, A.; Drori, A.; Grobgeld, D.; Eisenberg, N. PV module power gain due to bifacial design. Preliminary experimental and simulation data. In Proceedings of the 35th IEEE Photovoltaic Specialists Conference, Honolulu, HI, USA, 20–25 June 2010; pp. 2171–2175.