Performance of CPV System Using Three Types of III-V Multi-Junction Solar Cells

Preprint

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Presented at the 8th International Conference on Concentrating PV Systems (CPV-8)
Toledo, Spain
April 16–18, 2012

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Conference Paper
NREL/CP-5200-54988
April 2012

Contract No. DE-AC36-08GO28308

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Performance of CPV system using three types of III-V multi-junction solar cells

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Abstract. Performance of III-V multi-junction solar cells depends on spectral conditions according to which junction limits the photocurrent. Specifically, the response of concentrating multi-junction solar cells depends on the illumination at the cell surface. Because the illumination condition depends on alignment, it is important to characterize the CPV performance not only for a mono-module but also for a system or an array. In this paper the spectral effect on the CPV system and the mono-module consisting of III-V multi-junction solar cells from three different manufactures will be discussed.

Keywords: CPV, performance, field test, spectrum, multi-junction cells, alignment
PACS: 88.40.F, 42.79Ek, 42.88+h

INTRODUCTION

This project is based on the partnership between Japan and U.S. named Japan-U.S. Cooperation on Clean Energy Technologies [1]. In this project, a concentrating PV (CPV) demonstration compares CPV systems deployed in Japan with sister systems deployed in the United States [2]. Japan National Institute of Advanced Industrial Science and Technology (AIST) teamed with the National Renewable Energy Laboratory (NREL) to test how high efficiency solar cells (III-V multi-junction solar cells) from three manufacturers perform in two geographic locations with different lighting conditions [3].

Over the past few decades, a considerable number of studies have been conducted on the spectral effects on a multi-junction cell [4-7]. There is no report to discuss spectral effects on different manufacturers' cells that are mounted under the same optics. This paper discusses the issues related to spectral conditions on III-V multi-junction solar cells produced by three manufacturers.

SYSTEM AND MONO-MODULE

CPV mono-modules were investigated outdoors for a month after indoor test. Systems field-test data were also compared with mono-module field-test data at the same location and meteorological conditions. The system field-test data from two different locations are used to confirm consistency of results. The III-V multi-junction solar cells produced by three manufacturers were mounted in both mono-modules and systems to allow characterization. The manufacturers of the three III-V multi-junction cells are Spectrolab in U.S., Sharp in Japan and Azur space in Germany.

Mono-module for detailed analysis

The mono-module shown in Figure 1 consisted of a point focus PMMA Fresnel primary lens, a glass secondary optic and a single cell. The cells from three manufacturers are mounted in this device. A platinum resistance thermometer (T100) is also mounted close to the cell. Daido Steel Co., Ltd assembled these mono-modules. The mono-modules were mounted and aligned on one of the trackers of the CPV system in Okayama site.

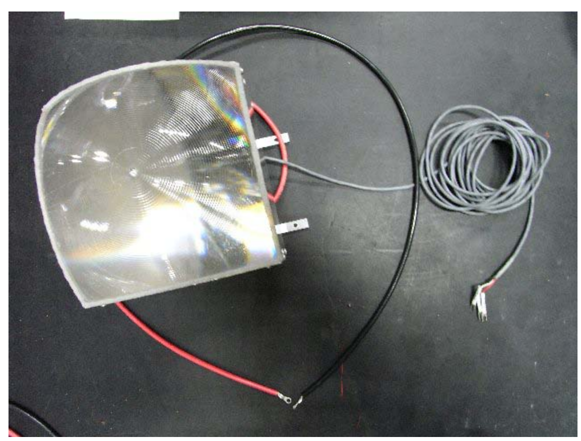

FIGURE 1. Example of mono-module consisting of a single cell with optics assembly.

System for field test

The systems field-test data were taken from systems installed in Aurora, CO, USA and Okayama, Japan. Both systems also employ the cells from three manufacturers with the same optics and tracker. Three types of arrays that consisted of three types of cells are connected to the grid and IV curves are measured every 10 minute by a PV measurement system (Nippon Kernel System. Co. Ltd.)

SPECTRAL EFFECT

In order to understand the spectral effect on the multi-junction cell, a spectro-radiometer MS-710 and MS-712 (EKO) with a collimator tube were installed at the Okayama site. According to the characteristic of pyrheliometer CHP-1 (Kipp & Zonen), the collimator tube for the spectro-radiometer is designed with a half angle of 2.5°, slope angle of 1.0° and limit angle of 4.0°. The measured direct normal spectral irradiance $E_{measured}(\lambda)$ [W/m^2/nm] represents the spectrum at the primary lens surface. The cell surface spectrum will be represented with primary optics transmittance $T_p(\lambda)$ [%] and secondary optics transmittance $T_s(\lambda)$ [%]. The spectral change under the optics (MM_o) for the top sub-cell under the reference spectrum $E_{AM1.5D}(\lambda)$ (ASTM G173-03, AM1.5D low AOD) is described with spectral response of top sub-cell $SR_{top}(\lambda)$ [A/W]:

$$MM_{o,top} = \frac{J_{top,measured}}{J_{top,AM1.5D}} = \frac{\int E_{measured}(\lambda)\cdot T_p(\lambda)\cdot T_s(\lambda)\cdot SR_{top}(\lambda)\cdot d\lambda}{\int E_{AM1.5D}(\lambda)\cdot T_p(\lambda)\cdot T_s(\lambda)\cdot SR_{top}(\lambda)\cdot d\lambda} \quad (1)$$

The spectral change under the optics for the middle sub-cell is described with spectral response of middle sub-cell $SR_{mid}(\lambda)$ [A/W]:

$$MM_{o,mid} = \frac{J_{mid,measured}}{J_{mid,AM1.5D}} = \frac{\int E_{measured}(\lambda)\cdot T_p(\lambda)\cdot T_s(\lambda)\cdot SR_{mid}(\lambda)\cdot d\lambda}{\int E_{AM1.5D}(\lambda)\cdot T_p(\lambda)\cdot T_s(\lambda)\cdot SR_{mid}(\lambda)\cdot d\lambda} \quad (2)$$

From these top and middle sub-cell's mismatch the Spectral Mismatch Ratio for the multi-junction cell (SMR) is defined as follows:

$$SMR = \frac{MM_{o,mid}}{MM_{o,top}} \quad (3)$$

SMR can describe the relative current mismatch for the reference spectrum. If SMR is greater than 1 (SMR>1) then the spectrum at the cell surface is rich for middle sub-cell (red rich spectrum) in comparison with reference spectrum. Inversely, if SMR is less than 1 (SMR<1) then the spectrum is rich for the top sub-cell (blue rich spectrum) in comparison with the reference spectrum. Please note that the spectral responses of cells from three manufacturers were measured at AIST and significant difference of the spectral mismatch of each cell was not observed.

RESULT/DESCUSSION

Mono-module performance

Indoor test

The performances of three mono-modules were measured under the solar simulator called HPCSS, which was developed at AIST [9]. Table 1 shows the Isc, Voc, FF and module temperature: T100 mounted in the heatsink close to the cell, under constant irradiation intensity and spectrum. The test condition is 900 W/m^2 of intensity and ASTM G173 spectrum. The differences of performance: Isc, Voc and FF from different manufactures cells were ±3%, ±3% and ±2.2%.

TABLE 1. The performance of mono-modules using three different manufacturers' cells (Spectrolab, Sharp and Azur space). Indoor test by highly parallel continuous solar simulator (HPCSS). DNI=900 W/m^2, AM1.5D low AOD (ASTM G173-03) and operating temperature

	Isc [A]	Voc [V]	FF [%]	Module Temperature [C]
Mono-module #1	2.44	2.74	79.3	54.8
Mono-module #2	2.51	2.90	81.8	58.7
Mono-module #3	2.38	2.97	82.1	56.6

Outdoor test (Field test)

The IV curves of the mono-modules were measured every 10 minutes. In order to consider the effect of cell temperature and intensity irradiance, the Isc measured outdoors was normalized to DNI=900 W/m^2 and translated to module temperature at the indoor test condition (Table 1). The Normalized Isc is calculated by:

$$Normalized\_I_{sc} = \frac{I_{sc,measured}}{I_{sc,indoor}}\cdot\frac{DNI_{indoor}}{DNI_{measured}}$$

In Okayama, the air turbidity varies in the afternoon due to an increase of aerosol particles and humidity. Thus, the data were filtered by time (<12:00). Figure 2 shows the normalized Isc of modules #1 to #3 as a function of SMR on a very clear day. The Air Mass (AM) is also indicated as a function of SMR, which is calculated from a linear regression. The normalized Isc of a mono-module increases linearly with SMR when the photocurrent is limited by the middle sub-cell. The rate of increase of normalized Isc to SMR (slope on left side of Fig. 2) is 0.55, 1.46 and 0.79 for #1, #2 and #3, respectively. When the photocurrents of the top sub-cell and the middle sub-cell match, the normalized Isc decreases as the SMR is further increased (the current is limited by the top sub-cell). The rate of the decrease of the normalized Isc to SMR (slopes of lines on the right side of Fig. 2) is -0.40, -0.29 and -0.40

for #1, #2 and #3. respectively. The SMR at the peak of normalized Isc is 1.04, 1.01 and 1.01 for #1, #2 and #3. In this case, the photocurrent of mono-module #1 is matched for a red rich spectrum compared with the reference spectrum. The photocurrents of mono-module #2 and #3 are matched close to the reference spectrum. Figure 3 shows normalized Isc of modules #1 to #3 as a function of SMR on a clear sky day (slightly higher AOD compared with the day at Figure 2). The increase ratio is 0.40, 0.87 and 0.24 for #1, #2 and #3. The decreased ratio is -0.36, -0.30 and -0.38 for #1, #2 and #3. The SMR at the peak of the normalized Isc for #1 to #3 is 1.03, 1.04 and 1.02. In this case, the photocurrents of all mono-module are matched for a red rich spectrum.

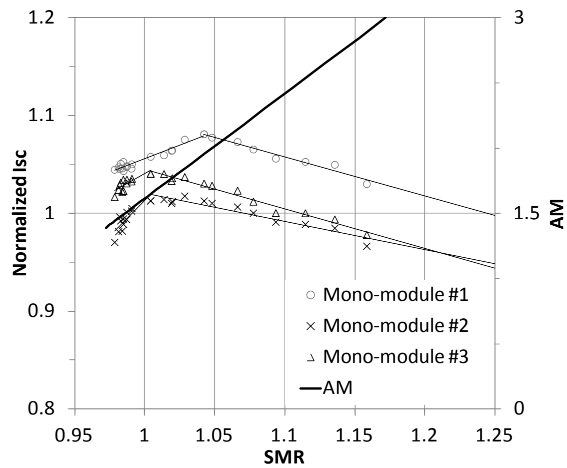

FIGURE 2. Normalized Isc of mono-modules as a function of SMR on a very clear day (DNI=910 W/m^2 at AM1.5). 18th of October 2011. (Japan site)

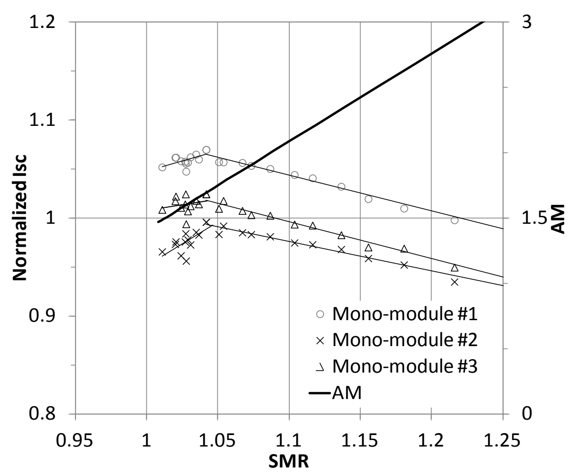

FIGURE 3. Normalized Isc of mono-modules as a function of SMR on clear sky day (DNI=874 W/m^2 at AM1.5). 27th of October 2011. (Japan site)

System performance

Outdoor test (Field test)

The array/system IV-curve was measured outdoors and the Isc was normalized to the labeled value, which is rated by the manufacturer (Daido steel).

$$Normalized\_I_{sc} = \frac{I_{sc,measured}}{I_{sc,labeled}} \cdot \frac{DNI_{labeled}}{DNI_{measured}}$$

Figure 4 shows the normalized Isc of systems #1 to #3 as a function of SMR on Oct. 18, 2011 with Figure 2. The system number #1 to #3 represents different cell manufacturers and these numbers are consistent with the numbering of mono-modules #1 to #3. The SMR at the peak of the normalized Isc is 1.01, 1.02 and 1.04 for #1, #2 and #3. The photocurrents of system #1 and #2 are matched at close to the reference spectrum and system #3 is matched for a red rich spectrum.

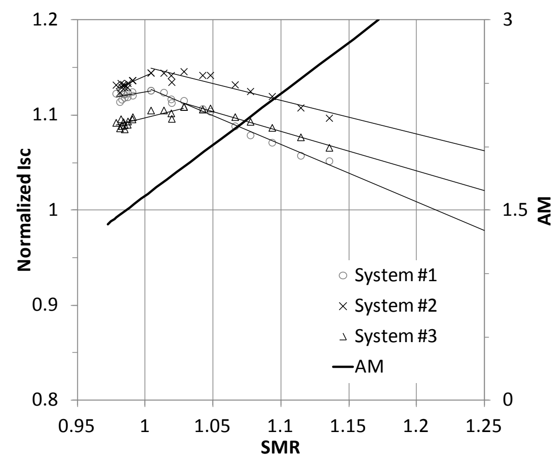

FIGURE 4. Normalized Isc of system as a function of SMR on a very clear day (DNI=910 W/m^2 at AM1.5). 18th of October 2011. (Japan site)

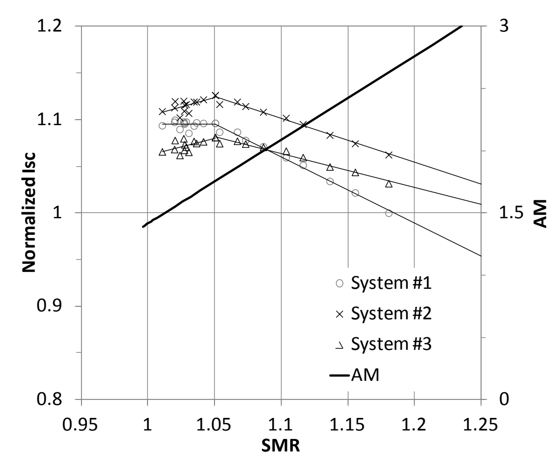

FIGURE 5. Normalized Isc of system as a function of SMR on a clear sky day (DNI=874 W/m^2 at AM1.5). 27th of October 2011. (Japan site)

Figure 5 shows normalized Isc of systems #1 to #3 as a function of SMR on the same day as Figure 3. The SMR at the peak of the normalized Isc is 1.04, 1.04 and 1.04 for #1, #2 and #3. The photocurrent of all systems matched at the red rich spectrum and this red shift trend of SMR value at the peak Isc corresponds to the mono-module result. The impact of circum solar and some tracking error remains as a matter to be discussed further.

Comparison with Japan and U.S. site (Field test)

The impact of optimal AM on normalized Isc at the U.S. site was investigated to confirm consistency of the spectral effects. Figure 6 shows normalized Isc of systems #1 to #3 as a function of AM. The system number #1 to #3 is consistent with the mono-module and system numbers for the Japan site. The AM at the peak of normalized Isc is not consistent with the result of the Japan site.The alignments of the modules vary. Therefore, the spectral effects on the systems become random. The comparison of data, which are collected under each of the alignments to separately optimize the alignment of the three individual systems by offsetting the tracker controller, is also considered. However, it was difficult to solve this issue. The alignment and tracking issue were equally effective on CPV system performance and need to be considered when characterizing III-V multi-junction solar cells under the illuminated condition by the optical devices.

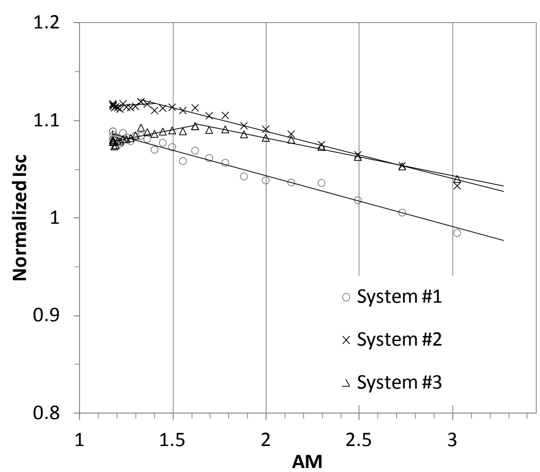

FIGURE 6. Normalized Isc of system as a function of AM on a very clear day (DNI=954 W/m^2 at AM1.5). 10^{th} of October 2011. (USA site)

CONCLUSIONS

In this paper, the spectral effect on the III-V multi-junction solar cells from different manufacturers was discussed. Three different cells, each mounted in a mono-module, were investigated indoors and outdoors. The systems that also use the cells from three manufacturers were investigated outdoors at the same location and meteorological conditions as the mono-modules. Most of the mono-modules were photocurrent matched at similar Spectral Mismatch Ratios (SMR). The result corresponds to the similarity of spectral response. From the comparison of mono-module and system data, the peak normalized Isc shifts to the red rich spectrum by the meteorological condition and the alignment. To define this issue, more accurate alignment including tracking error calls for further investigation. There is a possibility that the photocurrent match spectral condition will be changed by the circum solar radiation (CSR) due to chromatism. From now on, the study of relation between CSR and FF on the accurate tracking system will be needed to define spectral effect on III-V multi-junction solar cells.

ACKNOWLEDGMENTS

The authors would like to thank Daisuke Nishi, Takashi Ueda, Yanqun Xue, Yuki Tsuno and Yoshihiro Hishikawa at AIST. This work was supported by the Incorporated Administrative Agency New Energy and Industrial Technology Development Organization (NEDO) under the Ministry of Economy, Trade, and Industry (METI) and partially supported by the U.S. Department of Energy under Contract No. DE-A N-AC36-N-GO28308 with the National Renewable Energy Laboratory.

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