TRANSACTIONS ON ELECTRICAL AND ELECTRONIC MATERIALS
Vol. 18, No. 1, pp. 30-34, February 25, 2017

Regular Paper

pISSN: 1229-7607 eISSN: 2092-7592
DOI: https://doi.org/10.4313/TEEM.2017.18.1.30
OAK Central: http://central.oak.go.kr

Performance Ratio of Crystalline Si and Triple Junction a-Si Thin Film Photovoltaic Modules for the Application to BIPVs

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Received December 23, 2016; Revised February 3, 2017; Accepted February 3, 2017

The building integrated photovoltaic system (BIPV) attracts attention with regard to the future of the photovoltaic (PV) industry. It is because one of the promising national and civilian projects in the country. Since land area is limited, there is considerable interest in BIPV systems with a variety of angles and shapes of PV panels. It is therefore expected to be one of the major fields for the PV industry in the future. Since the irradiation is different from each installation angle, the output can be predicted by the angles. This is critical for a PV system to be operated at maximum power and use an efficient design. The development characteristics of tilted angles based on data results obtained via long-term monitoring need to be analyzed. The ratio of the theoretically available and actual outputs is compared with the installation angles of each PV module to provide a suitable PV system for the user.

Keywords: Building integrated photovoltaic system (BIPV), Performance ratio (PR), Triple junction(T/J) a-Si thin-film photovoltaic modules, Crystalline Si photovoltaic modules

1. INTRODUCTION

The renewable energy industry has attracted global attention because of multiple factors such as depletion of existing resources, climate change caused by greenhouse gases, and high oil prices. Photovoltaic power generation, solar heat power generation, geothermy, and wind force are spotlighted as major engineering developments [1,2]. Photovoltaic (PV) power generation is an important part of the renewable energy field and is usually used as an infinite energy source. Crystalline silicon solar cells account for 95% of the PV market, and amorphous solar cells take for 5% [3,4]. The thin-film photovoltaic type of amorphous silicon(a-Si) solar cell has the lowest research cost, achieved by reducing the use of raw materials.

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Applications of thin-film PV include installations on the roofs of buildings or outer walls as conventional crystalline-substrate-type modules, and on windows as translucent modules [6,7]. These developments are expected to provide the PV industry with future advantages as building integrated photovoltaic systems (BIPVs) [2,4]. A BIPV used by a crystalline solar cell could be installed in the grid-connected PV plant to deal with peak load current. Although scientific interest into modules with crystalline silicon solar cells is progressing, research into BIPV system models that use thin-film PV is not common [5,8]. In the domestic market, the production and use of thin-film cells are not yet commercialized even with the development of thin-film PV modules supported by the government projects. The research and applications of transparent thin-film cells used in BIPVs starts to make initial study [9].

Therefore, in the study, crystalline silicon and T/J a-Si thin-film solar cells that are already commercialized are manufactured for building application models. The generation performance depending on each installation angle are monitored, and the reliability of the system is analyzed with the data obtained over the 3 years. The goal of this study is to use that data in a preliminary manner to improve BIPVs with T/J a-Si thin-film and crystalline Si solar cell modules.

2. EXPERIMENTS

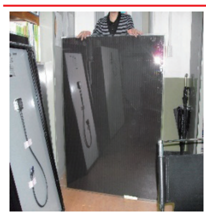
In this study, we compare and analyze the output values according to the angles of T/J a-Si thin-film solar modules and crystalline solar modules. After designing and construction, we process the data obtained from the long-term monitoring. Correlation between power generation characteristics and tilted angle are analyzed and solar radiation characteristics are analyzed depending on the tilted angle. The actual output value and the theoretical output value according to the amount of solar radiation were obtained for each module and compared each other using a performance ratio (PR).

2.1 Experimental field

Since T/J a-Si thin-film Si solar modules are not being produced, self-produced modules are used in this study. Single crystalline Si modules from the same company are used to eliminate environmental effects. The modules are installed on the rooftop of the building located in the middle of the Korean peninsula at a latitude of 37°. T/J a-Si thin-film solar modules are installed by connecting them in series using two 155 W modules for a total of 310 W. Crystalline solar modules are installed using 255 W modules. For the field test, each module of the T/J a-Si thin-film and crystalline types is installed at the angles of 0, 30, 60, and 90, as shown in Fig.1. The electrical characteristics and specifications for each module are shown in Table 1. For comparison, modules of less than 1 kW, single modules, T/J a-Si thin-film modules, and crystalline modules are installed together at the same angle and place. It would be very interesting to analyze the advantages of the angles 0, 30, 60, and 90 for a BIPV.

Fig. 1. Test field in the middle of korean peninsula at a latitude of 37°.

Table 1. Specifications of the T/J a-Si thin-film PV modules and crystalline modules.



	a-Si T/J thin-film
Module size	1,000×1,640 mm^2×2
P_{max}[W]	155 W
V_{oc} [V]	225 V
I_{sc} [A]	0.96 A
V_{mp} [V]	188.2 V
I_{mp} [A]	0.82 A
Efficiency of modules	11%

	c-Si
Module size	1,000×1,640 mm^2
P_{max}[W]	280 W
V_{oc} [V]	38.8 V
I_{sc} [A]	9.33 A
V_{mp} [V]	31.9 V
I_{mp} [A]	8.78 A
Efficiency of modules	17.1%

Table 2. Electrical characteristics of inverter periodic table of elements.

Manufacturer		Willings
Type		3 kW Inverter (UA-030)
Maximum voltage range	[V]	170~500
The maximum input current	[A]	16
Efficiency	[%]	94.5

Manufacturer		Hansol technics
Type		Micro inverter (HSPV-250)
Maximum voltage range	[V]	22~37
The maximum input current	[A]	9
Efficiency	[%]	93.7

Fundamentally, for the inverter, T/J a-Si thin-film solar modules have high open voltages owing to the high-energy band gap in the layers. T/J a-Si thin-film solar modules that consist of three PN junctions have higher open voltages ranging over 100 V compared with other conventional thin-film modules. Therefore, when a system of T/J a-Si thin-film modules utilizing a kilowatt scale is created, the open voltage must include the operating range of the inverter capacity assigned by domestic regulations.

A micro inverter is employed in each module of the crystalline type, and a 3 kW inverter is used in the T/J a-Si thin-film modules connected in series owing to the limited voltage of the micro inverter The inverter adopts a model with a transformer owing to the high open voltage of the T/J a-Si thin-film modules. On the other hand, crystalline modules are combined with an inverter having a power level of 3 kW. The electrical characteristics of the inverter are shown in Table 2.

The load of each component is monitored by connecting it to a real system under the same conditions for an actual operating power plant. Monitoring system is fabricated to collect a number of data by connecting sensors that measure multiple environmental parameters such as insolation, temperatures etc. The monitored average values are calculated using the average value for every five minutes, which is measured every five seconds. The measurement period is applied from January to September from the data. Fig ure 2 displays the output of 7 inverters and they are information on voltage, current, power, humidity, frequency and both the temperatures of environment and module.

Collectors applied to the monitoring system are ambient temperature sensor, precipitation sensor, humidity sensor, wind volume sensor, module temperature sensor, and inclined plane

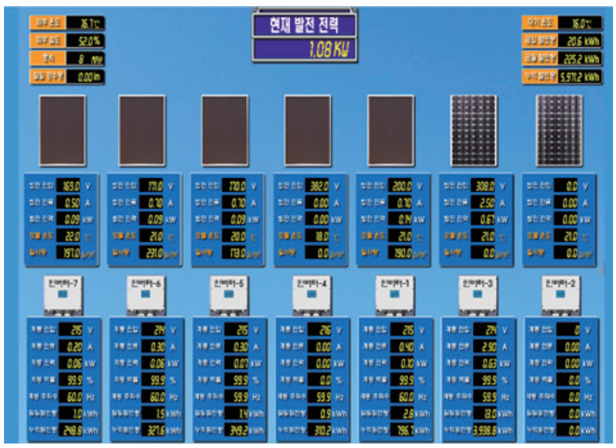


Fig. 2. Monitoring system installed on the roof of Konkuk University.

Fig. 3. The terminal box synthesized the measured value by each sensor.

insolation sensor. Among them, an inclined plane insolation sensor is installed in each module by each angle. In Fig. 3, the sensor consists of a system that sends measured values from each sensor in the terminal box besides the structure pillar to the main computer in place as close as possible to minimize data transmission errors.

2.2 Performance coefficient of performance ratio (PR)

In this study, the PR is adopted for analyzing the monitoring outcome [10]. The PR is the coefficient of performance on the PV system to analyze the monitoring data. This is the method that many researchers used to compare the performance of solar plants of various types in different environments. The PR is the proportion of theoretical generation performance of a PV system without loss in actual generation performance under a Standard Test Condition (STC). Specifically, PR is the ratio of the actual to theoretically possible energy output. PR does not represent the amount of generation power, because a system with high PR in low solar resource might produce less energy than a system with a low PR under high solar resource condition. This is widely used to evaluate PV plants around the world because it is largely independent on the orientation of the PV plant and the incident solar radiation [11-13]. It could be evaluated about the power generation performance loss of PV system or occurrence of problem. Depending on geographical location and season, a system could be evaluated to have very satisfactory power generation performance within the range above 0.7 of PR. If it is less than 0.7, it means that the loss factor which degrades the power generation performance is applied to the PV system. The photovoltaic system has high reliability when the value of PR is constant. Ideal annual values for the performance ratio PR factor are between 0.8 and 0.84.

The PR is given by

$$PR = \frac{\textit{Acual reading of plant output in kWh p.a}}{\textit{Calculated,nominal plant output in kWh p.a}} \quad (1)$$

The formula for the nominal plant output in kWh p.a. is the incident solar radiation at the generator surface of the PV plant multiplied by the relative efficiency of the PV plant modules and multiplied again by module area. The actual reading of the plant output in kWh p.a. is amount of the actual power generation

Thus, another expression of PR could be given by

$$PR = \frac{\textit{Actual plant output}\,[kwh]}{\textit{incident insolation}[\frac{kWh}{m^2}] \times \textit{modules area}[m^2] \times \textit{efficiency of the PV modules}} \quad (2)$$

The numerator of the PR is the rate of production in the electrical part. The denominator of the PR is the basic rate of production under light energy. The denominator indicates the number of times the light reaches the ground surface from solar radiation from the sun during a day under the STC condition. The performance ratio is a purely definition-based variable, which, under the influence of following factors, may even exceed value of 100%. Deviations in real operating conditions influence the performance ratio [10-16]. When the PR decreases moderately, this represents the PV system has less critical problems. It could be clearly identified from PR analysis that the system working even normally without any problems still has reliability issues [17]. Typical factors affecting the PR are module temperature, solar radiation and power dissipation of PV module under the shade and/or contamination. In this experiment, it is assumed that the module is not shaded and contaminated by the periodic cleaning.

3. RESULTS AND DISCUSSION

To establish a monitoring system, monthly average values recorded for 5 min of the total amount per day were used to analyze the overall electrical characteristics based on the results of the data collected for each module. In this paper, the performance of module system is then precisely analyzed and compared with actual data collected from January to September in 2015.

3.1 Evaluation of monthly generation performance

The solar radiation and power generation were evaluated among the factors affecting the PR value. It is quite well known that the PV plant generates the energy according to solar radiation. In order to compare the trends of solar radiation and power generation, the outputs are shown at a tilted angle of 60 degrees in Fig.4. From the graph, solar radiation versus power output results in a linear relation for the period measured.

Monthly solar radiations on a module at 30° and 60° are shown in Fig. 5. The installation angle of 30° shows lower value than that at 60° from January to March. Beginning on April, the insolation increased. The highest irradiated solar occurred on June and the lowest insolation occurred on January. On the other hand, the fact that a slope of 60° has a higher insolation than 30° from January to March is no longer valid. The highest solar radiation occurs on September and the lowest on January. The solar irradiation at 30° increases because the change in angle between the incidence angle and the normal sun's altitude is horizontal. The insolation at an angle of 60° is superior because the incidence angle and normal sun's altitude in winter are close to horizontal.

The monthly power outputs of each module are shown in Fig. 6 and Fig. 7 with different installation angles. The power output shows a similar inclination at 0° and 30° and has a similar trend at 60° and

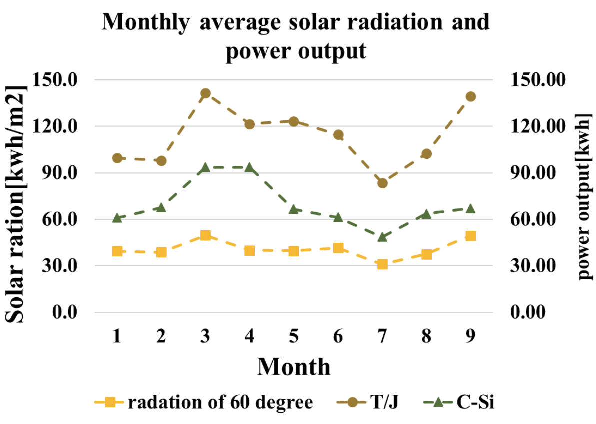


Fig. 4. Monthly average solar radiation and power output at 60 degrees.

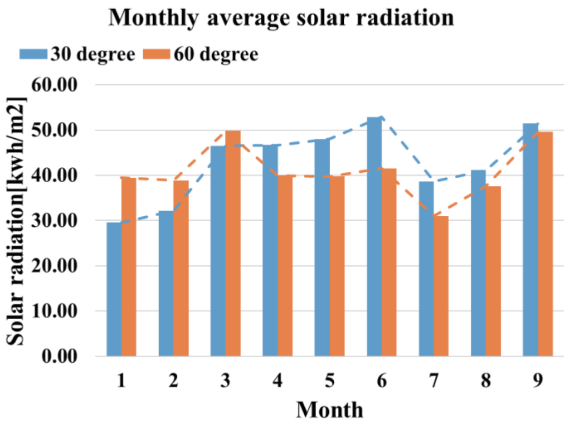


Fig. 5. Monthly average solar radiation according to angle.

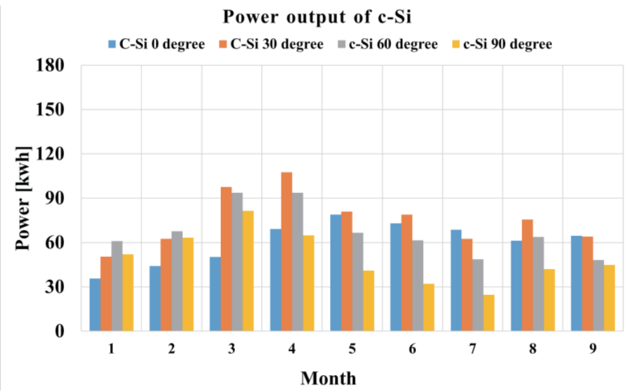


Fig. 6. Monthly average power output of single c-Si.

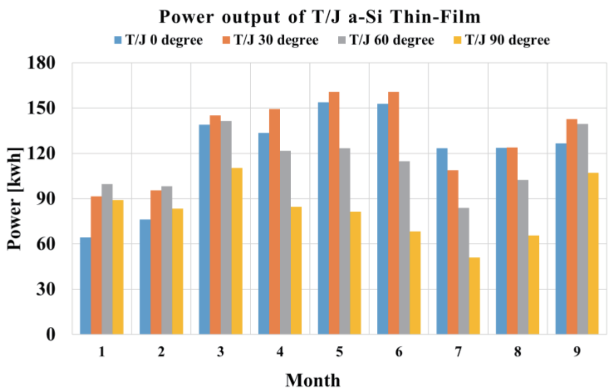


Fig. 7. Monthly average power output of a-Si T/J thin-film.

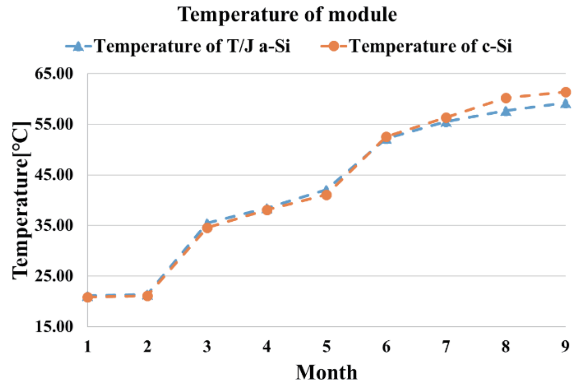


Fig. 8. Temperature of modules.

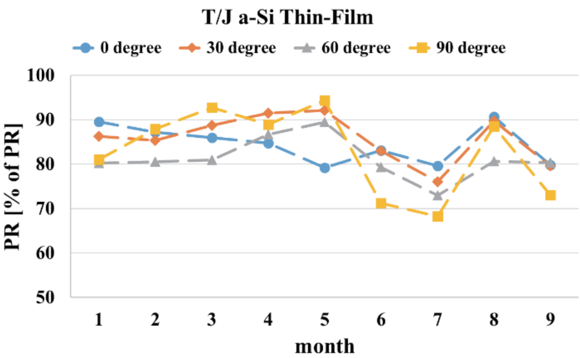


Fig. 9. The PR of T/J thin-film solar modules with different angles.

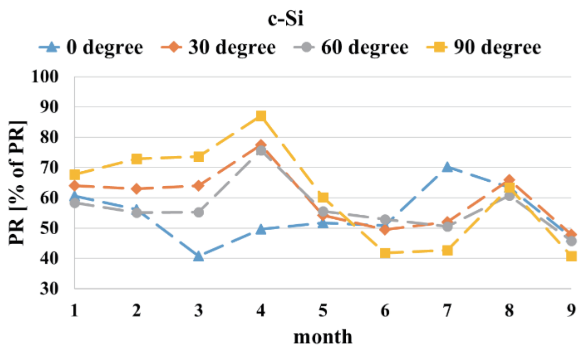


Fig. 10. The PR of crystalline solar modules with different angles.

90°for both solar modules. It is definitely because of the change of absorbable solar radiation on each module depending on the sun's altitude.

3.2 Evaluation of system performance ratio (PR)

As was explained before, one of the critical factors affecting the PR is the module temperature and the same assumption of periodic cleaning would be applied to this analysis for the limitation of the approach.

First, the temperature difference between the T/J thin film solar module and the crystalline silicon solar module is delicate. The PR(%) of the T/J thin film solar module stays within a stable range nearly 70 to 90 at all angles. In general, it tends to decrease from winter to summer due to the temperature.

On the other hand, crystalline silicon solar modules are not stable and tend to be jagged shown in Fig. 10. Their PR values are distributed below 70. The trend, however, results in a similar decrease for both T/J and c-Si solar modules from winter to summer. It is very important to note from the results that PR is very sensitive to the temperature and therefore shows very low values at high temperature especially in summer. The PR of T/J thin-film solar module is much higher than that of a c-Si solar module regardless of the installation angles and season partially due to the power dissipation of the module.

It is also very imperative to note from Fig. 9, that the module at 0° shows the highest PR in winter, the module at 90° the highest PR in spring, and the module at 30° the highest PR in summer. Similarly, crystalline solar modules have their highest PR at 30° in summer and at 90° in spring. This means that the system has superior PR

Table 3. The maximum and minimum PRs(%) and their differences with each module according to installation angles.

	T/J				C-Si			
	0°	30°	60°	90°	0°	30°	60°	90°
Max	90.7	92.1	89.4	94.4	70.2	77.5	75.7	87.1
Min	79.2	76.0	70.2	68.2	38.7	47.8	45.8	39.8
Diff	11.5	16.1	19.3	26.1	31.5	29.7	29.9	47.3

value depending on the angle and season.

There is another important factor from the variation of PR with angles from Table 3. From the table, maximum difference of PR for the c-Si module is as large as about 47%, while the one of a-Si T/J photovoltaic module is small to be 26.1%. It indicates that the PV system with a-Si T/J solar module has little variation in performance against seasonal changes. The small variation is expected to cause low degradation of the module, and therefore T/J photovoltaic system would be expected to show higher reliability which is perfect matching to desert condition.

BIPV systems are usually installed at 90° for the design perspectives. The variation of the PR at 90° of the T/J thin-film modules is smaller than that of the crystalline modules. In addition, it is also less than that of crystalline solar modules at all other angles. Since there are fewer PR changes in the solar module, this indicates that the system has high reliability. The graph represents the difference of minimum and maximum depending on each module showing. the most small difference values at 0 to 30° in both modules. So, both T/J thin-film solar modules and crystalline solar modules have high reliability at low installation angles. However, the PR of crystalline solar module has the value less than 0.7. Therefore, the consist of BIPV system using the T/J solar module has advantage on PR.

4. CONCLUSIONS

Since new renewable energy is generally increasing in use, the application of grid-connected BIPV systems is increasing in order to deal with peak power loads of buildings and to create added value. Accordingly, T/J a-Si thin-film modules are installed in windows using translucence modules, and are also installed on the roof of a building or outer wall as with conventional crystalline modules. This study compared and analyzed collected data through demonstration tests in the long term by designing a system suitable for various structures. The performance was compared, and the output of the modules was estimated.

Therefore, by monitoring the monthly average solar irradiation and output for T/J a-Si thin-film and crystalline modules, the generated amount changed depending on the solar radiation of the modules based on the altitude of the sun. Both T/J a-Si thin-film and crystalline modules exhibit superior the annual total power generation at 30°. It is notable to indicate that the installation angle should be decided based on the places where the modules are installed.

Compared with PR based on the installation angle of each module, an angle less than 30° has maximum point and could contribute to a system that has high reliability which could be applicable to floating PV system. Furthermore, T/J a-Si modules proved to have an advantage over crystalline modules in constructing a high-performance PR rating system for all angles.

ACKNOWLEDGMENT

This work was supported by the New & Renewable Energy Technology Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. (No. 20153010012060)

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