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Worldwide Performance Estimation of Silicon-based Photovoltaic Modules Using Meteorological Data

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Abstract

The worldwide yearly output energy of 4 types of silicon-based photovoltaic (PV) modules was estimated based on world meteorological data from 24 regions and actual outdoor performance data measured in Shiga Prefecture in Japan. As a result, multi-crystalline Si and amorphous Si PV modules showed high performance at high and low latitude. This is because that their performance depends mainly on temperature and spectrum, respectively. In contrast, tandem type thin-film Si PV modules were relatively independent from the ambient environment.

1. Introduction

The outdoor performance of photovoltaic (PV) modules depends on local environment where the PV modules are installed. The local environments in the world are different from each other. Therefore, the performance of same PV modules in different countries or cities shows a significant difference, and appropriate choices of module types in accordance with the installation environment are important for the efficient use of PV modules.

In this study, the yearly output energy of 4 types of silicon (Si) -based PV modules with the optimum tilt angle was estimated at 24 regions of 20 countries based on the past world meteorological data and the actual outdoor performance data of 4 types of PV modules at Kusatsu City in Shige Prefecture, Japan.

2. Analysis Data and Indexes

Meteorological Data

24 regions of 20 countries (15 and 9 regions from the northern and southern hemispheres, respectively) were selected as shown in Table I. The meteorological data of each region was collected by related state or international organizations and was provided through the U.S. Department of Energy [1]. The data includes global tilted irradiance (GTI), diffuse horizontal irradiance (DHI), beam normal irradiance (BNI) and ambient temperature etc. The typical yearly meteorological condition is described by 8,760 hourly data (365days × 24hours).

PV Performance Data

The actual outdoor performance data of all 4 types of PV modules [multi crystalline Si (mc-Si), amorphous Si (a-Si), a-Si/a-SiGe/a-SiGe three-stack, and a-Si/micro crystalline Si tandem] was obtained with a PV system installed at Kusatsu City, Shiga Prefecture, Japan (Lat. 34°58'N, Long. 135°57'E) facing due south with a tile angle of 15.3°. At the same time, GTI, solar spectra, module temperature (T_{mod}) and ambient temperature were measured under the same exposure condition.

Two indexes, PR (performance ratio [%]) as an index of the outdoor performance of PV modules [2], and APE (average photon energy [eV]) as an index of the solar spectral irradiance distribution [3], were used.

Table I Analysis regions (24 points).

Latitude	City/ Country	Latitude	City/ Country
0°15′ S	Quito/ ECU	19°12′ N	Mumbai/ IND
0°68′ S	Gan Island/ MDV	23°97′ N	Aswan/ EGY
1°32′ S	Nairobi/ KEN	25°80′ N	Miami/ USA
12°40′ S	Darwin/ AUS	31°40′ N	Shanghai/ CHN
15°87′ S	Brasilia/ BRA	31°57′ N	Kagoshima/ JPN
23°43′ S	Antofagasta/ CHL	34°78′ N	Osaka/ JPN
33°98′ S	Cape Town/ ZAF	36°83′ N	Tunis/ TUN
41°30′ S	Wellington/ NZL	39°80′ N	Beijing/ CHN
53°00′ S	Punta Arenas/ CHL	40°78′ N	New York/ USA
3°12′ N	Kuala Lumpur/ MYS	49°18′ N	Vancouver/ CAN
5°60′ N	Accra/ GHA	51°15′ N	London/ GBR
8°98′ N	Addis Ababa/ ETH	52°47′ N	Berlin/ DEU

3. Analysis Procedure

Fig. 1 shows the analysis procedure. First, the analysis of environment where PV modules were installed was conducted. The optimum tilt angle and GTI in 24 regions were calculated with System Advisor Model (SAM) [4]. Besides, APE and T_{mod} were estimated with approximate calculations [5]. APE was calculated from GTI and Air Mass (AM), and T_{mod} was calculated from GTI and T_{amb}. Then, contour maps of GTI for each PV module as a function of APE and T_{mod} were plotted as shown in Fig. 1 (a).

Next, the analysis of outdoor performance of PV modules was conducted. Contour maps of PR for each PV module as a function of APE and T_{mod} were plotted based on the two years data from Jan. 2010 to Dec. 2011 as shown in Fig 1 (b).

Finally, the yearly output energy of each PV module in each region was estimated by multiplying the GTI and PR contour maps. Moreover, the yearly PR was calculated by dividing the estimated yearly total energy by the yearly total GTI.

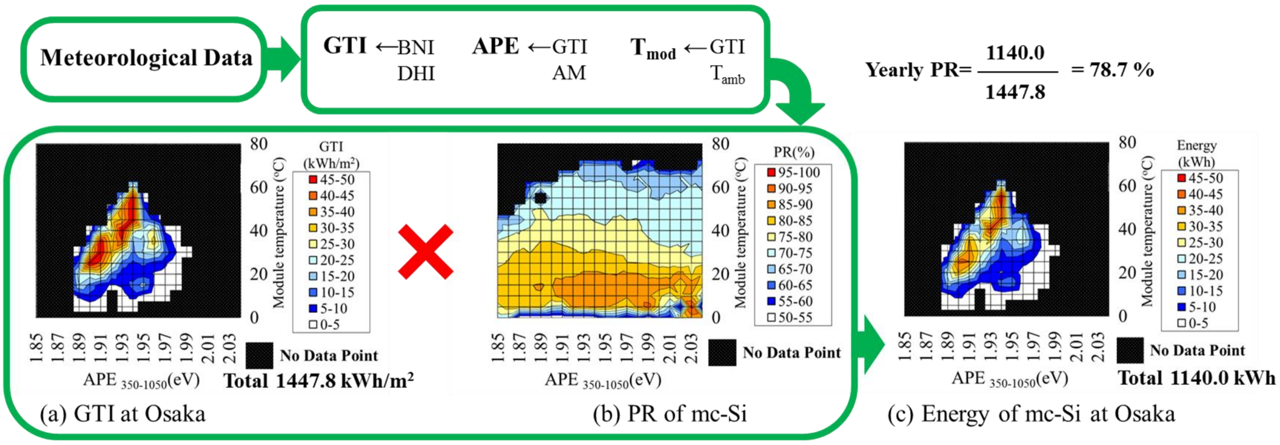
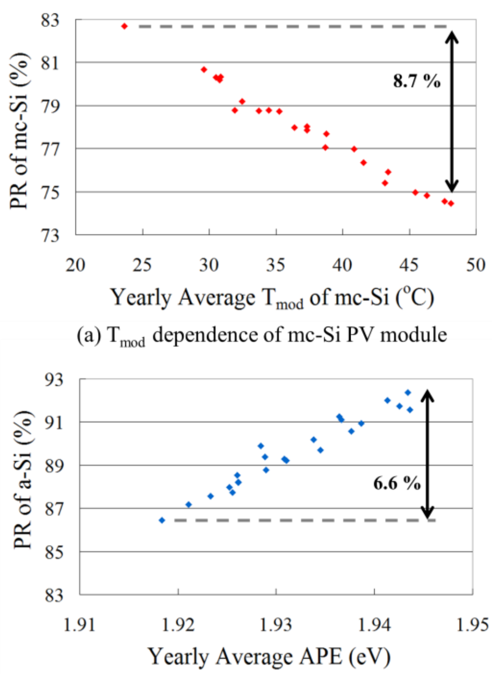


Fig. 1 Worldwide energy estimation using meteorological data.

4. Results and Discussion

The yearly output energy of 4 types of the Si-based PV modules in 24 regions was estimated. The PR of the mc-Si and a-Si PV modules differs substantially according to regions. Basically, the PR of the mc-Si PV modules was higher at high latitudes, but that of the a-Si was higher at low latitudes. It was caused by the facts that the performance of the mc-Si and a-Si PV modules mainly depends on T_{mod} and APE, respectively, as shown in Fig. 2, and that T_{mod} and APE are high at low latitudes. The largest PR difference between the regions for the mc-Si PV module was 8.7 % (Fig. 2(a)), and that for the a-Si PV module was 6.6 % (Fig. 2(b)). In contrast, the PR of the tandem type thin-film Si PV modules was roughly similar irrespective of the regions. The PR differences between the regions for the tandem type thin-film Si PV modules were 1.0~1.5 %.



(a) T_{mod} dependence of mc-Si PV module

(b) APE dependence of a-Si PV module

Fig. 2 Environmental dependence of mc-Si and a-Si PV modules.

5. Conclusions

The yearly output energy of the 4 types PV modules with the optimum tilt angle was estimated based on the two types of data: the world meteorological data, and the actual outdoor performance data for the PV modules at Kusatsu. The mc-Si PV module generated energy efficiently at high latitudes because the performance of mc-Si PV modules was high at low T_{mod}. Meanwhile, the a-Si PV module generated energy efficiently at low latitudes because the performance of a-Si PV modules was high at high APE. In contrast, the performance of the tandem type thin-film Si PV modules was comparatively independent from the T_{mod} and APE. Further study is needed to demonstrate the optimum choice of PV modules for each region in the world.

Acknowledgements

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