Study on Optimum Installation Angle of Photovoltaic Module Considering Sunlight Reflection

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Abstract. This paper shows photovoltaic (PV) power generation systems in Nagaoka University of Technology. On the basis of acquired data, installation angle of PV module and effect of sunlight reflection in winter are examined. Consequently, it is cleared that there is the optimum angle for each season, and the reflection against snow is very effective for the PV power generation. The angle usually depends on the latitude of location, but taking account of this effect, suitable installation angle changes. It implies that the optimum angle of all year round has flexibility. Actually, we can get about the same electric power when the angle is between 30 and 60 degrees.

Introduction

After the Great East Japan Earthquake, which occurred on 11th of March in 2011, discussions on renewable energy have increased significantly. In particular, photovoltaic (PV) power generation has been popularized rapidly in Japan.

It is important to discuss the optimum installation angle of PV module by experimental results, comparing with theory [1]. Generally speaking, PV system is unfavorable for snowy region, but this judgment is not always right. Here, the effect of sunlight reflection is examined in detail.

Photovoltaic Power Generation Systems and Specifications of Photovoltaic Modules

There are two kinds of PV power generation systems in Nagaoka University of Technology (NUT). One of them is installed on the roof of the library, and the other is attached on the outside wall of a hallway at Extreme Energy-Density Research Institute (EERI). These two PV systems and the specifications of PV modules are shown in Fig. 1 and Table 1.

While both the systems are facing south, the main differences between (a) and (b) are as follows; cell type, installation angle and peak output power (40kWp and 1.3kWp, respectively).

(a) PV system for the library (40kWp)

(b) PV system for EERI (1.3kWp)

Fig. 1 Photovoltaic (PV) power generation systems in Nagaoka University of Technology

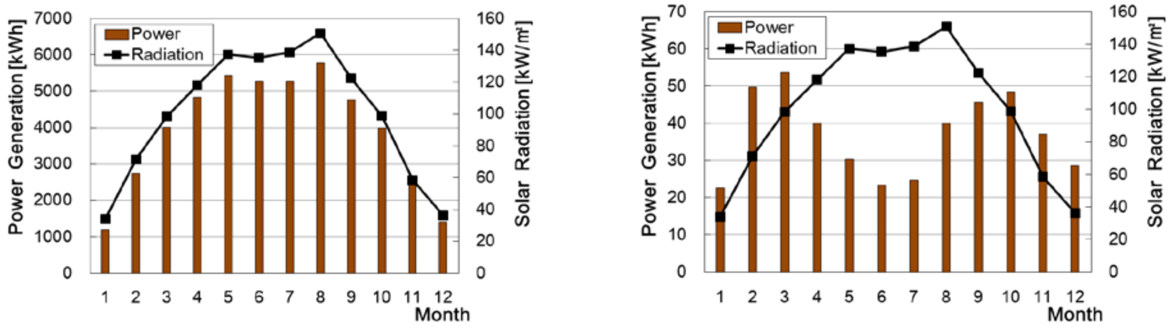
Table 1 Specifications of PV modules

	(a) Library	(b) EERI
Cell type	Poly-crystal silicon	Mono-crystal silicon
Peak output power [Wp]	208.4 (×192pcs.)	67 (×20pcs.)
Dimensions [mm]	1500×990×35	1200×440×35
Installation angle [degree]	30	90 (Vertical)

Power Generation of Two Photovoltaic Systems

Fig. 2 shows the power generation of two PV systems and solar radiation for each month. Electric power has been monitored by each device during 12 months from 2010 to 2012. These results indicate the average in three years. Besides, the solar radiation is measured at one point in NUT.

It is cleared that Fig. 2 (a) and (b) have different characteristics. The former is the typical data in Japan, because the summer season is from June to August and the winter season is from December to February. Nagaoka-city locates in snowfall area, so the generation in winter is less than the non-snow region. But, the latter shows that much power is gained in February and March (there are many fine days) when snow exists. It can be judged this result is due to the sunlight reflection against snow.



(a) PV system for the library (b) PV system for EERI

Fig. 2 Monthly power generation of two PV systems (average from 2010 to 2012)

Conditions for Experiments

Before discussing the effect of sunlight reflection, examining a common property of PV power generation is important. Fig. 3 illustrates a basic measurement system for current-voltage (I-V) and power-voltage (P-V) characteristics. The output current is measured by a shunt resistance. Here, the type (b) PV module (mono-crystal silicon, 67Wp) is used for every experiment.

The experiments were carried out for several kinds of installation angles (0, 15, 30, 45, 60, 75, 90 degrees). When the short current of PV module is measured, the load resistance is shorted electrically.

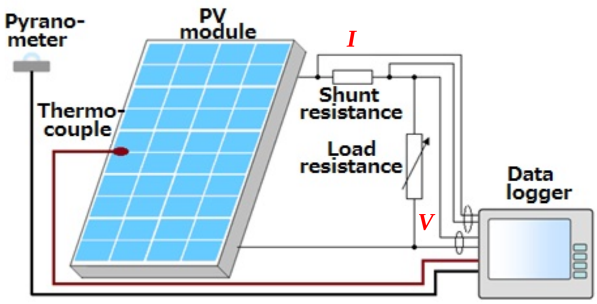
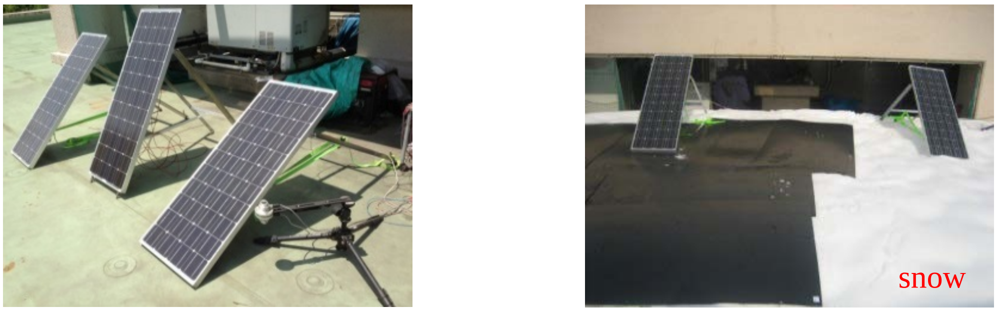


Fig. 3 Measurement system for PV module

Fig. 4 shows the setting of PV modules when the experiments were conducted. Fig. 4 (a) is for the ordinary setting in spring, summer and fall seasons. On the other hand, (b) is the setting in order to examine whether the sunlight reflection against snow affects the generation or not.



(a) Ordinary setting (except winter) (b) Examination of sunlight reflection (winter)

Fig. 4 Setting of PV modules for experiments

Experimental Results and Examinations

The maximum output power of *P-V* characteristics is defined “Pmax” (later, shown in Fig. 8). Fig. 5 indicates the Pmax which are acquired by the experiments for several installation angles on around the days of summer solstice and autumn equinox. Comparing with a theoretical curve in Fig. 6, which is derived from Cooper’s theory [2], the maximum points of the Pmax in Fig. 5 are almost the same.

Next, it is important to investigate the data for snowy season. Fig. 7 shows the short currents and the solar radiations throughout the day, which were observed in two fine days. Fig. 8 is the result of *P-V* characteristics. They are compared each other whether the sunlight reflection exists or not. From these figures, the effect of reflection against snow achieved about 15% at maximum point [3, 4].

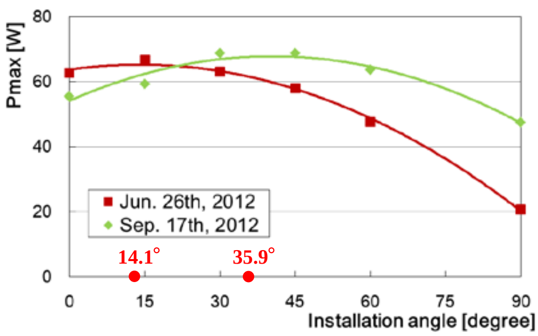


Fig. 5 Pmax when installation angle changes
(experiments in June and September)

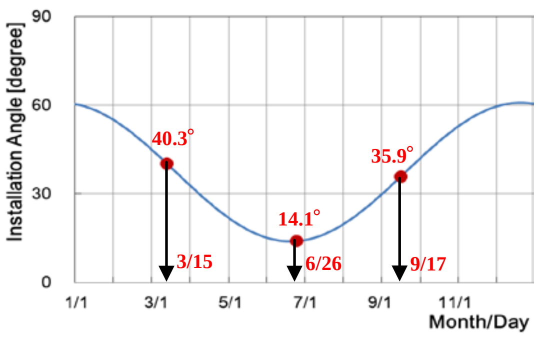


Fig. 6 Optimum installation angle
(theoretical data and date of experiments)

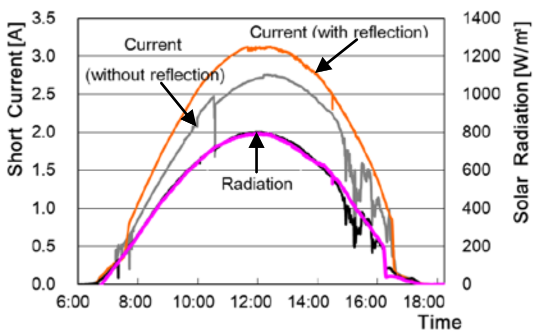


Fig. 7 Short current throughout the day
(examination of sunlight reflection)

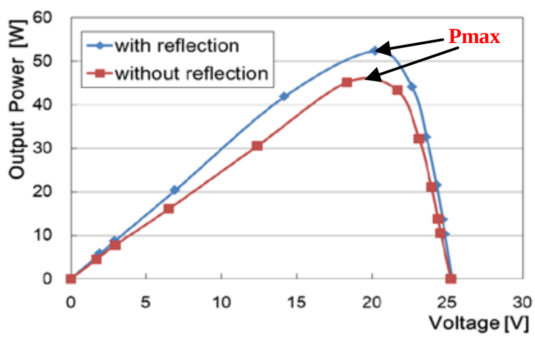


Fig. 8 *P-V* characteristics
(examination of sunlight reflection)

Fig. 9 shows the Pmax data on 15th of March (around the day of spring equinox); there is much snow on the ground in NUT. The experiments were carried out like Fig. 4 (b). In the case of considering the sunlight reflection against snow, the Pmax is larger than the non-reflection case. Especially, about 20% gain has gotten at 90 degrees of installation angle.

Total PV power generation of all year round considering the reflection effect is calculated and illustrated in Fig. 10. A measured value means the data of the PV system for the library. About the same generation is acquired from 30 to 60 degrees of installation angle (of course, the generation decreases at less than 30 degrees). This is an essential knowledge for the PV power generation.

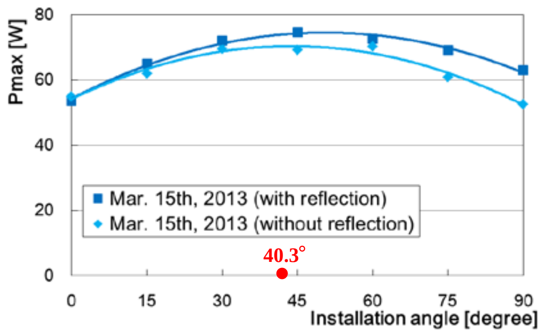


Fig. 9 Pmax when installation angle changes (examination of sunlight reflection)

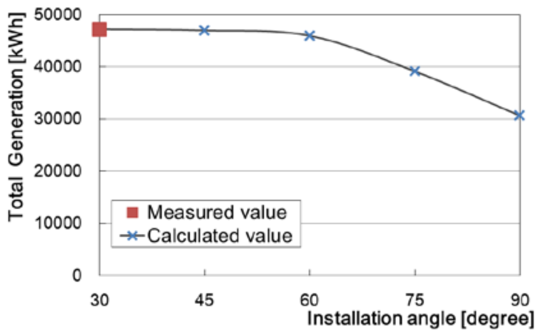


Fig. 10 Total generation of all year round (including sunlight reflection effect)

Summary

In this paper, we discussed the optimum installation angle of PV module and the effect of the sunlight reflection. As a result, it is confirmed that the theoretical and experimental optimum angles are almost the same. On the other hand, because the sunlight reflects on the snow surface, the power generation increases in winter or sometimes in spring season.

Consequently, the new knowledge for the installation of PV module in snowy region is obtained. It suggests that the PV power generation depends on the ground condition around PV modules, so it would be possible to invent the new type applications. That is, the PV systems are applicable to various conditions or terrains. Generally speaking in Japan, the best angle of PV module is around 30 degrees, but if the angle can be changed larger, snow slides down easily from the surface of PV modules. In addition, the vertical setting (90 degrees) is practical for the walls of buildings.

Acknowledgements

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