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OUTDOOR PERFORMANCE STABILITY AND CONTROLLED LIGHT-SOAK TESTING OF AMORPHOUS SILICON MULTIJUNCTION MODULES AT NREL

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ABSTRACT

The National Renewable Energy Laboratory (NREL) has been testing amorphous silicon (a-Si) Photovoltaic (PV) modules for more than a decade. NREL has been conducting controlled light-soak testing of multijunction a-Si modules to characterize their performance for stability evaluation as well as to benchmark the technology status. Some of the test modules, after controlled light-soak testing, have been installed outdoors. We have observed that under outdoor exposure, the modules further degrade in performance, possibly due to lower outdoor temperatures and varying spectra. The paper presents data on the light-induced degradation for the third controlled light-soak test on multijunction a-Si modules as well as outdoor performance data on single- and multijunction modules under prevailing conditions.

INTRODUCTION

The National Renewable Energy Laboratory (NREL) has been testing amorphous silicon (a-Si) photovoltaic (PV) modules since 1984, when the modules first became commercially available. Over the last few years, the technology focus, to a large extent, has been shifting from single-junction cell structure to multijunction configuration for reasons of higher efficiencies and improved stability. NREL has been conducting both outdoor and indoor controlled light-soak testing of multijunction a-Si modules to characterize their performance for stability evaluation and to benchmark the status of the technology. The controlled testing has been conducted in an environmental chamber with a fixed module temperature of 50°C and an irradiance of 1 sun, for periods ranging from 600 h to 2000 h under fixed maximum-power resistive loads. Two series of controlled light soak tests have been conducted on vintage 1990 and 1991 multijunction a-Si modules.[1],[2] After controlled light-soak testing, some of the test modules were installed outdoors at NREL's PV Outdoor Test Site to study their outdoor performance. We have observed that under outdoor exposure, the modules degrade further in performance, possibly due to lower outdoor temperatures and varying spectra.[3] A third series of controlled light-soak testing at NREL was initiated in 1994 and encompasses test specimens from major multijunction a-Si module manufacturers. In parallel with this controlled indoor light-soak testing, some of the modules were deployed outdoors. The controlled light-soak test was performed, and 250 h data, in addition to one year of outdoor performance data, have been collected.

This paper presents the above-described long-term data on the outdoor performance of commercially procured single- and multijunction modules under prevailing conditions, as well as data on the performance of multijunction a-Si modules under outdoor exposure after the modules had been light-soaked under controlled conditions for a period of 2000 h.

COMMERCIALLY PROCURED SINGLE- AND DUAL-JUNCTION a-Si MODULES

Single-Junction a-Si Modules:

Figure 1 illustrates the performance of two single-junction, large-area, power modules by a U.S. manufacturer. It shows the normalized (to 1000 W/m^2) outdoor performance of the modules after an outdoor exposure of approximately 2 years. The measurements were taken under prevailing outdoor conditions. The modules experienced approximately 25%-30% degradation in normalized power during the first 5 months of exposure. The data show that the modules have "stabilized" around 48-W normalized power. No temperature corrections have been applied to the data shown in the figure. Approximately 10% seasonal performance variation has been observed. Whether this seasonal variation is due to temperature or spectral effects is still being investigated.

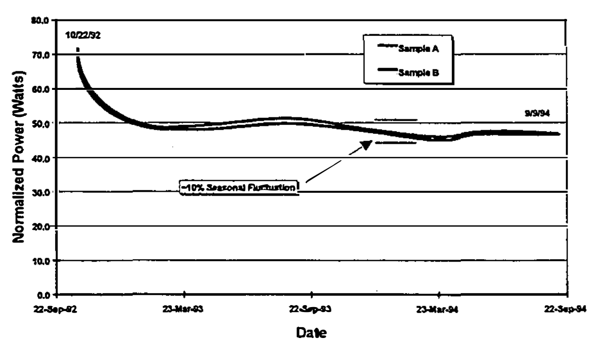

Figure 1. Single-junction a-Si performance

Dual-Junction a-Si Modules:

Figure 2 illustrates the performance of three commercially procured dual-junction a-Si modules under long-term outdoor exposure, since September 1991, at the NREL PV Outdoor Test Site. Current-Voltage (I-V) curve data were taken once every day around noon, when the irradiance was above 750 W/m^2. The power output is normalized to 1000 W/m^2; however, no temperature corrections are applied. The modules experienced an initial light-induced degradation of approximately 20%-25% in normalized power during the first few months of exposure. Since then, the modules appear to have stabilized in output, with seasonal performance variations of approximately 10%.

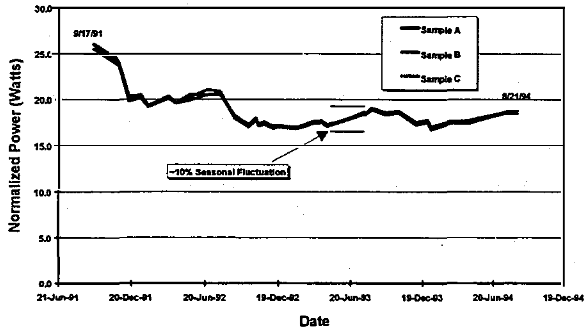

Figure 2. Dual-junction a-Si performance

LIGHT-SOAK TESTING OF PROTOTYPE a-Si MODULES:

The results of controlled light-soak tests #1 and #2 have previously been reported.[1,2] A few of the test modules from these experiments were then deployed outdoors for exposure testing at the NREL Outdoor Test Site. These modules are monitored periodically for stability performance characterization. The following paragraphs describe their outdoor exposure performance.

Outdoor Exposure of a-Si Modules after Light-soak Test #1:

Figure 3 illustrates the performance of one triple-junction and two dual-junction a-Si modules selected from the batch of modules in controlled light-soak test #1, in which the modules were light-soaked for a period of 2000 h. In NREL's light-soaking equipment, an environmental chamber with a filtered argon-arc light source simulating the solar AM1.5 spectrum (see Fig. 4) is utilized.[1],[2] The temperature uniformity of the test modules has been measured to be ±4°C, and the irradiance uniformity is within ±5%.

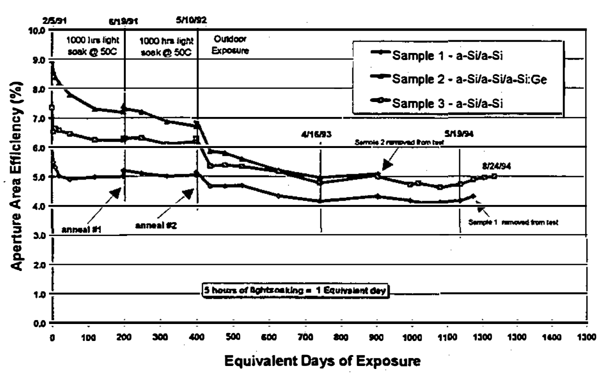

Figure 3. Performance of Light Soak #1 a-Si modules

These three modules were then deployed outdoors under maximum-power load resistors. The graph indicates a decrease in performance of approximately 10%-15% of initial efficiency during an outdoor exposure period of approximately 2 yr after the controlled light-soak exposure of 2000 h. The data highlight the differences in stabilized performance between the indoor and outdoor light-soak testing of multijunction a-Si modules. It indicates a potential need to revise the present indoor light-soak criteria of 1000 h of constant 1 sun illumination at the module operating temperature of 50°C for determining a-Si module stability.

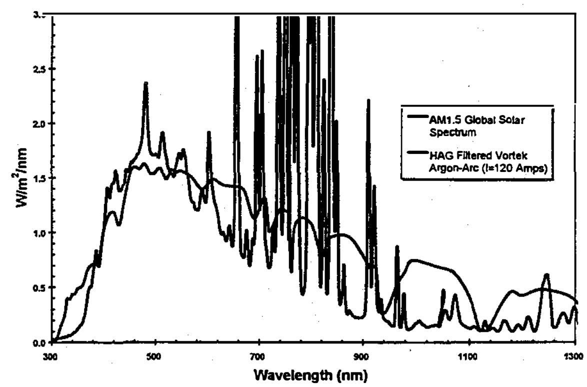

Figure 4. Comparison of Vortek argon-arc light source to ASTM standard solar Spectrum at AM1.5 global

Outdoor Exposure of a-Si Modules after Light-soak Test #2:

Figure 5 illustrates a similar difference in the indoor vs. outdoor stability performance for a dual-junction a-Si module selected from the batch of modules that completed the controlled light-soak test #2. This module, after completing 2000 h of controlled light-soak testing, was deployed outdoors at the NREL test site to determine the outdoor performance. Although the module had stabilized in performance under controlled light-soak test indoors, it experienced approximately 10% additional degradation outdoors. Though the module, whose performance is illustrated in Fig. 5, is of newer vintage than the modules used in light-soak test #1, the indoor vs. outdoor degradation differences are similar to the ones observed on the modules from light-soak test #1.

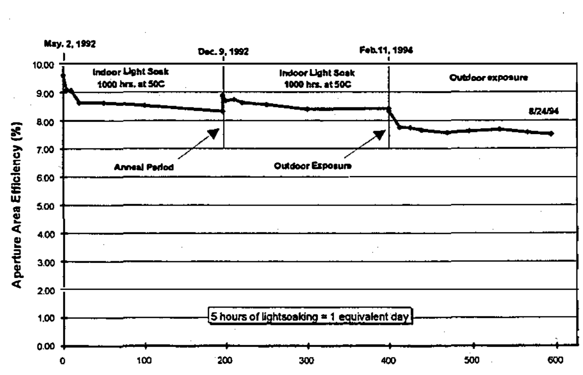

Figure 5. Performance of a Light Soak #2 a-Si module

Light-Soak Test #3 Results:

The controlled light-soak test #3 has completed 250 h of indoor light soaking. Several of the module types undergoing light-soak test #3 have also been deployed outdoors and have completed 1 year of outdoor testing. The multijunction a-Si modules that are part of this test are from several U.S. and foreign a-Si manufacturers. The comparison of indoor vs. outdoor stability performance of five selected modules from one manufacturer is presented in Fig. 6. These data also indicate higher outdoor light-induced degradation as compared to the controlled indoor light-soak test results similar to that observed from modules of light-soak tests #1 and #2.

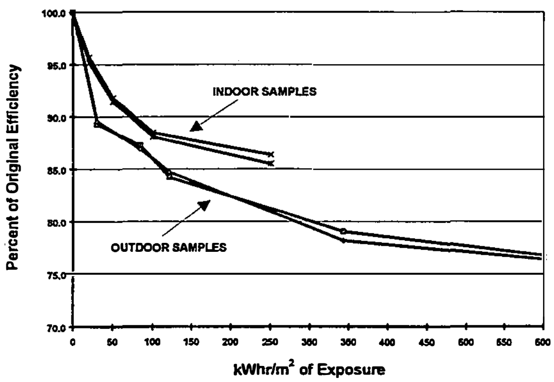

Figure 6. Indoor and outdoor performance comparison of triple-junction a-Si modules from Light Soak #3

CONCLUSIONS

The a-Si modules that were commercially procured a few years ago and have been under long-term outdoor testing at NREL have degraded approximately 25%-30% prior to "stabilization" outdoors. Most of the degradation observed is due to the initial light-induced degradation that occurs during the first few hundred kWh/m^2 of exposure. The modules show an approximately 10% seasonal power variation in Golden, Colorado. This may be due to temperature variations, spectral influences, or a combination of both.

Another issue that needs further investigation and resolution is that additional degradation is observed in the stabilized performance of a-Si modules when they are deployed outdoors (in Golden, Colorado) after having undergone controlled light-soak testing indoors at 50°C for 1000 h at 1-sun constant illumination. This could be due to light exposure at lower temperatures experienced outdoors or due to the cyclic nature of the outdoor exposure (in terms of both illumination and temperature). Several options of controlled light-soak testing are planned to reduce the differences in degradation between indoor and outdoor stability characterization of a-Si PV modules.

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