LONG-TERM PERFORMANCE ESTIMATION OF A 500X CONCENTRATOR PHOTOVOLTAIC SYSTEM

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1. Introduction

In order to reduce the power generation cost for a photovoltaic (PV) system, a prototype of a 500X concentrator photovoltaic (CPV) system with dome Fresnel lens was developed (Araki et al, 2005). Field tests of a prototype of a CVP system were carried out at Toyohashi, Japan, for two test periods: June 2004 to September 2005 and October 2005 to May 2009 (Kemmoku et al., 2005). In this study, the long-term system performance of a prototype of the CPV system was estimated along with the system efficiency by using the data collected during the second test period. In addition, the factors that influence the system efficiency were also investigated using the open-circuit voltage, fill factor (FF), and I-V curve data for the CPV module.

2. Outline of the prototype of a CPV system

2.1. Outline of the CPV system

Figure 1 shows a photograph of the prototype of the 500X CPV system with dome Fresnel lens (left side). The module consists of 20 pairs of dome Fresnel lenses and solar cells (InGaP/InGaAs/Ge three-junction cell). These cells are connected in series. The total area of the module is 0.545 m^2.

A two-axis solar tracking system controls the azimuth and elevation angles with high accuracy. The tracking system works when the solar elevation angle is greater than 15°. The solar tracking errors (RMS) in the azimuth and elevation angles are 0.045° and 0.027°, respectively (Hiramatsu et al., 2003).

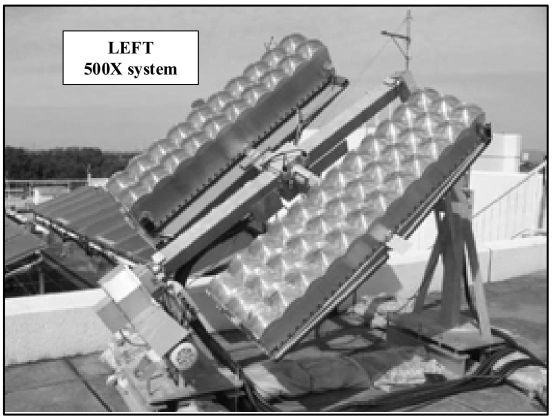

Fig. 1: The prototype of the 500X CPV system with dome Fresnel lens

2.2. Arrangement of the measurement system

Figure 2 shows the arrangement of the measurement system. The PV module output at maximum power point, open-circuit voltage, and short-circuit current were measured with an IV tracer every 20 s. The module temperatures were measured by thermocouples and a data logger. The direct solar irradiance was measured by a pyrheliometer fixed to the module. In addition, weather data such as the wind speed and direction, ambient temperature, humidity, horizontal global solar irradiance, and global solar irradiance on a sloping surface (angle : 35°) were measured.

Figure 3 shows an example of the measured data in the form of daily direct and global irradiance, module output, open-circuit voltage, efficiency, and FF curves for the 500X PV system on a clear-sky day (16/10/2006).

In Japan, the peak value of the global solar irradiance on a sloping surface during autumn is larger than the direct irradiance. However, the daily direct irradiation is larger than the daily global irradiation on a clear-sky day. In Fig.3, the values of the daily direct irradiation and global irradiation on a sloping surface are 30.1 MJ m^{-2} and 25.9 MJ m^{-2}, respectively.

The maximum efficiency of the 500X CPV system reaches 20.6% (uncorrected at 25 °C). The daily average efficiency (daily generated energy divided by daily direct solar irradiation) is 19.2%.

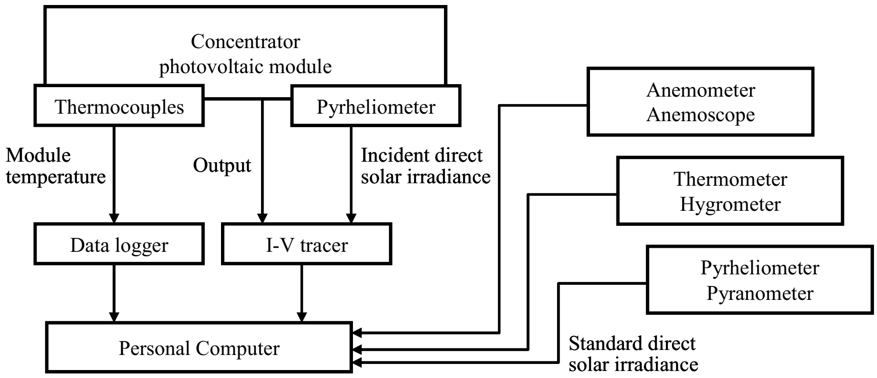

Fig. 2: Arrangement of the measurement system

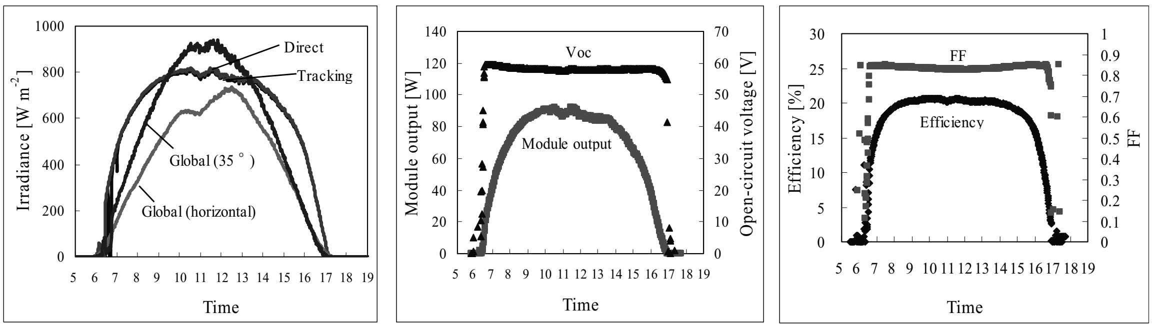

Fig. 3: Daily solar irradiance, module output, open-circuit voltage, efficiency, and FF curves for the CPV system (16/10/2006)

3. Performance and efficiency estimation of the system

It is required that the high generation performance of a PV system is maintained for more than 20 years. The performance ratio is usually used to estimate the generation performance of a flat-plate PV system. Because the definition of the rated output of a CPV system has not been clarified, the performance of the CPV system was simply estimated in this study on the basis of the efficiency calculated from the generated energy and irradiation.

3.1. Change in the daily average efficiency

First, the long-term change in the system performance was investigated on the basis of the daily average efficiency calculated from the daily direct solar irradiation and generated energy of the CPV system. Here, daily direct irradiation includes the irradiation during the period when the tracking system was not working.

Figure 4 shows the daily average efficiency of the CPV system during the second test period. The efficiency of the system appears to decrease gradually every year, although it increases during summer and decreases during winter and spring, owing to seasonal variations in the air mass and spectrum of the direct irradiance.

The daily average efficiency in October, 2008, after three years from the beginning of the system operation, was about 2.2 points lower than the efficiency in October, 2005.

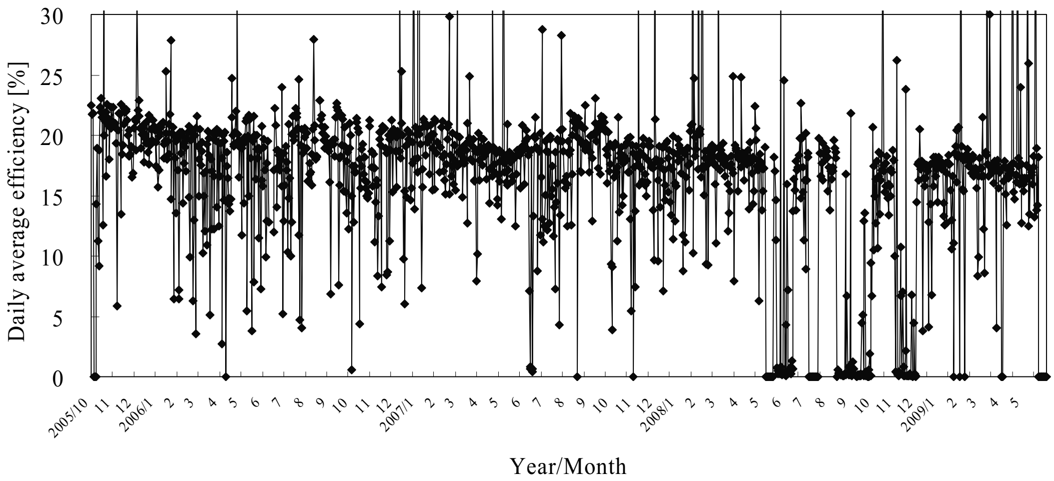

Fig. 4: Daily average efficiency of the prototype of the CPV system (October 2005 – May 2009)

3.2. Change in the average efficiency around the middle of each day

Next, the average efficiency for two hours before and after the middle (11:00-13:00) of each day was calculated, and the tendency of the change in the efficiency was investigated. Table 1 lists the values on a clear-sky day in October each year. Although the average efficiency around the middle of October, 2005, is 23.23%, it drops to 20.62% in the next October. However, it does not decrease this much after that and remains above 20% in October, 2008. Thus, the decrease in the average efficiency around the middle of every year for three years is about 3.0 points.

Tab. 1: Average efficiency of the CPV system around the middle of each clear-sky day in October

Date	Average efficiency around middle of the day [%]
19/10/2005	23.23
16/10/2006	20.62
21/10/2007	20.58
15/10/2008	20.22

4. Investigation of factors that influence the efficiency

In general, the following factors that influence the efficiency of the CPV system were considered: solar tracking error, damage of the solar cell, decrease in the transmission factor of the lens, and dew condensation, among others. To investigate the contribution of each factor to the reduction in the efficiency, the open-circuit voltage (Voc), fill factor (FF), and I-V curve data of the CPV module were analyzed.

The influence of dew condensation on the efficiency is limited during the condensation, and it is supposed that dew condensation does not influence the long-term system performance directly. Therefore, the influence of dew condensation is not discussed in this paper.

One measurement of the I-V curve takes few seconds. Thus, the measurement results would be incorrect when the direct irradiance varies widely during the measurement. For this reason, the average values of Voc and FF for each day were calculated using the measurement data for two hours before and after the middle.

4.1. Changes in the open-circuit voltage

Figure 5 shows the changes in the average open-circuit voltage for each day. Voc exhibits seasonal variations owing to the change in the solar cell temperature. The value of Voc in summer is about 2 V lower than that in winter. However, the value of Voc shows no apparent reduction every year.

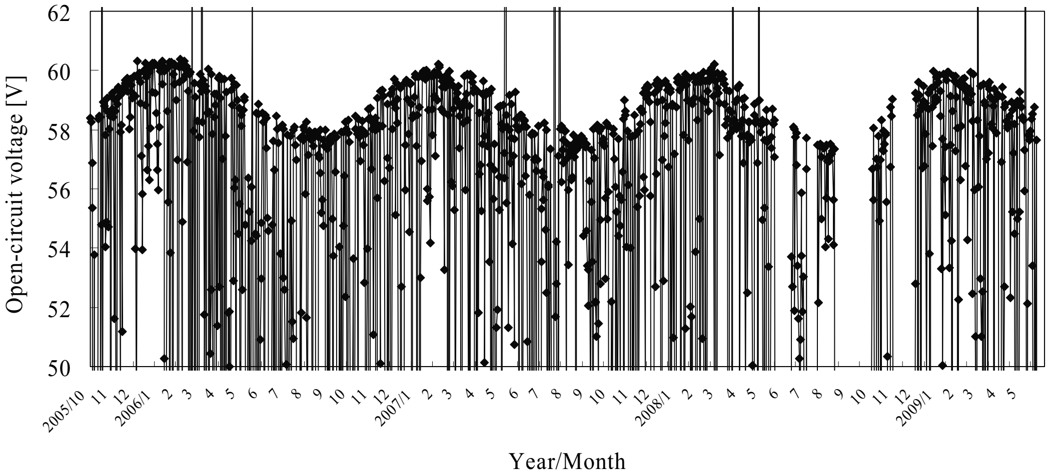

Fig. 5: Open-circuit voltage of the prototype of the CPV system (October 2005 – May 2009)

4.2. Changes in the fill factor

Figure 6 shows the changes in the average FF for each day. FF exhibits seasonal variations owing to those in Voc. Moreover, FF dropped greatly in middle of October, 2007. Thus, the value of FF dropped from 0.849 to 0.825 over a period of three years.

Figure 7 shows a comparison of daily FF and efficiency curves on a clear-sky day in October for each year. The values of FF in 2005 and 2008 greatly reduced until 10 a.m. because of dew condensation. The results show that the values of FF throughout a day in 2008 are lower than those for another year.

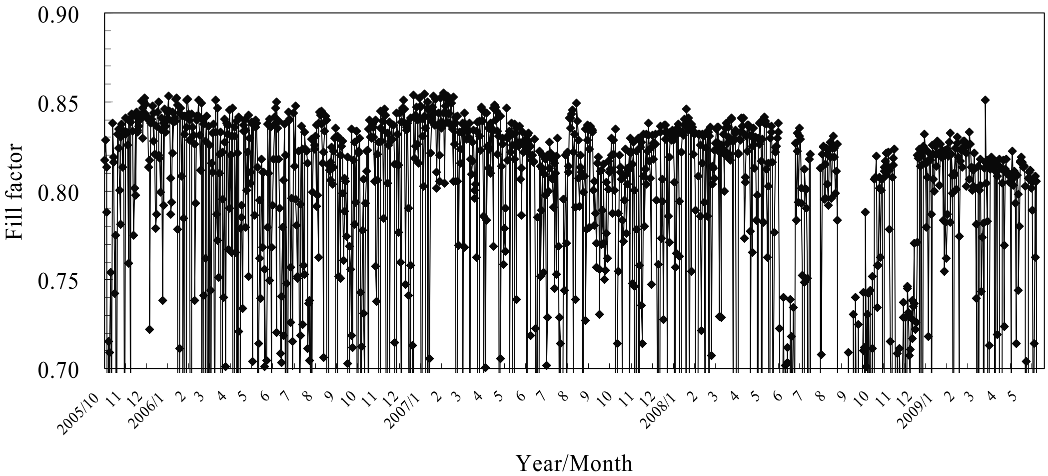

Fig. 6: Fill factor of the prototype of the CPV system (October 2005 – May 2009)

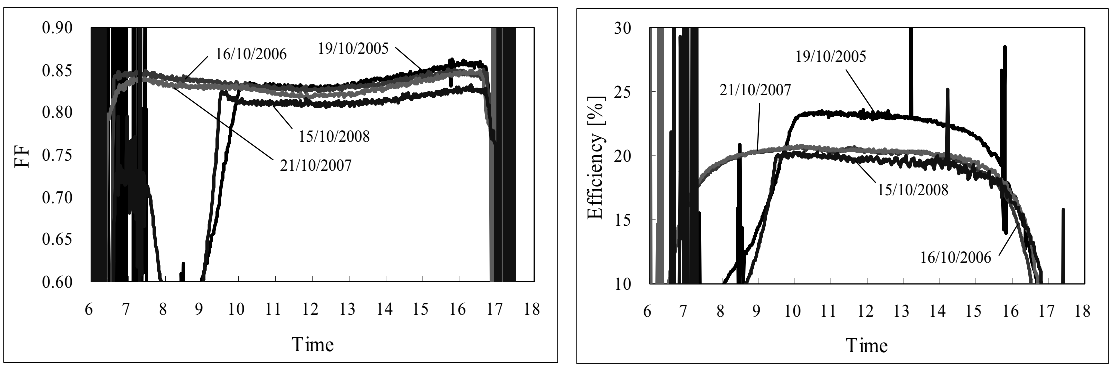

Fig. 7: Comparison of daily fill factor and efficiency curves on a clear-sky day in October for each year

4.3. Comparison of I-V curves

The reason for the reduction in FF was investigated by comparing the I-V curves. Figure 8 shows the I-V curves for the middle of a clear-sky day in October for each year. The curve for 01/03/2009 is shown instead of the curve for 15/10/2008. The direct irradiances for each day are also shown in this figure.

The differences in the values of Voc for each year are very small. On the other hand, the gradations of the curve from 0 to 50 V increase every year. Such tendencies could often be observed when solar tacking errors occurred.

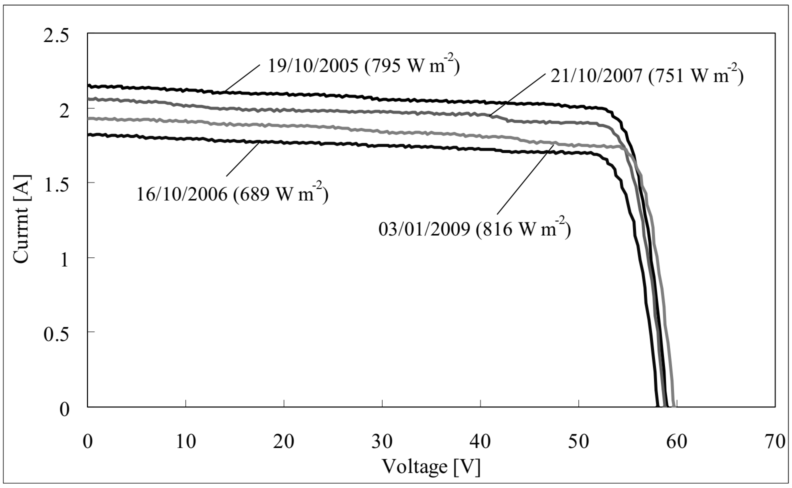

Fig. 8: Comparison of I-V curves for a clear-sky day in October for each year

4.4. 4. Investigation of the factors that influence the efficiency

By considering the results obtained for Voc, it can be reasonably assumed that no solar cell was broken. The reduction in the efficiency due to a decrease in the transmission factor of the lens might be considered, but FF should not be neglected in such a case. On the other hand, one may say that solar tracking errors occurred and influenced the efficiency from reduction in FF and changes in the shapes of the I-V curves.

Therefore, it is reasonable to assume that the reduction in the system efficiency is not because of the deterioration of the solar cells, but the influence of solar tracking errors.

By considering the reduction in FF, the tracking error was estimated at 0.4-0.7°.

5. Conclusion

In this study, the long-term system performance of a prototype of a CPV system was estimated along with the system efficiency. In addition, the factors that influence the efficiency of the system were investigated using the open-circuit voltage, fill factor, and I-V curve data for the CPV module.

The following results were obtained: (1) the daily average efficiency decreased by about 2.2 points over three years, (2) it can be reasonably assumed by considering the values of Voc that no solar cell was broken, and (3) it appeared that solar tracking errors influenced the reduction in the system efficiency.

In the future, a more detailed analysis of the influence of solar tracking errors on the fill factor and I-V curves would be required.

References

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