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# Seasonal variation analysis of the outdoor performance of amorphous Si photovoltaic modules using the contour map

Y. Nakada, S. Fukushige, T. Minemoto *, H. Takakura

*College of Science and Engineering, Ritsumeikan University, 1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, Japan*

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ABSTRACT

The effects of module temperature ($T_{mod}$) and spectral irradiance distribution on the outdoor performance of amorphous Si (a-Si) photovoltaic (PV) modules were investigated using contour maps. Compared to PV modules based on crystalline Si, such as single-crystalline Si (sc-Si) and multicrystalline Si, a-Si PV modules exhibit complex behavior with seasonal variation. In this study, we statistically analyzed the outdoor performance of a-Si and sc-Si PV modules. The influence of environmental factors on outdoor performance of a-Si PV modules was analyzed for two seasons, spring and autumn, in which the data periods had nearly the same average $T_{mod}$ and integrated irradiation. The outdoor performance of the a-Si PV module depends on both temperature history and light-induced degradation.



## 1. Introduction

The outdoor performance of photovoltaic (PV) modules is influenced by environmental conditions such as rain, ambient temperature, and wind. To enable more widespread deployment of PV modules, it is important to analyze the influences of environmental factors on outdoor performance of PV modules. Among these environmental factors, incident irradiance strongly affects the outdoor performance of PV modules. In addition, the outdoor performance of crystalline Si PV modules, such as single-crystalline Si (sc-Si) and multicrystalline Si, are affected by module temperature ($T_{mod}$). Unlike crystalline Si PV modules, amorphous Si (a-Si) PV modules are affected by both $T_{mod}$ and spectral irradiance distribution. The performance of a-Si PV modules improves with increasing $T_{mod}$ due to annealing effect [1], and the spectral sensitivity of a-Si PV modules is high in the short wavelength region. These effects combine to make the outdoor performance of a-Si PV modules more complicated than that of crystalline PV modules. In this study, we compare the outdoor performance of sc-Si and a-Si PV modules, and investigate the effects of temperature history on a-Si PV modules.

## 2. Experimental

sc-Si and a-Si PV systems with capacities 5 and 2 kW, respectively, were installed at Kusatsu city in August 1998, facing due south with a tilt angle of 15.3°. Daily average irradiation was 3.9 kWh/m$^2$. This was comparable to the daily average irradiation of Japan's main island. The system was connected to a utility grid through an inverter. Direct-current output and output voltage were measured once per minute. The solar spectra in the wavelength range 350–1050 nm were also recorded once per minute by a spectro-radiometer (MS700, EKO) installed under the same exposure conditions as the PV modules. The $T_{mod}$ on the back side of the PV modules were also measured every minute.

To analyze the effect of environmental factors on the output performance of PV modules, contour maps of the performance ratio (PR) as a function of average photon energy (APE) and $T_{mod}$ were created. The PR indicates PV module efficiency with no effect from the irradiance intensity, which is defined as the actual output energy divided by the nominal output energy calculated from the solar module performance under standard test condition (STC: 1 kW/m$^2$, AM1.5 standard solar spectrum). Only irradiance values above 0.2 kW/m$^2$ were used, and the lower performance of PV modules at low irradiance was omitted. In order to analyze the effect of the solar spectrum, the index for the spectral irradiance distribution of APE, with units of eV [2], was used. APE is defined by the following equation:

$$\mathrm{APE} = \frac{\int_a^b E(\lambda)d\lambda}{q\int_a^b \Phi(\lambda)d\lambda} \quad (1)$$

where $q$ is the electronic charge, $E$ is the spectral irradiance, and $\Phi$ is the spectral photon flux density. APE is calculated from measurements of spectral irradiance by dividing irradiation by integrated photon flux density, yielding the average energy per

* Corresponding author. Tel./fax: +81 77 561 3065.
*E-mail address:* minemoto@se.ritsumei.ac.jp (T. Minemoto).

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photon. In this study, $a$ and $b$ were set to 350 and 1050 nm, respectively. The APE value for the standard solar spectrum calculated from this range is 1.88 eV [3,4], while a spectrum with an APE of 1.93 eV is the most frequent spectrum in Kusatsu city [5]. The method employed to create contour maps is described elsewhere [5]. To create our contour maps, field test data from January 1, 2004 to December 31, 2005 (2 years) were used. The total number of data points was approximately 2,20,000.

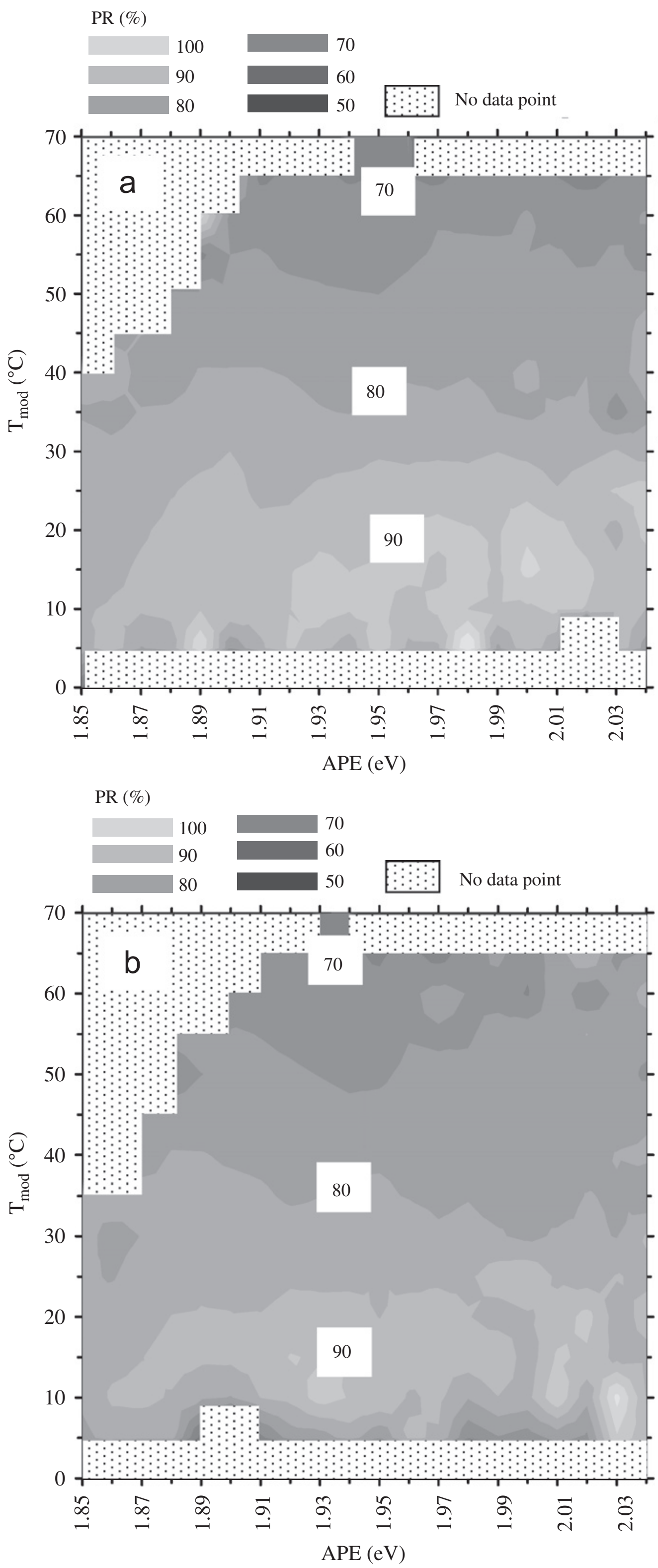


Fig. 1. Contour maps of PR for the sc-Si PV module as a function of APE and $T_{mod}$ in years (a) 2004 and (b) 2005.

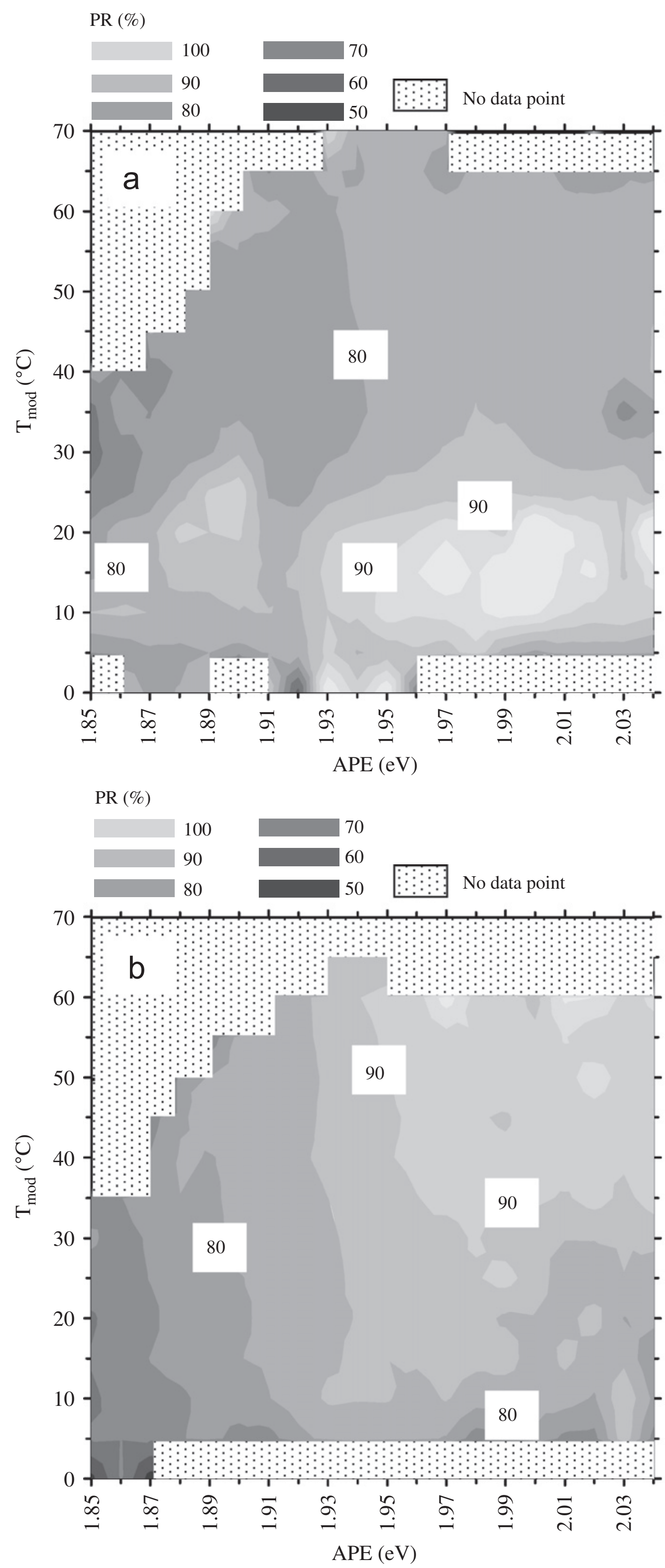


Fig. 2. Contour maps of PR for a-Si PV module as a function of APE and $T_{mod}$ in years (a) 2004 and (b) 2005.