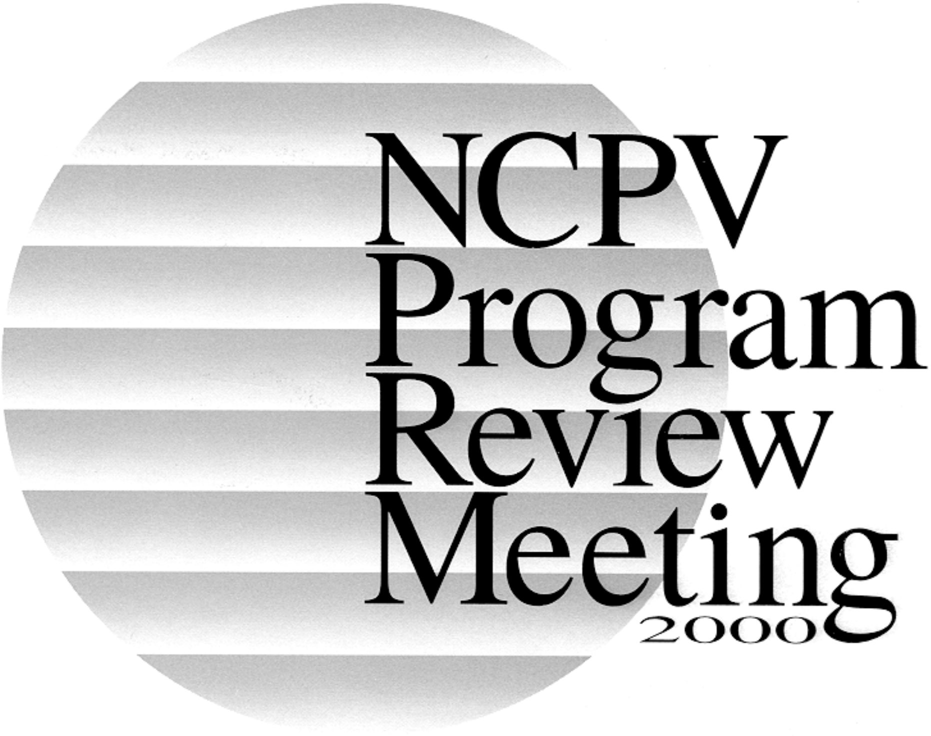
PROGRAM AND PROCEEDINGS



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Forward-Biased Thermal Cycling: A New Module Qualification Test

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ABSTRACT

Following a proposal by BP Solarex to modify the standard module qualification sequence, we performed forward-biased thermal cycling on three types of commercial modules to evaluate the procedure. The total number of thermal cycles was doubled to 400 and maximum power measurements were made every 50 cycles. During this test, we discovered several technical pitfalls that should be avoided. The results showed that current commercial modules are able to pass this proposed modification.

1. Introduction

Silicon modules deployed outdoors in systems are known to exhibit slow fill-factor degradation on the order of 1% per year. This has been attributed to gradual increase in series resistance associated with solder bonds [1]. In an attempt to test for susceptibility to such degradation, BP Solarex has proposed that a forward-bias current equivalent to the current at the maximum power point under 1-sun conditions be passed through modules during the thermal cycling portions of the standard qualification sequence [2].

The standard thermal cycling test consists of either 50 or 200 cycles (depending the sequence) of -40°C to +90°C module temperature excursions in 4- to 6-h cycles, with the test modules open-circuited [3]. Because modules in use have current flowing through them during daily temperature excursions, it was thought that a current bias during thermal cycling would simulate this degradation. We have therefore attempted to evaluate this procedure by performing biased thermal cycling on several types of commercial modules.

2. Test Design

We decided to evaluate biased thermal cycling by performing the test on three models of medium-power commercial modules. The models chosen were the Siemens Solar M55 Si, the ASE Americas 50-AL Si, and the USSC US-32 a-Si. In order to exaggerate the effects of the test, we chose to extend the test to 400 cycles total (this is double the number of the standard test), while stopping the test every 50 cycles to measure the performance. Rather than compare the effects against untested control modules, we compared them against modules that were thermal cycled at the same time, but were left open-circuited. The modules were cycled in a BMA Corp. 81-cu. ft. environmental chamber. Forward biasing was done with Kepco bipolar power supplies-amplifiers, operated in the current mode. Current-voltage (I-V) measurements were done using a Spire Corp. model 240A solar simulator at standard reporting conditions (25°C, 1000 W/m^2 global irradiance).

3. Technical Issues

The test program immediately showed a number of issues that must be dealt with if current biasing is to be included in the standard qualification test. First, the current biasing dissipates power that results in heating of the modules. Even though E 1171 specifies the temperature profile in terms of the actual module temperature, this heating makes it difficult to reach the -40°C low point of the cycle. We found that the temperature could be 6° to 8°C higher than the unbiased modules. Because of this, it is recommended that the biasing be turned off when the temperature is less than 0°C. The heating also affects the +90°C high point, although to a lesser amount (we noted a 2° to 4°C difference between the biased and unbiased modules). It is therefore important to measure the actual module temperatures and adjust the programming of the environmental chamber controls so that the correct profile is obtained.

Second, the dark current-voltage characteristics of a-Si modules changes greatly between -40°C and +90°C. In this test, the changes were so large that the power supply was unable to provide the correct amount of current to the USSC module during the low temperature excursion and changed over to voltage limit mode. This resulted in a much smaller amount of forward-bias current through the module. Fortunately, this issue can also be resolved by simply turning off the bias current during the low temperature portion of the cycle.

4. Results

Figures 1-3 show the normalized maximum power results for each of the three types of modules. The M55 showed little or no detectable difference between the biased and unbiased cases, with an 8% drop for the entire test. At the 200-cycle point, the drop was less than half of this amount, only 2-3%. This is much different from the a-Si US-32, which dropped 6% within the first 50 cycles when biased, with little additional degradation thereafter. The unbiased module changed very little. For the 50-AL case, the unbiased module dropped only a slight amount, while the biased module was about twice as much, to 2% overall.

The most striking result in Figures 1-3 was the initial a-Si drop. This was attributed to a forward-biased degradation mode similar to light-induced degradation in a-Si, but one that acts much faster [4]. If this were the case, it should be possible to anneal the modules and recover the lost power. IEEE 1262 has an annealing procedure that is intended to remove light-induced degradation from a-Si modules that are exposed to light during the qualification sequences [2]. This procedure consists of successive 24-h, +90°C anneals each followed by an I-V measurement. The steps are ceased when the performance changes by less than 1% from the previous step. Figure 2 shows the results of this procedure on the US-32 modules. Note that the biased module recovered almost half of its initial power.

5. Conclusions

This initial evaluation of the biased thermal cycling test showed, first of all, that the commercial modules tested are able to pass well within the degradation limits of IEEE 1262 [2]. Second, two of the three module types showed increased degradation when forward-biased. This implies that the procedure does stress the module interconnections more than unbiased test, and therefore meets the original objective. While none of the modules failed the qualification limits, we believe this test should cause failures in modules that have poor interconnections. Finally, the current biasing introduces a few complications over the standard test, but these can be overcome with some simple precautions.

6. Acknowledgements

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[4] T. McMahon, NREL, personal communication.

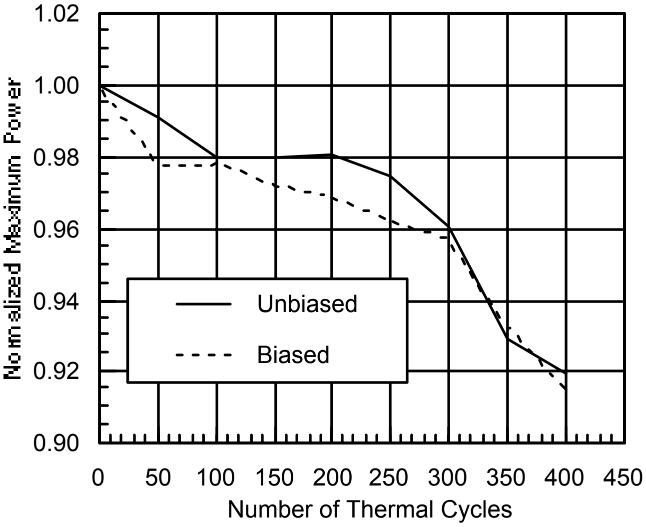

Figure 1. Normalized maximum power versus the number of thermal cycles for the Siemens M55 modules.

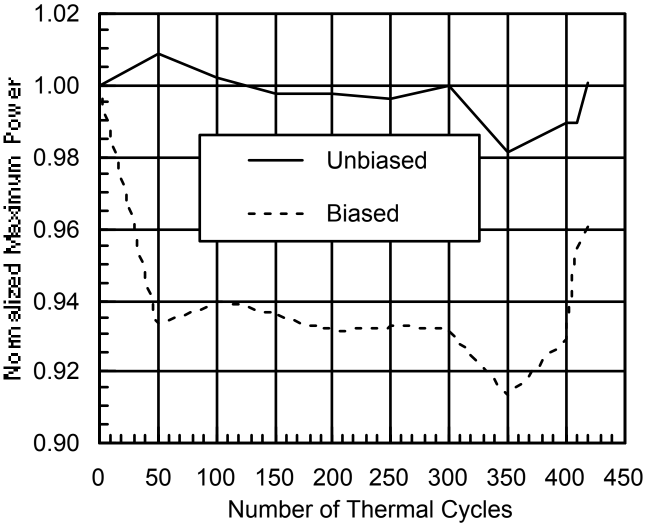

Figure 2. Normalized maximum power versus the number of thermal cycles for the USSC US-32 modules. The last two points are annealing steps.

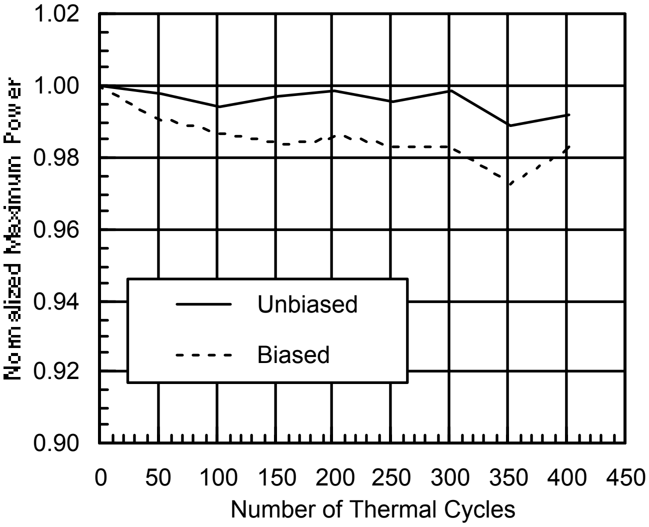

Figure 3. Normalized maximum power versus the number of thermal cycles for the ASE Americas 50-AL modules.