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Technical Evaluation of Four Amorphous Silicon Systems at NREL

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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B. Kroposki and R. Hansen
National Renewable Energy Laboratory
Golden, Colorado

ABSTRACT

The National Renewable Energy Laboratory (NREL) has been studying the performance of small grid-tied systems since 1992. These 1 to 2 kW_{ac} systems are designed to conduct in-situ technical evaluations of the PV arrays in a high voltage configuration. This paper will concentrate on the performance and reliability of four amorphous silicon systems currently being tested in Golden, Colorado. The four systems include arrays from United Solar Systems Corp., Solarex, and Advanced Photovoltaic Systems. Each of these systems is tied to the grid with an Omnion inverter. The data show that most systems employing amorphous silicon exhibit stable performance over time and are viable for commercial scale up to larger systems.

INTRODUCTION

The National Renewable Energy Laboratory has been conducting in-situ technical evaluations on the performance of small 1to 2 kW_{ac} grid-tied systems since 1992. This paper examines the performance and reliability of four amorphous silicon (a-Si) systems currently being tested in Golden, CO. The four systems include arrays from United Solar Systems Corp. (USSC), Solarex, and Advanced Photovoltaic Systems (APS). Each of these systems is tied to the grid with an Omnion inverter. This research focused on determining the amount of initial degradation, annual degradation and seasonal fluctuation in the systems' power output. The array's operating temperature will also be examined to determine whether they have any effect on performance.

EXPERIMENTAL PROCEDURE

System Descriptions

The first system installed at NREL is the 1.8 kW a-Si/a-Si system from USSC. A photograph of this system is shown in Fig. 1. This system was commissioned on December 7, 1992. When the system was deployed it originally contained 96 modules. The output of the system did not meet rated system ac output of 1.8 kW. Six additional modules were then added to the array on April 19, 1993, for a total of 102 modules. As a consequence of adding the six modules, data before April 20, 1993, have been multiplied by 102/96 (1.0625) for this paper. The PV array consists of 102 modules configured in a bipolar system with six strings. The modules are dual-junction same-bandgap a-Si UPM-880 modules.

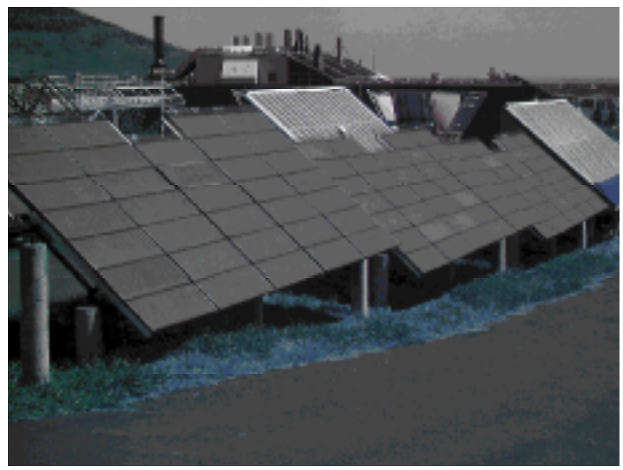

Fig. 1. USSC 1.8kW a-Si/a-Si system

These modules are unique due to the use of construction-grade insulation on the back of each module. This use of insulation is an attempt to levelize the annual array power by increasing the operating temperature of the modules. The array is connected to the utility grid through an Omnion Series 2200 inverter rated at 2 kW_{ac}. This system is installed at a fixed 40• tilt [1].

Fig. 2. USSC 1kW roofing system

The second system installed is the integrated/direct-mount PV roofing module system from USSC. The modules are mounted on simulated roof attics and are shown in Fig. 2. This system was commissioned on September 3, 1993. Data collection started on January 7, 1994. The modules were deployed and short-circuited prior to the connection of the data acquisition system. The PV array consists of 64 a-Si/a-Si modules that are identical in structure to the UPM-880. The system consists of four strings connected to the utility grid through an Omnion Series 2200 2 kW_{ac} inverter. This system is installed at a fixed 40• tilt [2].

The third system installed is from Solarex. The modules used in this system were research prototypes of the new dual-junction, dual-bandgap amorphous silicon developed at Solarex. The system was commissioned on October 11, 1995. The PV array is made of 48 MST-22ES modules. The system consists of 8 strings connected to an Omnion Series 2200 2 kW_{ac} inverter. This system is installed at a fixed 40• tilt. A picture of the Solarex array is shown in Fig. 3.

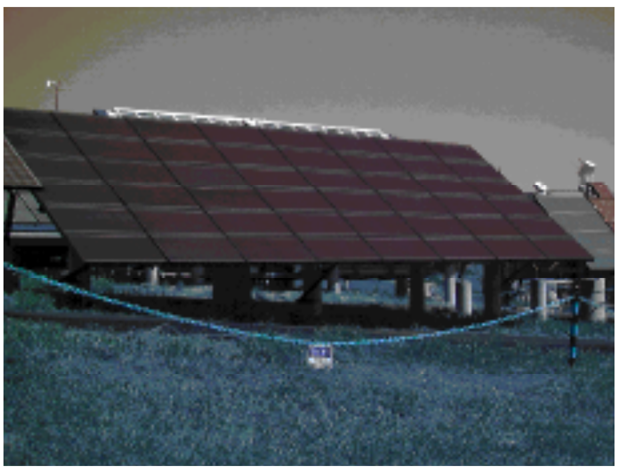

Fig. 3. Solarex 1 kW a-Si/a-Si:Ge system

The fourth system is a 1.5kW a-Si system from APS. The system was commissioned on June 20, 1996. This system uses single-junction a-Si modules and is mounted at a 20• tilt on a unique one-axis tracking structure known as the delta-tracker. This system was purchased as a turn-key system and the modules were commercially available. APS has since gone out of business, but the single-junction a-Si process is being pursued by several other companies. The array is connected to the grid with an Omnion Series 2200 inverter. A photograph of the APS system is shown in Fig. 4. Table 1 gives a summary description of the four amorphous silicon systems.

System Data Acquisition Systems

Each system has an independent data acquisition system (DAS). The DAS is based on a Campbell Scientific data logger. The data are sampled every 5 s and are stored as 15-min averages, except for the USSC 1.8 kW system, which stores hourly averages. Data collected include dc currents and voltages, ac currents and voltages, plane-of-array (POA) irradiance, array temperature, ambient temperature, and inverter temperature.

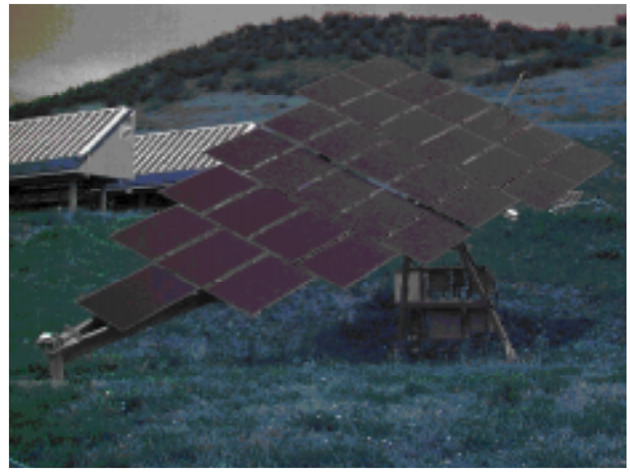

Fig. 4. APS 1.5 kW a-Si system

Table 1. Description of a-Si Systems at NREL

Manu-facturer	Module	Structure	Rated Size (AC)	Inverter	Date Installed
USSC	UPM-880	a-Si/a-Si	1.8 kW	Omnion 2200	12/92
USSC	Roofing Prototype	a-Si/a-Si	1 kW	Omnion 2200	9/93
Solarex	MST-22ES Prototype	a-Si/a-Si:Ge	1 kW	Omnion 2200	10/95
APS	EP-55, EP-60	a-Si	1.5 kW	Omnion 2200	6/96

RESULTS AND DISCUSSION

For the following graphs, the data were restricted to plane-of-array (POA) irradiance between 950-1050 W/m², except for the APS array, which is between 850-1050 W/m² during December and January. The dc and ac powers are normalized to 1000 W/m².

USSC 1.8 kW a-Si/a-Si System Performance

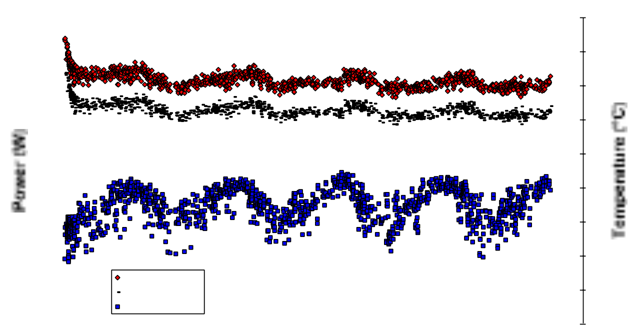

Fig. 5 shows the dc power, ac power, and array temperature vs. time for the USSC 1.8 kW system. This graph shows that the system experienced an initial drop in power of about 12% due to initial light-induced degradation [3]. After an initial 6-month period, the average dc and ac power values were 1891 W and 1664 W, respectively. The array temperature averaged 61• C during this time. Although the air temperature is not recorded on the graph, the average air temperature was 18• C. The array temperature is elevated by the use of construction-grade insulation on the back of each module. The high operating temperature does not appear to improve the performance of the array. Over the almost 5-year period of study, the system shows approximately a 5% degradation in performance. This degradation in system performance of 1% per year is actually less than other reported crystalline-Si PV arrays [4].

Fig. 5. Performance of USSC 1.8 kW System

The array also shows a distinctive seasonal fluctuation. The array power changes approximately 10% between a high in summer and a low in winter. This effect is suspected to involve the thermal annealing of the modules and more-favorable spectra during the hot summer conditions, and continued light-induced degradation in the modules and less-favorable spectra during the winter months [1]. The 10% seasonal fluctuation is consistent with other a-Si systems described in the literature [5,6].

USSC 1 kW Roofing System Performance

The USSC 1 kW roofing system performance vs. time is shown in Fig. 6. The initial degradation of this system is not shown because the DAS was not completed until 5-months after the initial exposure. The average dc and ac power values of the system are 1240 W and 1138 W, respectively. Over the almost 4-year test period, the modules do not show any degradation in the power output. This system also shows the same seasonal variation of approximately 10% from summer to winter as the USSC 1.8 kW system. The average array temperature was 44• C, and the average air temperature was 18• C. The array operated at an average 26• C above the air temperature. These modules are directly integrated into the attic roof structure (with no air gap) and take the place of asphalt shingles. Even though they are mounted to the roof, they do not operate at higher temperatures than modules on open-air racks such as the Solarex array.

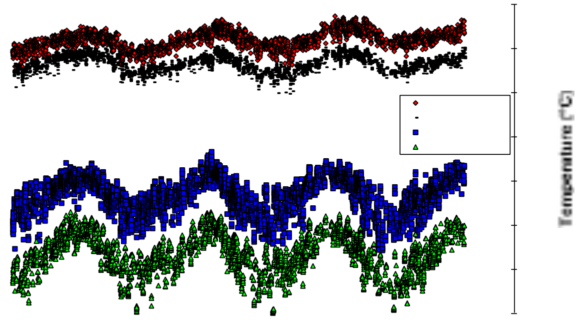

Fig. 6. Performance of USSC 1 kW roofing system

Solarex 1 kW a-Si/a-Si:Ge System Performance

The performance of the Solarex 1 kW array is shown in Fig. 7. Gaps in this data set appear because of problems with inverters and/or individual modules. Data for these times are removed. This graph gives dc power, ac power, array temperature, and air temperature vs. time. The system has an initial degradation of about 16%. After the first 6-months of exposure, the average dc power is 994 W and the average ac power is 889 W. The power also exhibits a 10% seasonal fluctuation between summer and winter, as seen in the USSC systems. Over the 2-year test period, the system's performance appears to have stabilized. During the test period, the average array temperature was 47• C and the average air temperature was 18• C. Therefore, the array operated at about 29• C above ambient conditions.

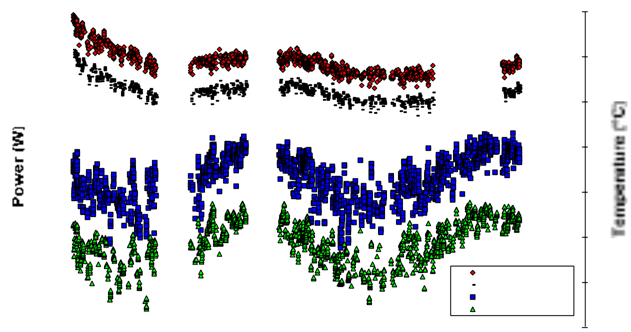

Fig. 7. Performance of Solarex 1 kW System

APS 1.5 kW a-Si System Performance

The performance of the APS a-Si system is shown in Fig. 8. Because of the low tilt angle of the array, the amount of data between 850-1050 W/m[2] is small. The array experienced a 23% degradation in the first 6-months of exposure. After the first six months, the average dc and ac power values were 1157 W and 1036 W, respectively. The power fluctuates about 6% between winter and summer. The average array temperature for the time period was 51• C and the average air temperature for the time period was 20• C. These are slightly higher than normal due to the data restrictions. The system performance appears to be stabilizing even though there is only 1 year of data. This system was constructed from 20 EP-55 modules and 10 EP-60 modules. The rated output under PVUSA test conditions (1000W/m[2], 20• C ambient temperature, and AM1.5 global spectrum) was to be 1.5 kW_{ac}. This compares to the average measured power output of 1036 W. We can see that the output of this system is considerably less than the rating.

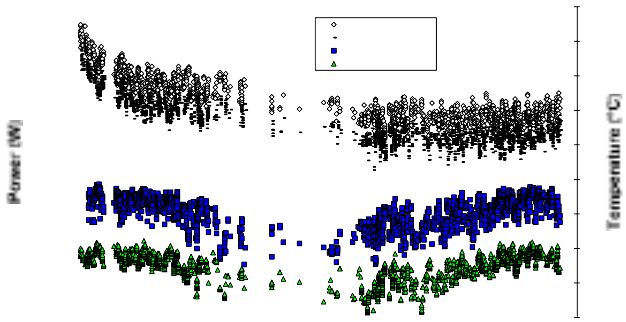

Fig. 8. Performance of APS 1.5 kW system

CONCLUSIONS

The performance of the four systems shows that amorphous silicon is a viable technology for use in future PV systems. The systems show excellent stability after the period of initial degradation. Two of the arrays with long-term data exhibit degradation trends equal to or better than crystalline-silicon systems.

The average initial degradation for the dual-junction arrays was 14%, where as the initial degradation for the single-junction array was 23%.

Seasonal fluctuations ranged from 6% to 10% for the arrays. The system performance also shows the well-documented seasonal changes in performance exhibited by amorphous silicon. This effect is probably due to thermal annealing of the modules and more favorable spectra during the hot summer conditions, and continued light induced degradation in the modules and less favorable spectra during the winter months. For the dual-junction modules, it is suspected that the spectral shift from winter to summer (red to blue) also causes an increase in performance during the summer due to increasing fill factor.

The arrays' average operating temperatures ranged from 44• C to 61• C. The USSC 1.8 kW system operated much higher than the rest because of insulation attached to the back of each module. This insulation does not appear to improve performance compared with the other arrays. The higher operating temperature also does not appear to reduce the amount of degradation the array experiences.

Finally, all systems performed within 11% of their rated output, except for the APS system, which was 30% below its rated output. This shows the need for accurate systems ratings. Table 2 gives a summary of the systems' performance.

ACKNOWLEDGMENTS

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Table 2. Summary of System Performance

System	Initial Degradation	Yearly Degradation	Seasonal Fluctua-tion	Array Operating Temp.	AC Output
USSC 1.8kW	12%	1%	10%	61• C	1664 W
USSC Roof	-	<1%	10%	44• C	1138 W
Solarex	16%	NA	10%	47• C	889 W
APS	23%	NA	6%	51• C	1036 W

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