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Outdoor test of Si-based photovoltaic system for estimation of output energy in Japan

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Abstract:
Currently the value of photovoltaic (PV) modules is evaluated by power rating given by energy conversion efficiency under the standard test condition (STC), i.e., incident solar irradiance: 1kW/m^2; solar spectrum distribution: AM1.5G; module temperature: 25°C; and the total area of the PV modules. The output power of the PV modules is greatly influenced by environmental factors which can change every minute outdoor. Thus, the evaluation at the one fixed condition cannot accurately rate the real value of the PV modules. Also, the impact of the environmental factors is different on different PV technologies such as crystalline Si and thin-film Si PV technologies. In this study, we demonstrate how to evaluate the output power of various kinds of Si-based PV modules under real working condition using contour maps. Also, we propose one of the promising methods for energy rating, which is the method for the rating of the PV modules by output energy in certain period and conditions, using the contour maps.

Keywords: *Photovoltaic module; Outdoor exposure; Environmental factor; Temperature; Spectrum*

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1. Introduction

Output performance of photovoltaic (PV) modules outdoor is greatly influenced by ambient environmental conditions such as rain, ambient temperature and wind. To maximize the output energy from the PV modules, it is important to analyze the influences of environmental factors on the outdoor performance of the PV modules. Currently, the PV modules are usually rated by "power rating" given by energy conversion efficiency under the standard test condition (STC), i.e., incident solar irradiance: 1kW/m^2; solar spectrum distribution: AM1.5G; module temperature: 25°C; and the total area of PV modules. However, the environmental factors can change every minute outdoor, thus the evaluation at the one fixed condition cannot accurately rate the real value of the PV modules. Also, the impact of the environmental factors is different on different PV technologies. We currently work on the analysis of the PV modules outdoor, especially the impact of temperature and spectrum on different kinds of Si-based PV modules (Minemoto et al., 2007; 2009a; 2009b), using contour maps. In this contribution, we demonstrate the method of the evaluation of the output power of various kinds of Si-based PV modules under real working condition using contour maps. Also, we propose one of the promising methods for "energy rating", which is the method for the rating of the PV modules by output energy in certain period and conditions.

2. Experimental details

Outdoor exposure data from the different kinds of Si-based PV modules were used in this study. Single-crystalline Si (sc-Si), multi-crystalline Si (mc-Si), amorphous Si (a-Si), a-Si/microcrystalline Si tandem (tandem) and a-Si/a-SiGe/a-SiGe three stack (3stack) PV modules with capacities of 5, 5, 2, 1 and 1 kW, respectively, facing due south with a tilt angle of 15.31 were installed at Kusatsu city, Shiga prefecture in Japan (latitude 34^{o}58' north, longitude 135^{o}57' east). We have been measuring meteorological and PV data from 1998. Tilt irradiance (Irr) was measured by pyranometer (MS-62, EKO, Japan). Solar spectra of the wavelength range of 350–1050 nm were recorded by a spectro-radiometer (MS-700, EKO, Japan) that experiences the same exposure conditions as the PV modules. To analyze the effects of module temperature and spectrum on PV modules, contour maps for performance ratio (PR) of PV modules as a function of average photon energy (APE) and module temperature (T_{mod}) were made. The details for creating contour maps are available in our literature (Minemoto et al., 2009). T_{mod} was measured by thermo-couple attached at the backside of the PV modules. PR indicates PV module efficiency normalized by irradiance intensity, which is defined as the actual output energy divided by the nominal output energy calculated from the PV module performance under STC. APE is an index that indicates a spectral irradiance distribution and is defined as the integrated irradiance divided by the integrated photon flux density, yielding the average energy per photon (Williams et al., 2003). In this study, APE was calculated in 350-1050 nm wavelength range because of the limitation of the measurement system. The APE value for the standard solar spectrum (International Electrotechnical Commission, 1989, Japan Industrial Standard Committee, 2001) calculated with a 350–1050nm wavelength range is 1.88 eV. All the environmental data and output data from the PV modules were measured every minute.

3. Results and discussion

Fig. 1 shows the contour map of accumulated Irr for three years in this test site. The circle and star symbol in the Fig. indicate the conditions corresponding to STC and to most frequent condition (MFC) outdoor. The T_{mod} was for the mc-Si PV modules. Note that the absolute value of vertical axis of T_{mod} can be shifted on different PV technologies for different structure and component used. The map clearly shows that the outdoor condition deviates from STC and the spectrum more than 90 % to total was blue-rich and T_{mod} was quite high. Thus, STC is not representing the outdoor condition at this test site.

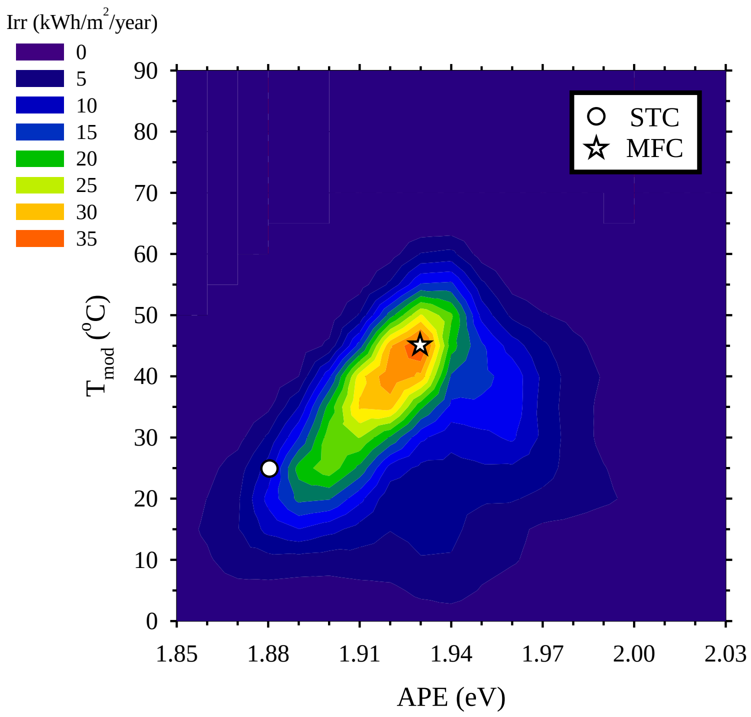

Fig. 1 Irr contour map at this test site.

Fig. 2 shows the PR maps of the different PV technologies. The PR map of the mc-Si PV modules was quite similar with that of the sc-Si PV modules, thus the map for mc-Si is not shown here. These maps demonstrate the clear difference in output behaviors, i.e., strong T_{mod} dependence for sc-Si, strong APE dependence for a-Si and tandem, and weak T_{mod} and APE dependences for 3stack. The difference comes from the absorber material and structures. As clearly indicated here, the PR of the PV modules greatly varies and the output energy also varies. Thus, the estimation of the energy output which leads energy rating needs outdoor environmental data and performance data of the PV modules. We propose one of the promising methods for energy rating using contour maps as shown in Fig. 3. Irr map can be created from the estimation or the actual data on the site. PR map can be created by actual output data or the inspection by the module supplier. If the two maps can be generated with high accuracy, then output energy at each site can be estimated with high accuracy.

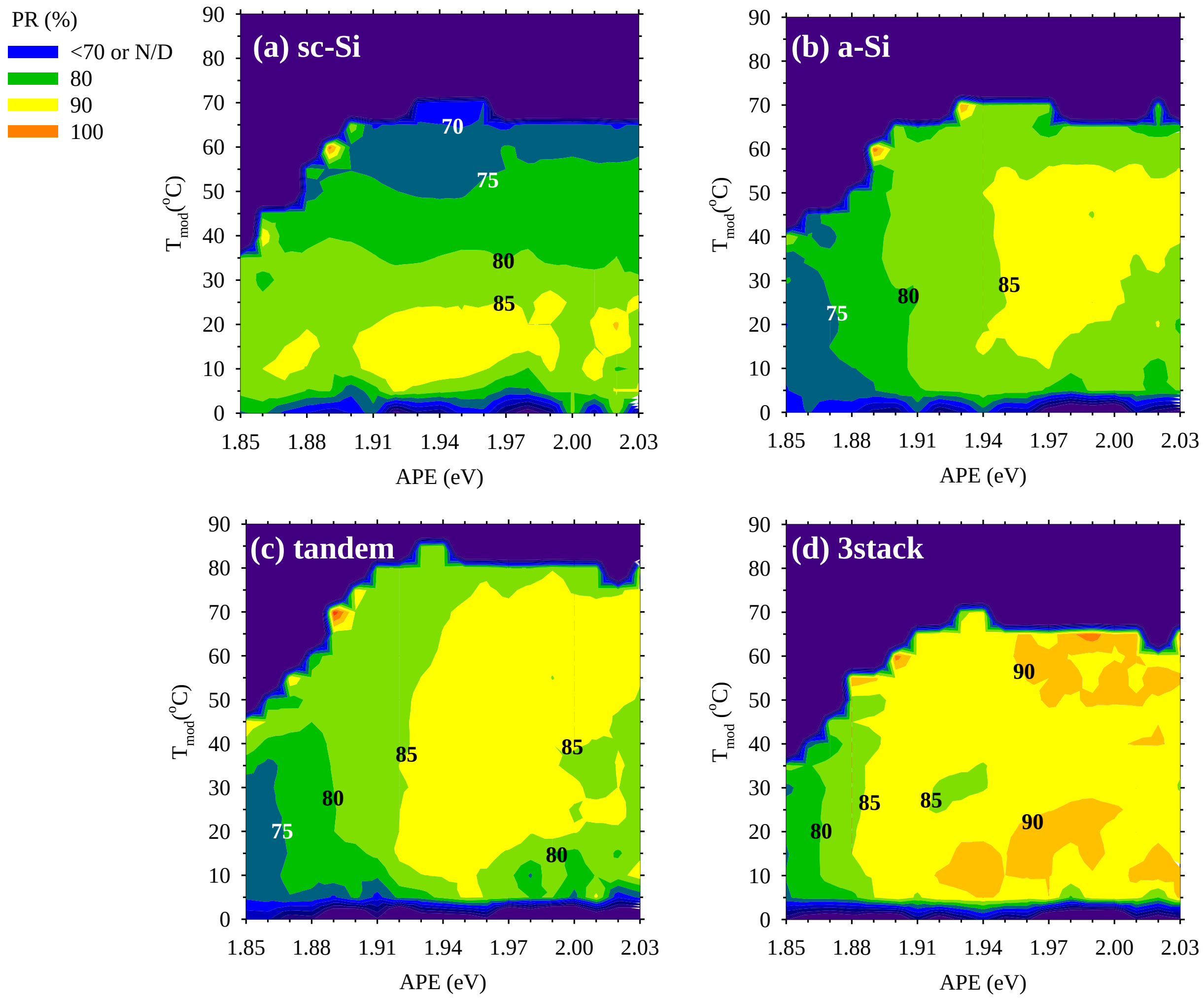

Fig. 2 PR maps of different PV technologies.

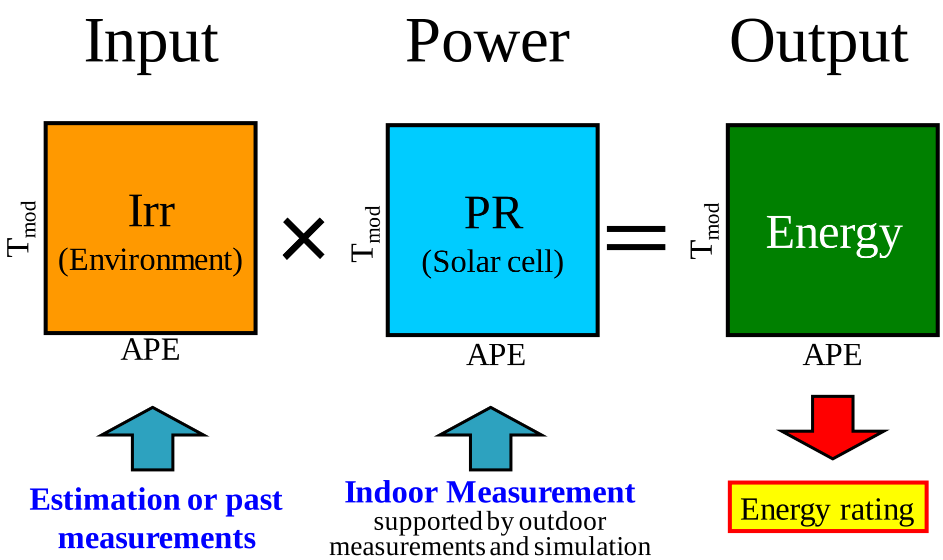

Fig. 3 Proposal of energy rating using Irr and PR contour maps

4. Conclusion

The impact of the environmental factors on the PV modules outdoor was clearly presented by the contour maps. The contour maps revealed the characteristics of the different kind of the PV technologies, i.e. temperature sensitive or spectrum sensitive. The contour maps also clearly presented the outdoor environment at the site of installation. Thus, we proposed the method of energy rating using the irradiation map (site dependent) and PR map (PV technology dependent), which should be useful for the rating of the PV modules outdoor.

5. Acknowledgement

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