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B. Kroposki and R. Hansen

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National Renewable Energy Laboratory
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Golden, Colorado 80401-3393
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Improvements in the Performance of a 1-kW Copper Indium Diselenide Array

Benjamin Kroposki and Robert Hansen

National Renewable Energy Laboratory
1617 Cole Blvd., Golden, CO 80401

Abstract. A new copper indium diselenide (CIS) array installed at the National Renewable Energy Laboratory (NREL) shows a marked improvement over the previous generation in terms of power output and efficiency. The new array is part of NREL's technical validation, started in 1992, of small (1-2 kW) thin-film systems. The purpose of this testing is to evaluate the performance and reliability of thin-film modules in a system application. The first array had a rated power at 969 W and an average efficiency of 7.2% at standard test conditions (STC). The second array is rated at 1008 W, and the average efficiency is 9.0% at STC. The data in this paper shows that the new CIS modules have improved by about 37% in relative efficiency under actual operating conditions. The new array's results demonstrate that Siemens Solar Industries has made significant improvements in the performance of their large-area CIS modules.

INTRODUCTION

A new copper indium diselenide (CIS) array from Siemens Solar Industries which was installed June 1997 at the National Renewable Energy Laboratory (NREL) and has shown a marked improvement over the previous generation in terms of power output and efficiency. The new array is part of NREL's technical validation, started in 1992, of small (1-2 kW) thin-film systems. The purpose of this testing is to evaluate the performance and reliability of thin-film modules in a system application.

SYSTEM BACKGROUND

The NREL Outdoor Test Facility (OTF) is located at 39.7°N latitude, 105.2°W longitude, at an elevation of 1,782 meters. Arrays at the test site are fixed at a 40° tilt and aligned true south. The first installation of a large-area array of CIS modules (Array #1) from Siemens Solar was completed in September 1993. Data acquisition commenced in April 1994. This group of 34 CIS modules was subjected to accelerated environmental testing by Siemens Solar prior to deployment. The second group (Array #2) of 28 modules replaced the first group in June 1997.

MODULE DESIGN

Each module from Array #1 consisted of 53 series-connected cells that were monolithically integrated on a glass substrate [1]. This group of modules also had a reaction-injected molded frame that showed signs of weathering. The modules measured 3946.3 cm^2 in aperture area. The average module from this group had the following electrical characteristics at standard test conditions (STC): P_{max} = 28.5 W, V_{max} = 15.56 V, V_{oc} = 22.38 V, I_{max} = 1.832 A, and I_{sc} = 2.264 A. Using the average max-power, the summation of module maximum powers at STC is 969 W, and the average efficiency is 7.2% [2].

In Array #2, each module consisted of 16 sub-modules with 50 series-connected cells that were integrated into a single module. These modules are designed to fit into the standard Siemens M55-module aluminum mounting rails. The modules had a measured aperture area of 4000 cm^2. The average module from this group had the following electrical characteristics at STC: P_{max} = 36 W, V_{max} = 18.0 V, V_{oc} = 25.3 V, I_{max} = 2.0 A, and I_{sc} = 2.4 A. Using the average max-power, the summation of module maximum powers at STC is 1008 W, and the average efficiency is 9.0%.

SYSTEM CONFIGURATION

Each array is divided into three separate subarrays. Each subarray is connected to an individual peak-power tracker. The outputs of the three peak-power trackers are tied to a common 0.95-ohm, 2-kW fixed resistive load.

The arrays are configured with a Campbell Scientific data acquisition system (DAS). The DAS collects data every 5 s and saves 15-min averages. The data taken on the arrays include: plane-of-array irradiance, dc voltage (max), dc current (max), array temperature, and air temperature. The dc power of the array is determined from multiplying the dc voltage and current.

SYSTEM PERFORMANCE

For the following graphs, the data were restricted to irradiance levels between 950 – 1050 W/m^2. Figure 1 shows the efficiency, array temperature, and air temperature of Array #1 for the period April 1994 to May 1997. This graph shows a large fluctuation in array efficiency over the seasons, which is because of the large effect that temperature has on module performance. The efficiency ranges between 4.8% during the summer and 6.8% during the winter. The array has an average efficiency of 5.7%. The array shows a 30% fluctuation from the peak in winter to the low in summer.

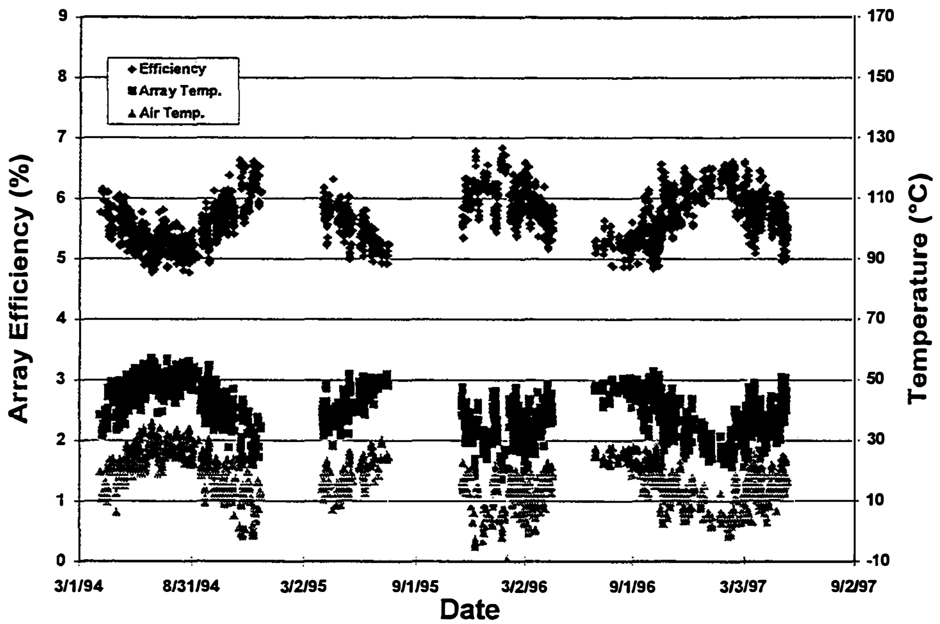

Figure 1. Array #1 efficiency, array temperature, and air temperature.

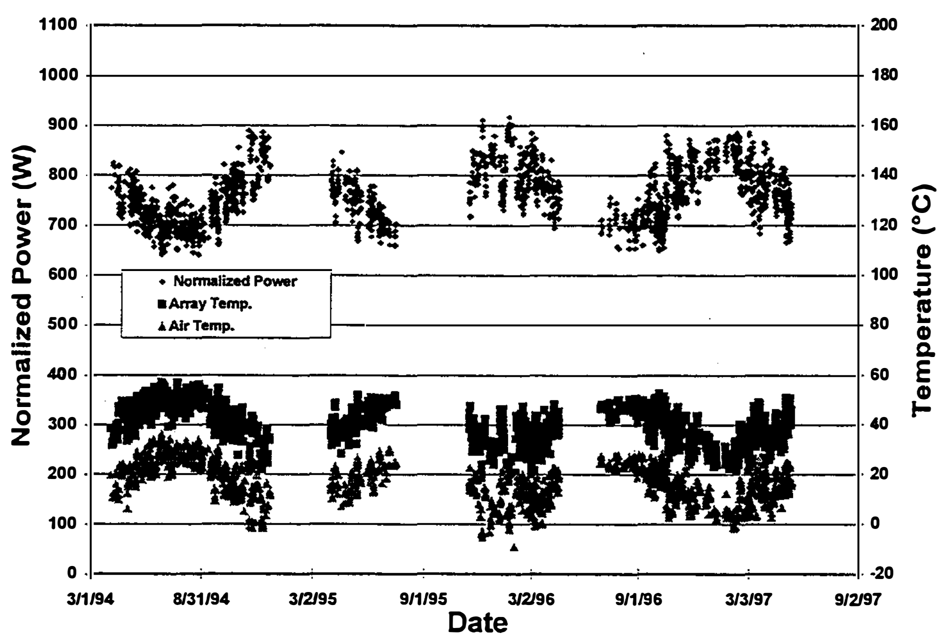

Figure 2. Array #1 normalized DC power, array temperature, and air temperature.

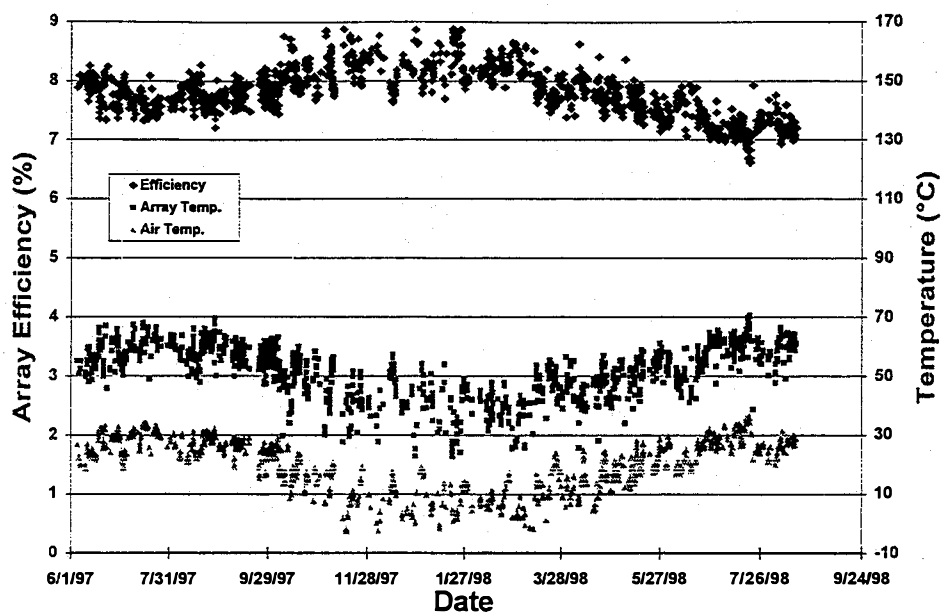

Figure 3. Array #2 efficiency, array temperature, and air temperature.

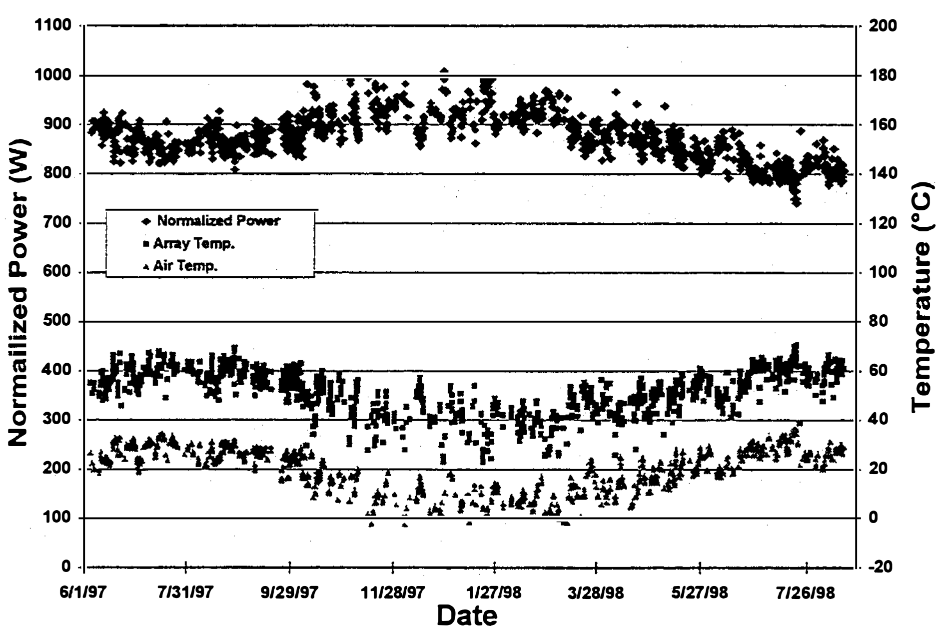

Figure 4. Array #2 normalized DC power, array temperature, and air temperature.

Figure 2 shows the normalized dc power, array temperature, and air temperature for Array #1. The data are normalized to 1000 W/m^2. The power of the array varies from 920 to 640 watts. The average power output was 760 watts, the average array operating temperature was 40.5 °C, and the average air temperature was 17.3 °C over the time period.

Figure 3 describe the performance of the new CIS array (Array #2). Figure 3 shows the array efficiency, array temperature, and air temperature for the period June 1997 to August 1998. The array efficiency varies from a high of 9.0% to a low of 6.6% and has an average of 7.8%. The array shows a 26% fluctuation from the peak in winter to the low in summer.

Figure 4 shows the normalized dc power, array temperature, and air temperature for Array #2. The data are normalized to 1000 W/m^2. The power of the array varies from 1010 to 740 watts. The average power output was 870 watts, the average array operating temperature was 52.3 °C, and the average air temperature was 20.5 °C over the time period.

CONCLUSIONS

Table 1 gives a summary of each array's performance at STC and under actual operating conditions. The STC data are based on individual module data taken indoors under a simulator. The outdoor data were taken in a system configuration and includes losses for wiring and peak-power-tracking accuracy. The average module power at STC has also been improved from 28.5 W to 36 W. The results also show that the new CIS modules have improved by about 37% in relative efficiency under operating conditions. The new CIS module results demonstrate that Siemens Solar thin-film technology has made significant improvements in the performance of its large-area modules.

Table 1. Summary of Array Performance

		At STC		Under Actual Operating Conditions			
Array	**# of modules**	**Efficiency (%)**	**Power (W)**	**Average Efficiency (%)**	**Avg. Power (W)**	**Array Temp. (°C)**	**Air Temp. (°C)**
#1	34	7.2	969	5.7	760	40.5	17.3
#2	28	9.0	1008	7.8	870	52.3	20.5

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