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Impact of spectral irradiance distribution on the outdoor performance of photovoltaic system under Thai climatic conditions

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ABSTRACT

This paper presents the effects of spectral irradiance distribution on the performance of polycrystalline (p-Si) and amorphous silicon (a-Si) photovoltaic (PV) modules under Thai climatic conditions. The annual outdoor solar spectrum measurements bouncing on the PV modules installed at Energy Park, School of Renewable Energy Technology (SERT), Naresuan University, Thailand revealed that the average photon energy (APE) of total incident solar irradiance was 50% higher than that at standard test conditions. The results show that the power output of a-Si PV module mainly depends on spectrum distribution. In contrast, the power output of p-Si is not sensitive to spectrum distribution. Because of the different spectrum response of p-Si and a-Si PV modules, the actual irradiance spectrum data of each location under real working conditions are necessary for optimizing PV design.

1. Introduction

PV modules directly convert solar energy into electricity by photovoltaic effect. Presently, PV technology is widely used for various types of applications. PV module output power is generally calculated at standard test conditions (STC), which corresponds to1 kW/m^2 of solar irradiance, 25 °C module temperature, and 1.5 air mass. However, in a real system installation situation, those conditions are rarely met [1–3,11].

The outputs of PV modules operating under real working conditions are influenced by two main factors: spectral irradiance distribution [1–4] and module temperature. When the photon strikes on the solar cell, it can produce electrical energy if the photon energy is greater than or equal to an energy band gap of the material. Each solar cell has a different energy band gap; for example, amorphous silicon solar cell has an energy band gap of 1.7 eV [5] whereas a polycrystalline silicon solar cell has 1.1 eV [6]. Solar cells have different spectrum responses at different ranges of wavelength. For example, the spectrum responses of a-Si and p-Si lie between 305–820 nm and 305–1200 nm, respectively. Although the spectral response of a-Si is narrower than p-Si, the spectral irradiance distribution has a higher energy response with a-Si [2]. Spectrum distribution of solar irradiance is an important factor for finding average photon energy (APE) that strikes with a solar cell. Generally, APE is an important parameter used to estimate the energy of photons. For a photon that has higher energy than the band gap of a solar cell, the electron in a solar cell can be excited from a ground state, thus generating free electrons. In other words, if APE is higher than the solar cell band gap, the solar cell can generate free electrons. In this paper, the outdoor performances of PV arrays were compared with spectral irradiance distribution in hot climatic condition.

2. Experimental set up

A 10 kWp PV power system was installed at the School of Renewable Energy Technology (SERT), Naresuan University (latitude 16°49′N, longitude 100°15′E). The system consists of three types of arrays using three different PV technologies, namely Heterojunction with Intrinsic Thin Layer (HIT), amorphous silicon (a-Si), and polycrystalline silicon (p-Si). However, this paper considers only the a-Si and p-Si modules, which have power capacities of 3.67 kWp and 3.60 kWp, respectively. The PV modules face to the south with a tilt angle of 16°. The spectrum irradiance, PV module power outputs, module temperature, and solar irradiation were all measured at intervals of five minutes from January 2008 to December 2008. To analyze the spectral irradiance distribution, solar spectra were recorded at a wavelength range of 350–1050 nm by using a spectro-radiometer (MS720, EKO). Solar irradiance was measured by a pyranometer (MS-601, EKO), and the characteristic

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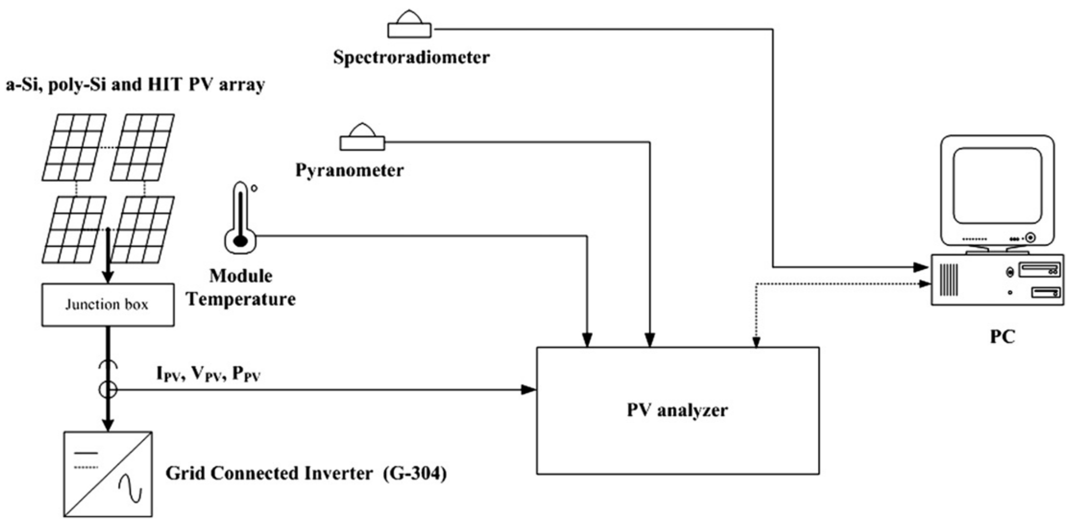

Fig. 1. Data measurement points of the experiment.

curves of PV arrays were measured by a PV analyzer (PVA01982, Kernel) connected with pyranometer and thermocouple to measure solar irradiation and module temperature as shown in Fig. 1.

The characteristics were found useful for the spectral irradiance distribution with a simple and device-independent index, APE [7]. APE is defined as the total irradiance contained in the spectrum divided by the total photon number flux density [8,9] as shown in Eq. (1).

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

where q is the electronic charge (Coulomb), E is the spectral irradiance ($\mathrm{W\,m^{-2}\,nm^{-1}}$), and Φ is the spectral photon flux density ($\mathrm{photon\,m^{-2}\,s^{-1}\,nm^{-1}}$). In this study, a and b are set to be 350 nm and 1050 nm, respectively.

The APE of each spectrum was calculated from the wavelength range of 350–1050 nm of the measured spectrum. The APE value for the AM 1.5 standard solar spectrum calculated at wavelength range of 350–1050 nm is 1.878 eV.

To characterize the outdoor performance of the PV modules, field output factor (FOF) was used. FOF is defined as the actual power output of PV module divided by the nominal power output of PV module calculated from the PV module performance under standard test conditions as shown in Eq. (2). FOF indicates PV system efficiency without the effect of the irradiance intensity [10]. The effect of APE on the FOF of the a-Si and the p-Si PV modules were evaluated.

$$\mathrm{FOF}(-) = \frac{\text{actual power(kW)}}{\text{nominal power output(kW)}} \tag{2}$$

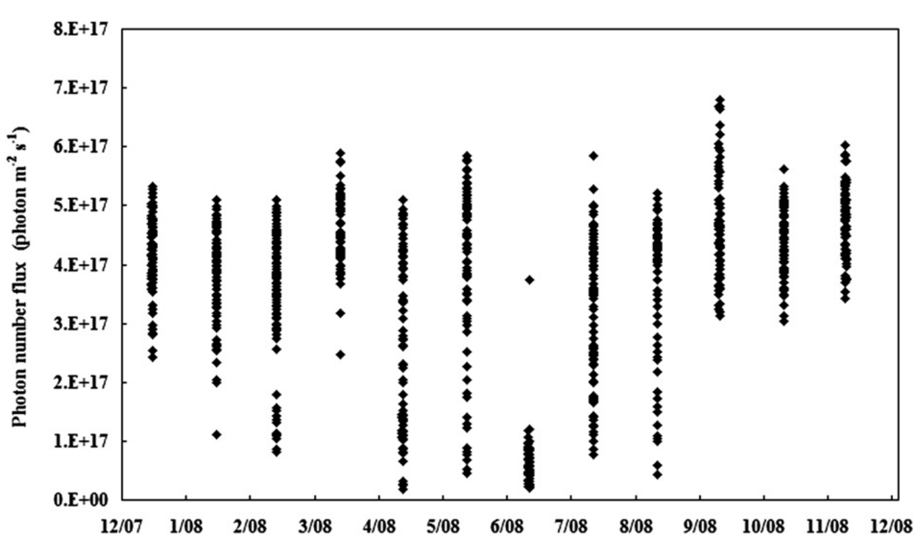

Fig. 2. Annual average photon number flux at Naresuan University, Thailand.