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The effect of average photon energy and module temperature on performance of photovoltaic module under Thailand's climate condition

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Abstract

This article present the effect of average photon energy and module temperature on performance of amorphous silicon (a-Si), polycrystalline (p-Si) and hetero-junction intrinsic thin layer (HIT) photovoltaic (PV) modules under Thailand climatic condition which located at the equator zone. The outdoor solar irradiance distribution measurements on the PV array installed at Energy Park, School of Renewable Energy Technology (SERT), Naresuan University, Thailand revealed that the field output factor of the poly-Si and HIT PV modules depended almost only on a module temperature, while that of the a-Si ones mainly depended on APE. The behaviors were reasonable considering from the operating mechanisms of the PV modules. These results demonstrate that APE is a reasonable and useful index to describe the spectral irradiance distribution for evaluating the performance of PV modules.

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Keywords: Average photon energy, Module temperature, Performance

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1. INTRODUCTION

Photovoltaic (PV) modules straightly transform solar energy into electricity by photovoltaic effect. PV module output power is generally calculated at standard test conditions (STC), which corresponds to1000 W/m2 of solar irradiance, 25oC module temperature, and 1.5 air mass. However, in a real system installation situation, those conditions are rarely met. The outputs of PV modules operating under real working conditions are influenced by two main factors: spectral irradiance distribution [1-9] and module temperature. Factor variables that contribute to the performance of solar cells are different in each area and the important considerations applied in each area. As well as to the system or the number of solar panels to be used in each area is the light intensity and temperature. Power is directly proportional to the intensity of light means that when the intensity of light. Current from solar cells will be higher as the voltage or volt hardly varies according to the intensity of light. In this paper, the effects of average photon energy and module temperature on performance of PV arrays were compared.

2. EXPERIMENT SET UP

The 10 kWp PV power station was installed at School of Renewable Energy Technology (SERT) north latitude 16o49', east longitude100o15'. The PV array consists of three different types of PV technology as amorphous silicon (a-Si), polycrystalline silicon (p-Si), and Heterojunction with Intrinsic Thin Layer (HIT) which have power capacities of 3.67 kWp, 3.60 kWp and 2.88 kWp, respectively And the supporting structures of all were installed with an inclination angle of 16 degrees face to south as shown in Fig.1

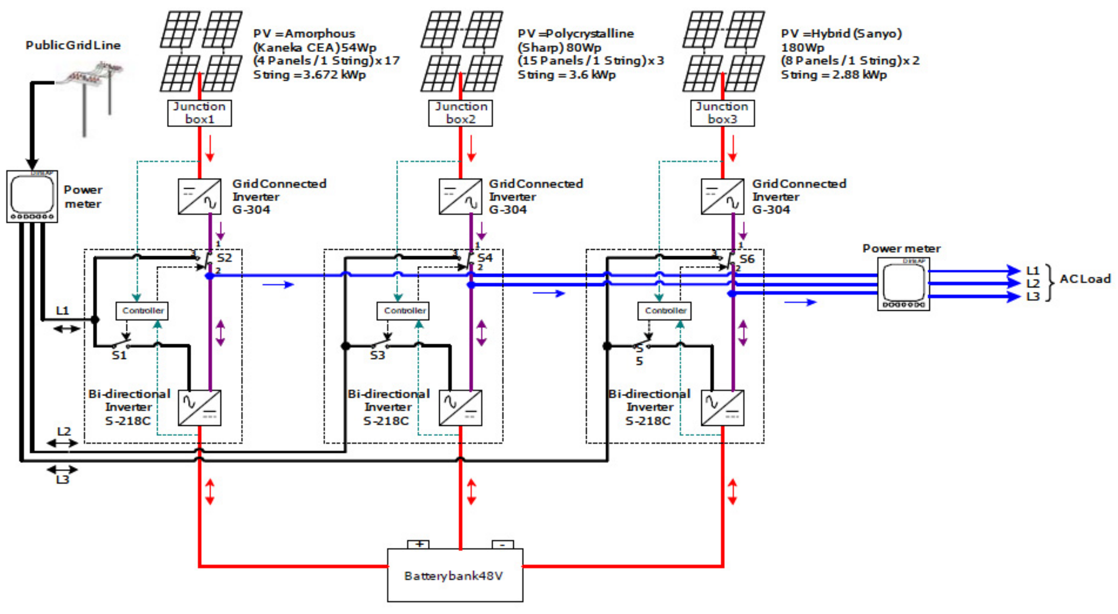

Fig. 1. Schematic diagram of 10 kWp PV power station

The characteristic were found useful for the spectral irradiance distribution with a simple and device-independent index, average photon energy (APE) [2-5]. APE is determine as the total irradiance contained in the spectrum divided by the total photon flux density [5]. The APE of each spectrum is 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.

3. DATA COLLECTION

Measured the data of spectral irradiance, power outputs of PV modules, module temperature and solar radiation at interval of five minutes. To analyze the spectral irradiance distribution, solar spectra with the wavelength range of 350–1050 nm were recorded every 5 minute by spectro-radiometer (MS720, EKO). Solar irradiance was measured by pyranometer (MS-601, EKO). The characteristic curves of PV array were measured by PV analyzer (PVA01982, Kernel) and it was connected with pyranometer and thermocouple to measure solar irradiation and module temperature.

In another words, APE is defined as the integrated irradiance divided by the integrated flux density, which yields the average energy per photon [6]

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

Where, q is the electronic charge, E is the spectral irradiance, and is the spectral photon flux density. In this study, a and b are set to be 350 nm and1050 nm, respectively.

To characterize the outdoor performance of the PV modules, field output factor (FOF) is used. FOF is determine 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 (1 kW/m2, AM 1.5 standard solar spectrum and 25 degree centigrade module temperature). FOF specific to PV system efficiency without the effect of the irradiance intensity [7-15]. The annual measurement data of spectral irradiance and power output of PV module from January 2008 through December 2009 were used. The effect of APE on the FOF of the a-Si, the p-Si and the HIT PV module was evaluated.

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

4. RESULTS AND DISCUSSIONS

The average photon energy has an effect to power output of PV. APE is an index that indicates a spectral irradiance distribution. APE is calculated from measurements of spectral irradiance by dividing the integrated irradiance by the integrated photon flux density, yielding the average energy per photon.

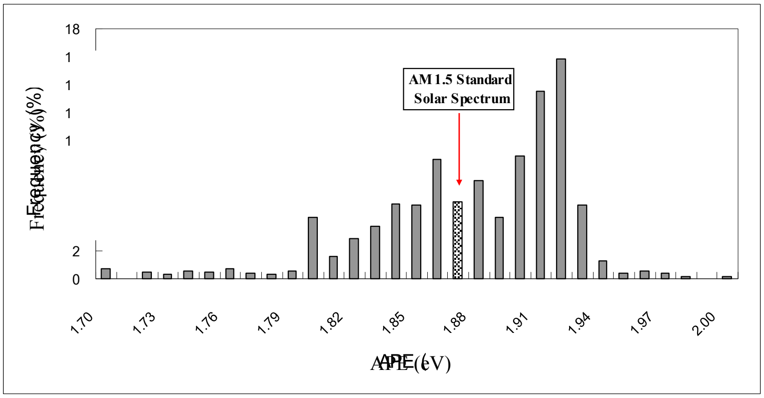

Fig. 2. Annual collected solar irradiation and APE measured.

The annual spectrum measurements revealed that the annual irradiance of APE had the peak at 1.92–1.93 eV which was a 0.04–0.05 eV greater than that calculated from the AM1.5 standard solar spectrum (1.88 eV). Also, more than 95% of the whole spectra were blue rich compared to the standard spectrum. The measurements confirmed that the APE where the maximum outputs were obtained ranged between 1.92 and 1.93 eV, which well corresponded to the peak of the APE histogram of the annual total irradiance. These results indicate that the actual irradiance spectrum data (not standard spectrum) is important for the optimization of performance of photovoltaic module.

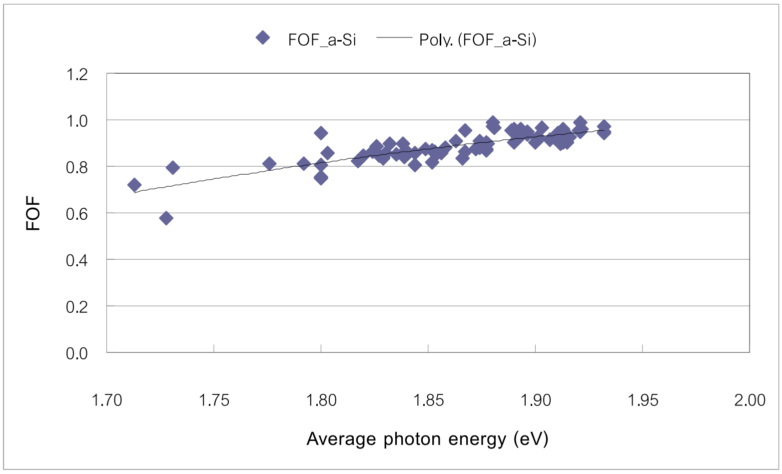

Fig. 3. Impact of APE on FOF of a-Si PV module

Spectral irradiance distribution used to calculate APE value from the wavelength range of 350-1050 nm, which effects on PV performance, as showed in Figure 3. These relationships between the field output factors of a-Si PV module were found to have an average FOF of 0.778. The maximum frequencies of APE that gave the maximum outputs were obtained in the range 1.84-1.94 eV, and the FOF was found to be directly proportional to APE. In case of a-Si, FOF is strongly depended on APE which was found to be increasing with increase in FOF which FOF was found to be directly proportional to APE.

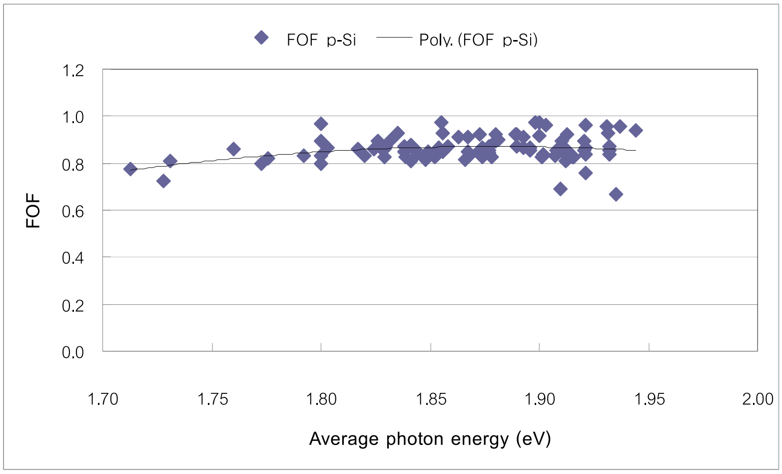

Fig. 4. Impact of APE on FOF of p-Si PV module

Figure 4 shows the relationships between the field output factors of p-Si PV module was found to have an average FOF of 0.802. The maximum frequencies of APE that gave the maximum outputs which were obtained in the range 1.84-1.94 eV, and the FOF was found to be directly proportional to APE. In case of poly-Si, FOF is not strongly depended on APE.

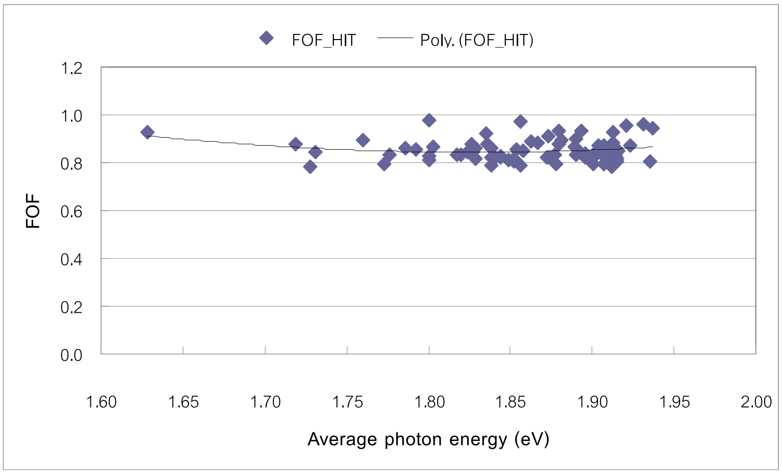

Fig. 5. Impact of APE on FOF of HIT-Si PV module.

Figure 5 shows the relationships between the field output factors of HIT-Si PV module was found to have an average FOF of 0.645. The maximum frequencies of APE that gave the maximum outputs which were obtained in the range 1.84-1.94 eV, and the FOF was found to be directly proportional to APE. In case of HIT, FOF is not strongly depended on APE was found to be decreasing with decrease in FOF. The figure 34 -36 above, using linear regression, these relationships are shown in Equation 4.1, 4.2 and 4.3 for a-Si, p-Si and HIT-Si respectively.

$$FOF = - 7.27 + 7.69APE - 1.78APE^2$$
$$FOF = - 12.09 + 13.8APE - 3.67APE^2$$
$$FOF = 6.67 - 6.38APE - 1.675APE^2$$

In the other hand this research, analyzing how both module temperature and APE affects FOF is a paramount importance for further understanding the effect of spectral variation. Figure 6, 7, and 8 illustrate the variation of FOF with both APE and module temperature of a-Si, p-Si and HIT-Si, respectively.

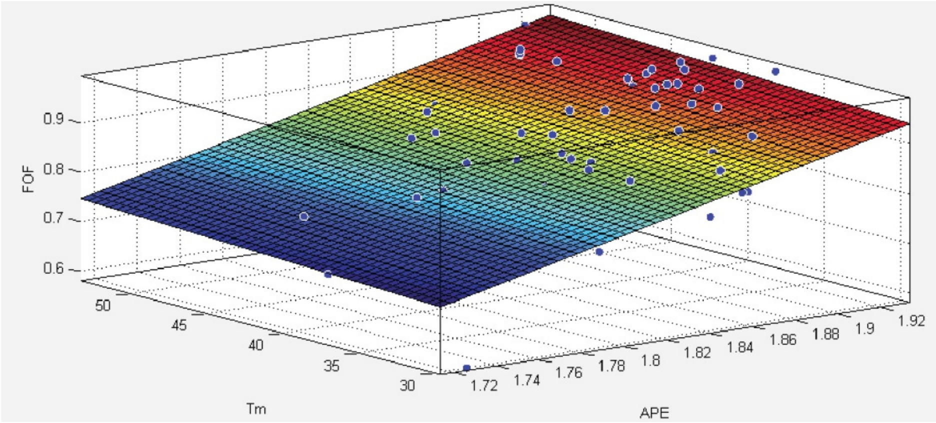

Fig. 6. Impact of APE and module temperature on FOF of a-Si PV module

Notably from Figure 37 is showed that the APE has directly effects to FOF of a-Si PV array. But the temperature was not more effects to FOF of a-Si. The maximum FOF occurs at 1.94 APE and 55oC module temperature as shows in the dark red colour. And the dark blue colour shows the minimum value of FOF at 1.70 APE and 30oC.

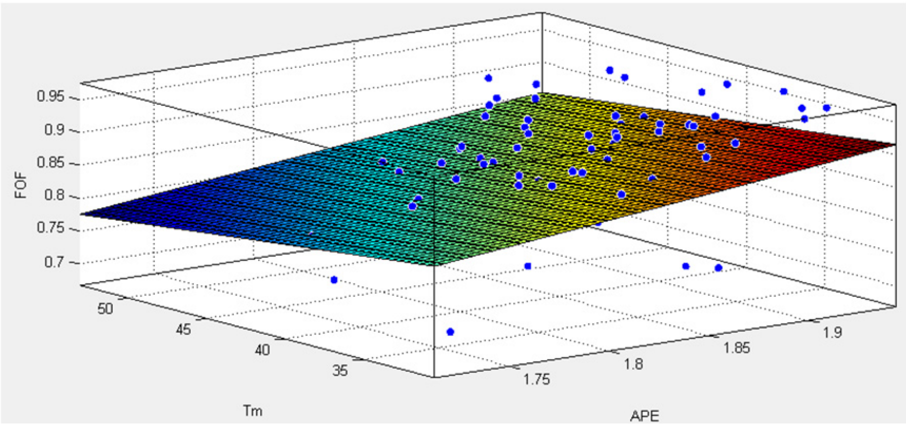

Fig. 7. Impact of APE and module temperature on FOF of p-Si PV module

Notably from Figure 38 is showed that the APE and module have directly effects to FOF of p-Si PV array. The maximum FOF occurs at 1.95 APE and 30oC module temperature as shows in the dark red colour. And the dark blue colour shows the minimum value of FOF at 1.70 APE and 55oC.

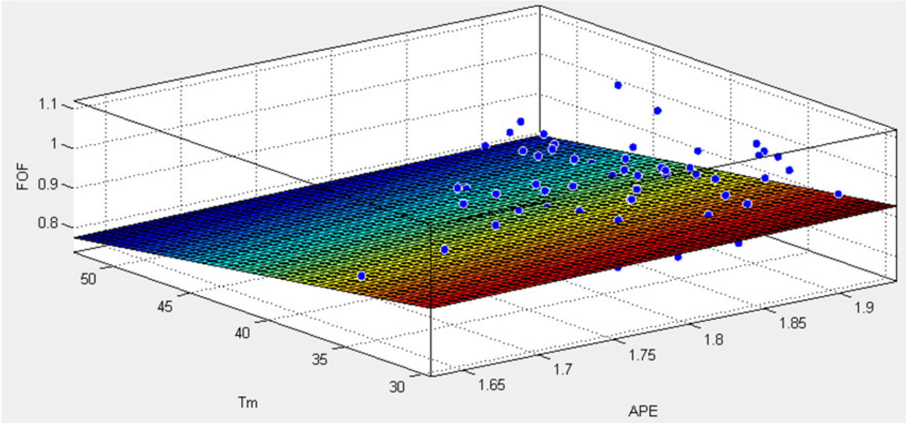

Fig. 8. Impact of APE and module temperature on FOF of HIT PV module

Notably from Figure 39 is showed that the module has directly effects to FOF of HIT-Si PV array. But the APE was not more effects to FOF of HIT-Si because the spectra response of HIT is cover range from 350 nm–1150 nm. The maximum FOF occurs at 1.95 APE and 30^{o}C module temperature as shows in the dark red colour. And the dark blue colour shows the minimum value of FOF at 1.70 APE and 55^{o}C.

5. CONCLUSION

In conclusion, it was found that the FOF of the poly-Si and HIT PV modules depended almost only on a module temperature, while that of the a-Si ones mainly depended on APE. The behaviors were reasonable considering from the operating mechanisms of the PV modules. These results demonstrate that APE is a reasonable and useful index to describe the spectral irradiance distribution for evaluating the performance of PV modules.

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