Development of Concentrator Photovoltaic System

Kenji SAITO*, Yoshiya ABIKO, Kazumasa TOYA, Kouji MORI, Yoshikazu KOGETSU
and Takashi IWASAKI

Sumitomo Electric Industries, Ltd. has developed a concentrator photovoltaic (CPV) system under the design concepts of light weight, small size, high heat dissipation and display feature. At its Yokohama Works, a megawatt-class power generation/storage system has been deployed and in operation since July 2012 to evaluate the performance of the CPV modules. The module recorded a conversion efficiency of approximately 30% under measurements both in sunlight and using a solar simulator. The power generation performance was compared between the CPV module and the most commonly used polycrystalline silicon module. These modules were set to track the sunlight, and the total amount of power generated for one day was measured. The results showed that the CPV module generates 2.0 times as much power per unit area and 1.7 times as much per unit weight as that of the poly-Si module.

Keywords: concentrator photovoltaic (CPV), high concentrating photovoltaic (HCPV), direct normal irradiance (DNI)

1. Introduction

As we see increasing expectations for distributed generation systems which utilize renewable energy, the Sumitomo Electric Group has been actively pursuing research and development of various technologies for power conversion/control, and generation/storage(1).

A power system which can provide stable electric power to large scale power consumers has been deployed and in operation at our Yokohama Works since July, 2012. The system consists of the world's largest MW-scale Redox Flow battery and Japan's largest concentrator photovoltaic (CPV) system, and is controlled by the Energy Management System (EMS). **Figure 1** shows a diagram of the system setup, and **Photo 1** shows the entire CPV system. In this paper, we will discuss the characteristics and generating performance of the CPV module that we developed.

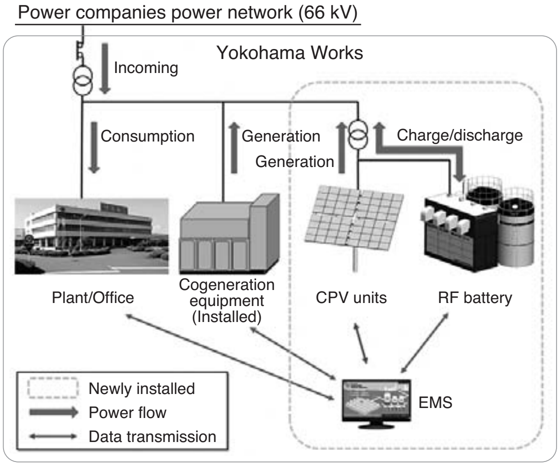


Fig. 1. MW-class power generation/storage system

2. Characteristics of CPV

CPV is a photovoltaic power generation system which converts energy using a small generating device by letting in high-density light from the sun that has been concentrated with lenses(3). For the generating device, we use solar cells which have high photoelectric conversion efficiency from the wide emission spectrum of sunlight, using compound semiconductor materials which have different band gap energies, layered by tunnel junctions. For these multi-junction compound solar cell, Solar Junction, has recorded

Photo 1. CPV system at Yokohama Works

the world's highest efficiency of 44%(4) at 947 suns (1 Sun (1kW/m^2)), as of October 15, 2012. Efficiency greater than 50% can be expected in the near future for these multi-junction cells(5).

For light collection, flat Fresnel lens, dome-shaped Fresnel lens, and mirror reflective types have been developed. For CPV systems, in order to achieve high module conversion efficiency optically, it is important to have high transmittance efficiency over the light receiving bandwidth of the cells, reduction in chromatic aberration, and uniform distribution of light collection intensity(3).

CPV systems use a dual-axis tracking system to move the optical module to have a perpendicular incident for collecting sunlight. The tracking method either uses sensors to track the sunlight by sensing light, or uses timing method to track the trajectory of the sun from the latitude and longitude of the installation location and the time of the day. Sometimes, these two methods can be combined together. Companies choose different tracking method based on the accuracy and cost.

Daido Steel Co., Ltd. conducted an outdoor proof experiment of the CPV system in Aichi Prefecture. The results showed that compared to a non-light condensing flat PV system, the CPV system has a 1.6 times higher annual generation output per unit area and approximately 2 times the module conversion efficiency of the conventional PV system(6). In addition, because the CPV system tracks the sun, it has a high power generation during early morning and evening hours so it has stable supply even during the high demand hours in the evenings. Furthermore, the module is designed to be installed in high locations which enable the space below the modules to be used, such as for parking lots, parks and farmlands. As a next generation PV system, there are high expectations for the CPV system.

3. The Development of CPV Modules

We have been developing CPV modules largely based on the following three concepts.

(1) Light weight modules, easy to assemble and install; can be carried by a single person.
(2) High heat dissipation performance
(3) Can be used as display

This CPV module has a size similar to that of a 40 inch TV, with a weight of 8 kg. With this size and weight, the module can easily be carried by a single person, therefore the costs for assembling and installation can be reduced. Moreover, by reducing the load on the tracker as it supports a lighter module, the driving torque and material strength can be minimized. Therefore, the cost of the tracker can also be reduced.

High performance of heat dissipation is crucial from the following two perspectives. 1) A solar cell's power output decreases when temperature rises. Generally speaking, multi-junction solar cells have about 5-7 times better thermal resistance compared to crystalline silicon solar cells(7). Their power output changes in response to the temperature increase are much smaller. However, as the CPV system applies hundreds to thousands times more energy to the multi-junction cell by concentrating sunlight, it is necessary to suppress the power loss due to the temperature rise to a minimum. 2) Long-term reliability. When the cell's operating temperature rises, it is expected that the thermal stress will be applied largely to the peripheral components and circuit boards, and therefore, shorten the system life. On the other hand, choosing high thermal resistance materials can help achieve long system life but will increase the cost. We designed our CPV module using a small lens array of 192 Fresnel lenses, each at 50 mm x 50 mm, to disperse the light energy collection so that the temperature increase on the cell and the peripheral components can be minimized. Also, by placing the cells in an aluminum case designed for good heat dissipation, the operating temperature of the cells can remain at a low level.

Furthermore, our CPV panels are designed to have an additional value of displaying company names and logos without sacrificing the output of power generation. **Figure 2** shows an example of the CPV system installed at Sumitomo Electric's Yokohama Works. Characters can be displayed on CPV panels by placing color plates into the space inside of the lenses which is not occupied by the solar cells. In addition, by devising the arrangement of the color plates, display content in the same CPV system can be changed by changing the viewing angles.

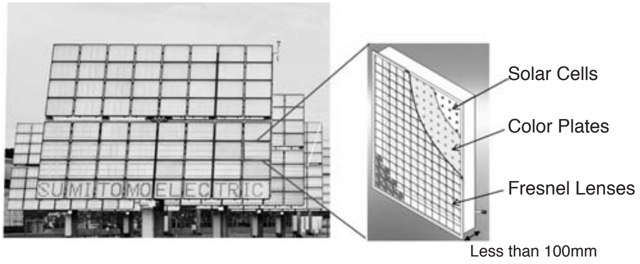


Fig. 2. CPV's structure and display

4. Power Generation Performance of CPV Module

Figure 3 shows the CPV's characteristics measured under direct sunlight. When the module internal temperature was 46.7°C and the direct normal irradiance (DNI) was 699 W/m^2, a conversion efficiency of $\eta = 30.1\%$ (light receiving area: 0.48 m^2) was recorded.

Figure 4 shows the results of characterization measurements on the same module done by a third party institute in Spain, Instituto De Energía Solar - Universidad Politécnica de Madrid (IES-UPM), using the solar simulator produced by Solar Added Value S.L (SAV) . When the module temperature was 25°C and DNI = 1000 W/m^2, a conversion efficiency of $\eta = 29.5\%$ was recorded. Our CPV module has recorded a conversion efficiency of approximate 30% for both indoor and outdoor measurements.

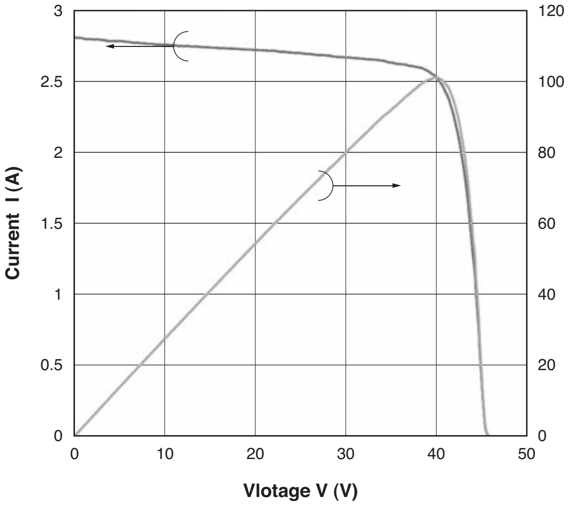
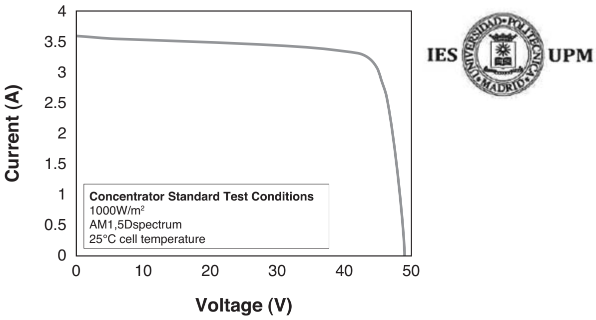


Fig. 3. CPV's outdoor measurements



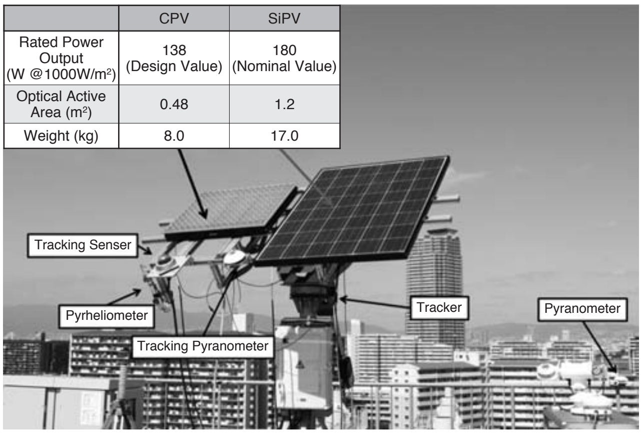
Concentrator Standard Test Conditions
1000W/m²
AM1,5Dspectrum
25°C cell temperature

Fig. 4. CPV characterization measurement results from third party institute (using solar simulator HELIOS 3198)

5. Comparison between CPV and Crystalline Silicon PV (SiPV)

As shown in **Fig. 5**, a CPV module and a SiPV module were mounted on the same tracker, at Sumitomo Electric's Osaka Works, to measure their characteristics simultaneously. The insolation intensity was measured by a pyrheliometer, a pyranometer and a tracking pyranometer. Both back surfaces were measured with a thermocouple. For the SiPV, we used the polycrystalline silicon type. **Figure 6** shows the conversion efficiency changes for both modules in one day. The temperature shown is that of the modules back side. Throughout the day, CPV's conversion efficiency was between 27.5% and 30% with the peak at $\eta = 30.1\%$ around 8:00-9:00 a.m. SiPV kept fluctuating slightly around $\eta = 11\%$ and peaked at 13.5% in the evening when the modules temperature dropped. Where the conversion efficiency dropped significantly, it was because the sun was blocked by clouds. In addition, the DNI for this day was at a high of 836 W/m^2 from 9:00 to 15:00 and had an average of 700 W/m^2 except for when there were clouds.

Figure 7 shows the changes of output per unit area (W/m^2) in one day. The output per unit area of CPV was much higher than that of SiPV. CPV's output per unit area (Wh/m^2) was 2.0 times that of SiPV between 9:00 and 15:00. Therefore, CPV is very space efficient because, for the same amount of output, it only needs about half of SiPV's area.



	CPV	SiPV
Rated Power Output (W @1000W/m^2)	138 (Design Value)	180 (Nominal Value)
Optical Active Area (m^2)	0.48	1.2
Weight (kg)	8.0	17.0

Fig. 5. Comparing CPV and SiPV by outdoor measurements

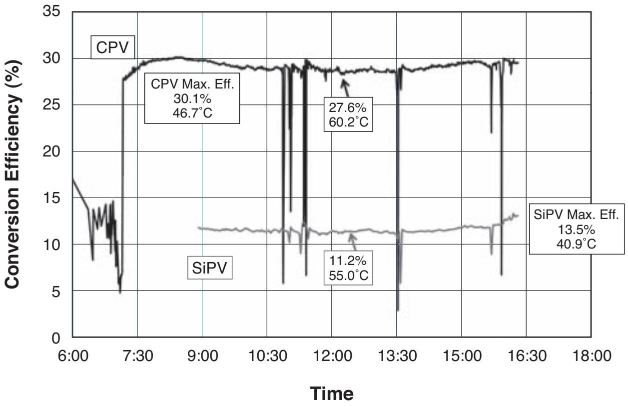


Fig. 6. Conversion efficiency changes of CPV and SiPV

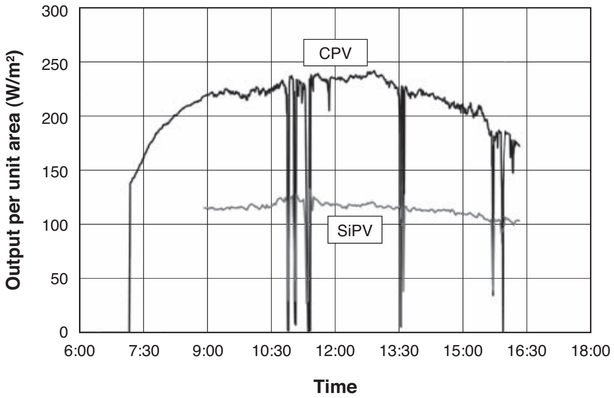


Fig. 7. Changes in output of CPV and SiPV per unit area in one day

In addition, the accumulated power generation per unit weight (Wh/kg) of CPV's was approximately 1.7 times that of SiPV. That means, compared to tracked SiPV, more CPV modules can be mounted on a single tracker. Therefore, CPV also has a significant advantage when output per tracker is compered. It is also expected that this advantage will increase in areas with higher DNI such as the Sunbelt regions.

6. Conclusion

We have developed a CPV system under the design concepts of light weight, small size, high heat dissipation and display features. Our CPV module has recorded a conversion efficiency of around 30% under measurements both in real outdoor operation and using a solar simulator. When the output is compared with that of tracked SiPV, CPV generates 2.0 times as much power per unit area and 1.7 times as much per unit weight. We are continuing the development towards the commercialization within the next few years.

References

(1) Naoki Ayai, "DC Micro Grid System," SEI Technical Review, No.75, pp132-136 (2012)

(2) Toshio Shigematsu, "Redox Flow Battery for Energy Storage," SEI Technical Review, No.73, pp4-13 (2011)

(3) Masafumi Yamaguchi, "Ultra high efficiency compound solar cells – Materials, Technology trends and challenges," Industrial Materials, Vol.58 No.4, pp49-53, April (2010)

(4) URL http://www.excite.co.jp/News/release/20121015/Kyodo_prw_201210157628.html

(5) K. Kurokawa, Proceedings of the 34th IEEE Photovoltaic Specialists Conference (2009)

(6) "Ex-post evaluation report photovoltaic technology research and development," NEDO, pp31-33 (2007)

(7) Yoshihiro Hamagawa and Yukinori Kuwano, "Solar energy engineering," Baifukan co., Ltd., pp219-237 (1998)

Contributors (The lead author is indicated by an asterisk (*).)

K. SAITO*
- Power System R&D Laboratories

Y. ABIKO
- Assistant Manager, Power System R&D Laboratories

K. TOYA
- Power System R&D Laboratories

K. MORI
- Assistant Manager, Power System R&D Laboratories

Y. KOGETSU
- Senior Assistant General Manager, Power System R&D Laboratories

T. IWASAKI
- Group leader, Power System R&D Laboratories