Light Soaking Effects in Commercially Available CIS/CIGS Modules

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Non-Confidential Information

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Background

- CIGS devices exhibit performance changes with continuous light exposure (a.k.a “light soaking”)
  - For literature summary, see Ref. [1]
- Therefore, preconditioning protocols needed for performance rating in the lab / factory
- Understanding of metastabilities needed for analysis of field performance data

Ref. [1]: “Light Soaking Effects On Photovoltaic Modules: Overview and Literature Review”, by M. Gostein and L. Dunn, presented at the 37th IEEE PVSC, Seattle WA, 2011.

Project Overview

- Objectives
  - Investigate CIGS performance changes with light soaking and dark relaxation
  - Demonstrate useful preconditioning protocols
  - Simulate effects of day/night cycles
- Experiment
  - Tests conducted on three commercially available CIGS modules from different manufacturers
  - Used Atonometrics Continuous Solar Simulator with integrated I-V system

Questions We Want To Answer

- What level of performance change can be seen upon light exposure for commercially available CIGS modules?
- How long must modules be exposed to light to stabilize?
- What effects may be seen outdoors with diurnal light/dark exposure?
- How quickly do modules relax in the dark?
- What are the implications for module performance rating protocols? In the lab? Outdoors?

Experimental Apparatus

Module Loading

Integrated I-V System

Atonometrics Continuous Solar Simulator & Light Soaking Chamber

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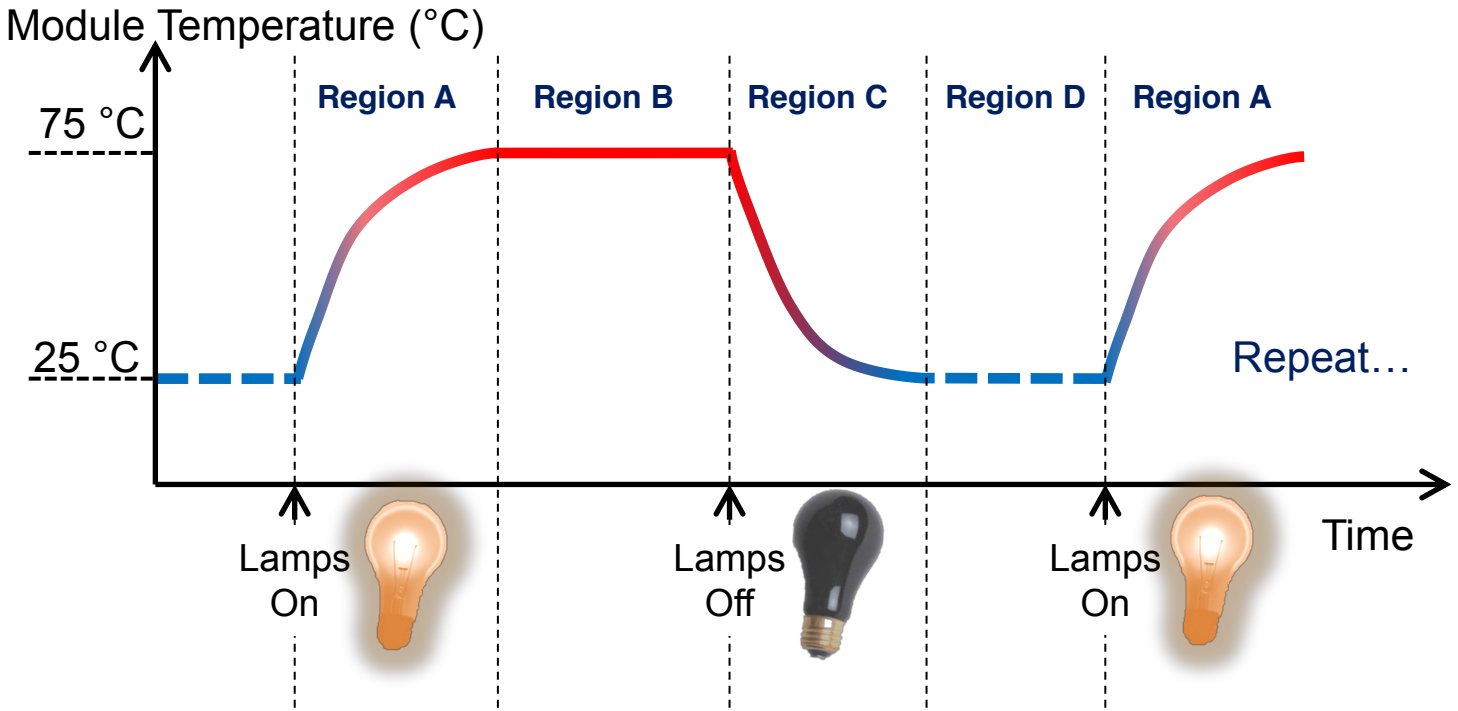
Experiment Details

- Tests performed using 3 different CIGS modules
  - Commercially available products
- All data corrected for light intensity and temperature to STC.
- Tests carried out at 1000 W/m^2
- Modules kept at MPP with periodic I-V curves taken.

- Future plans: explore module behavior with Voc and Isc tracking.

Test Recipe Diagram



Light Intensity	**1 sun**		**Dark**		**Repeat…**
I-V	**MPP with periodic I-V**		**None**		
Time	**<30 min**	**2-8 hrs**	**<30 min**	**1-16 hrs**	

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Dunn and Gostein, NREL 2012 PVMRW

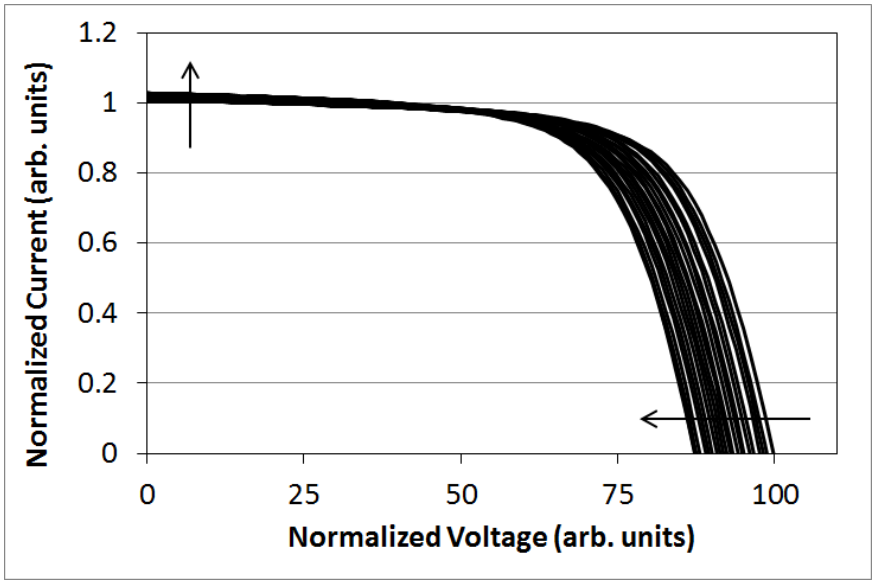
Test 1 Details

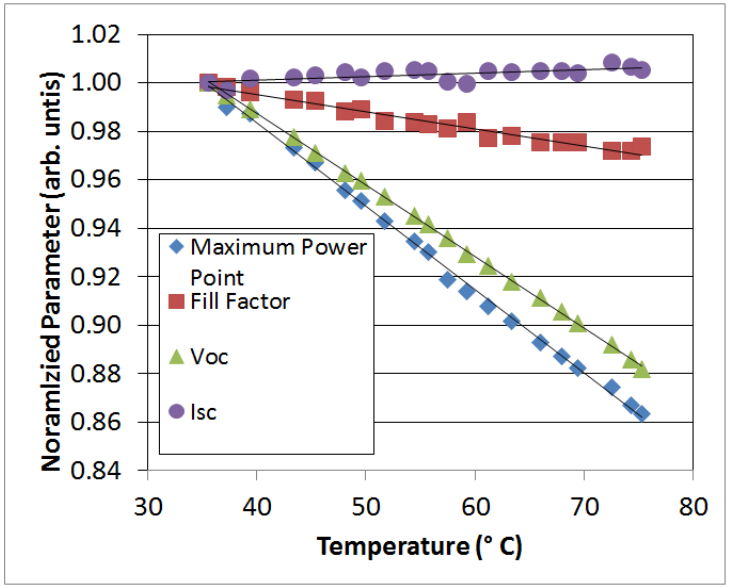
- Modules stabilized ~30 days in the dark prior to test
- Test Details:
  - Each cycle = 8 hours of light + 16 hours dark.
  - 16 day test (*i.e.*, 16 light/dark cycles)
  - Intensity: 1000 W/m^2
    - Measured using NREL-calibrated c-Si reference device
  - Module Temperature held at 75 °C after warmup
- Temperature coeffs. measured during module warmup.
- All I-V curves corrected to 25 °C and 1000 W/m^2.

Temperature Coefficient Extraction

- Temp. coeffs. extracted during module warmup
- Used temp. coeffs. to correct subsequent data to STC

Representative Temperature Coefficient Extraction Data for Module #3





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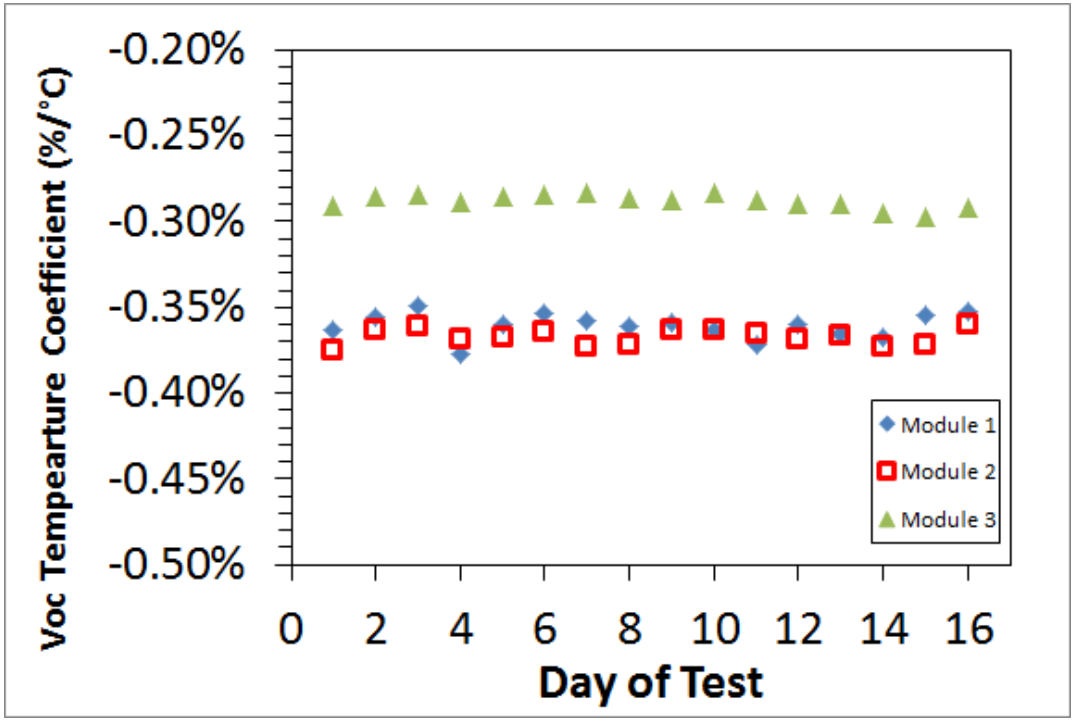
Compiled Voc Temperature Coefficients

- Extracted temperature coefficients were repeatable for multiple test cycles
- Temperature coefficients appeared stable for duration of test



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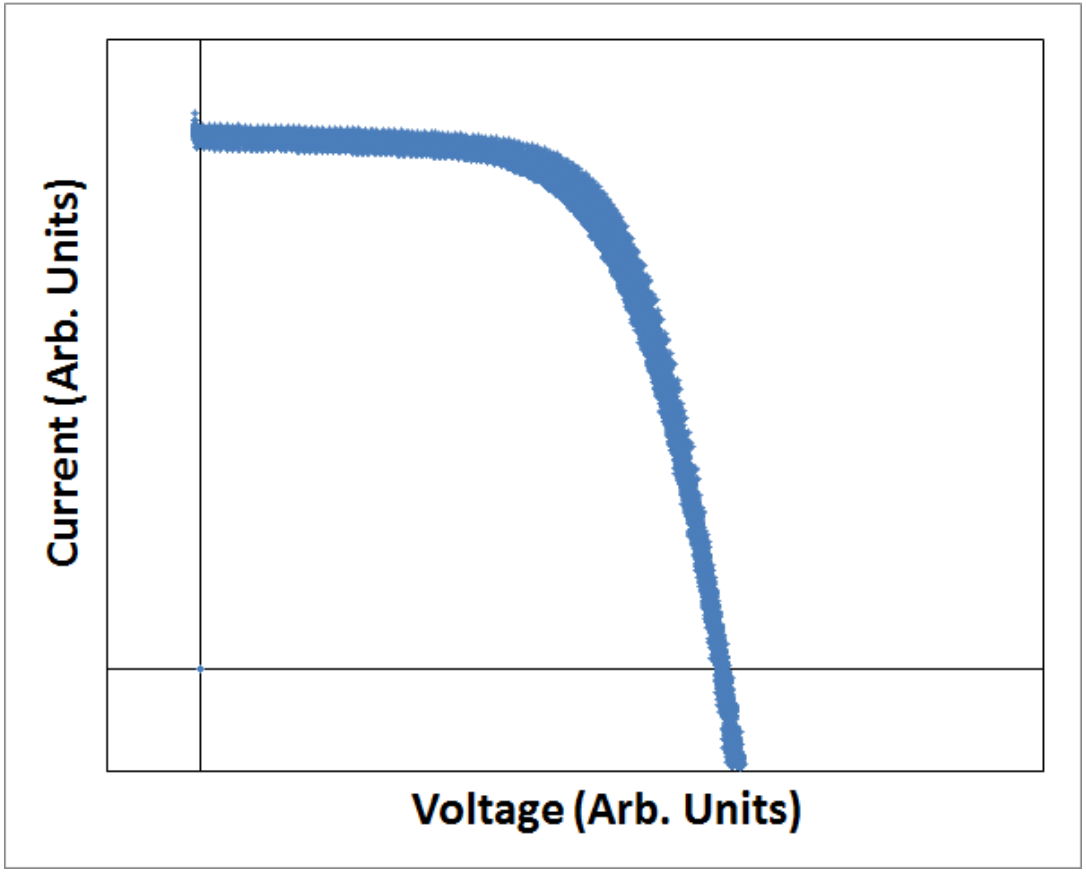
I-V Curve Correction to STC

- All I-V curves corrected for temperature and irradiance to 25 °C and 1000 W/m^2.

~1000 Representative I-V Curves for Module #1



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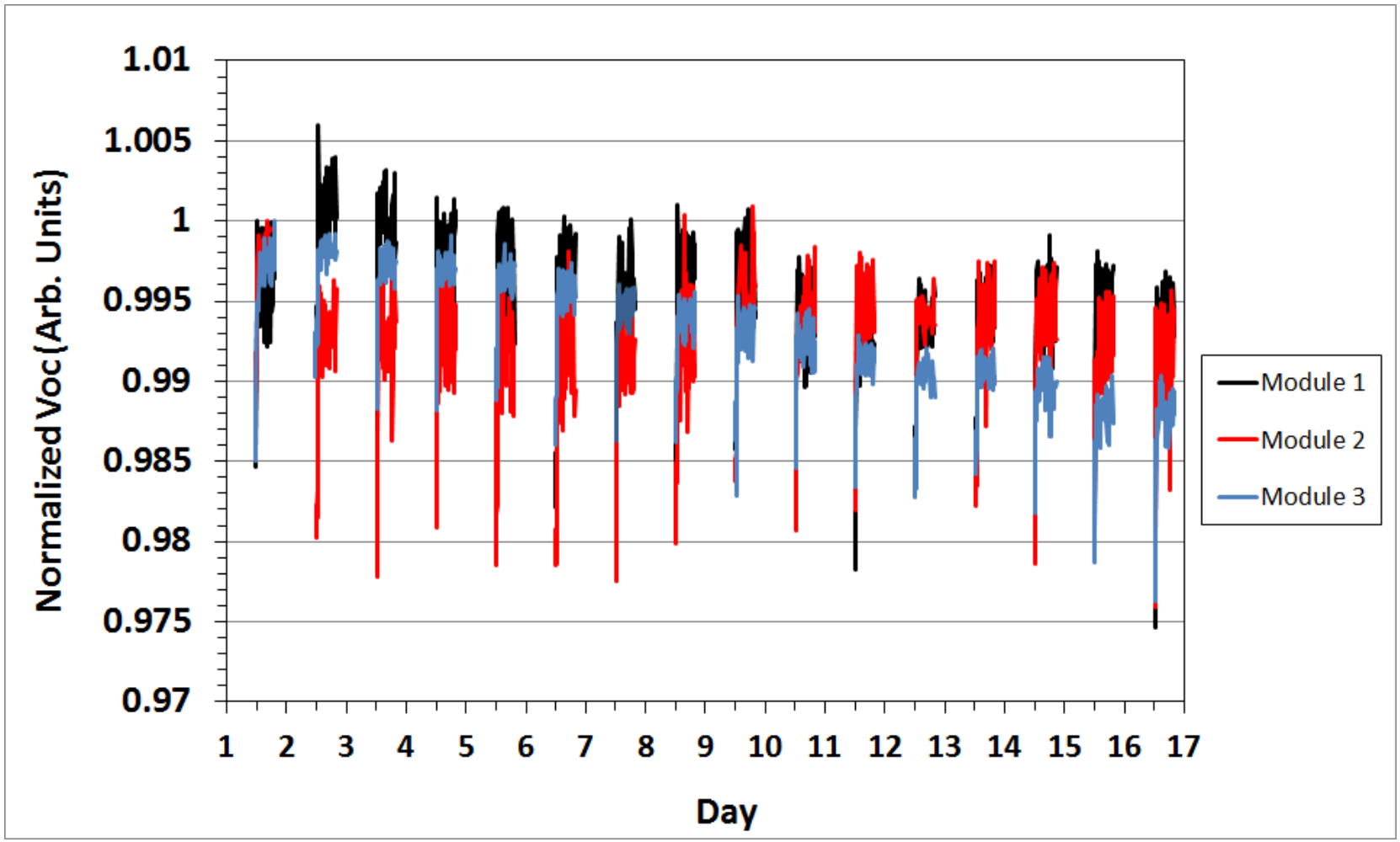
Test 1 Results: Normalized Voc



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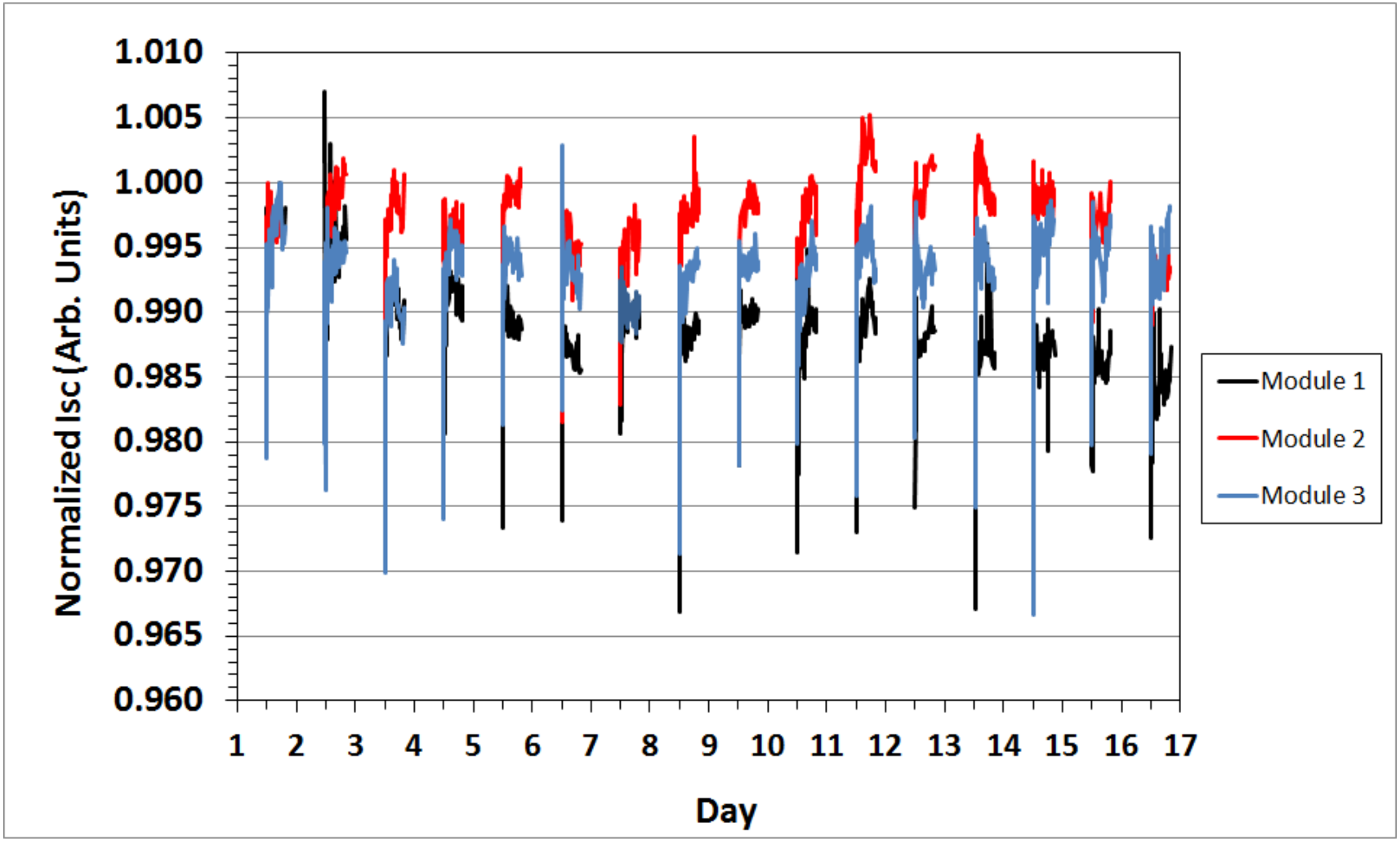
Test 1 Results: Normalized Isc



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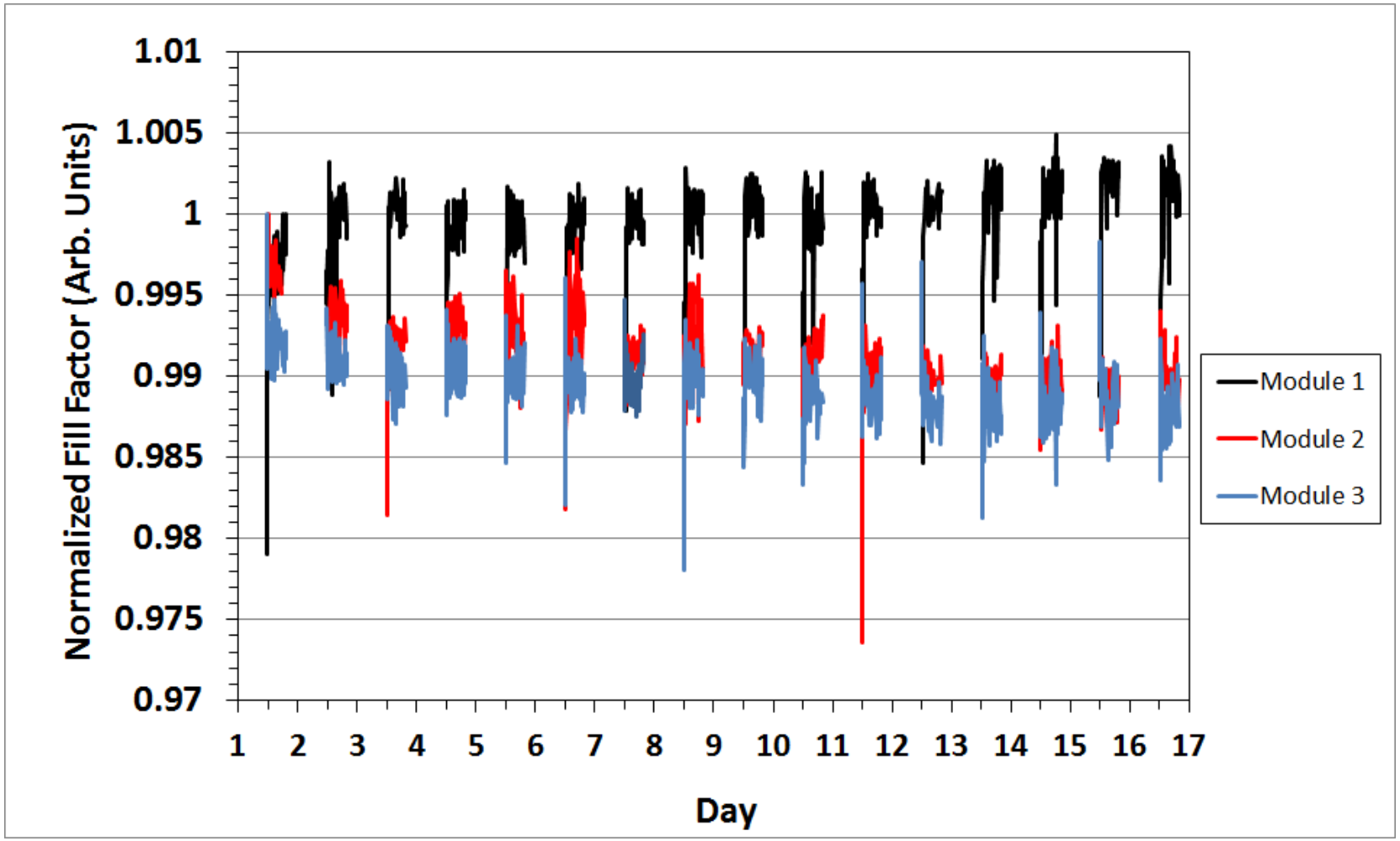
Test 1 Results: Normalized FF



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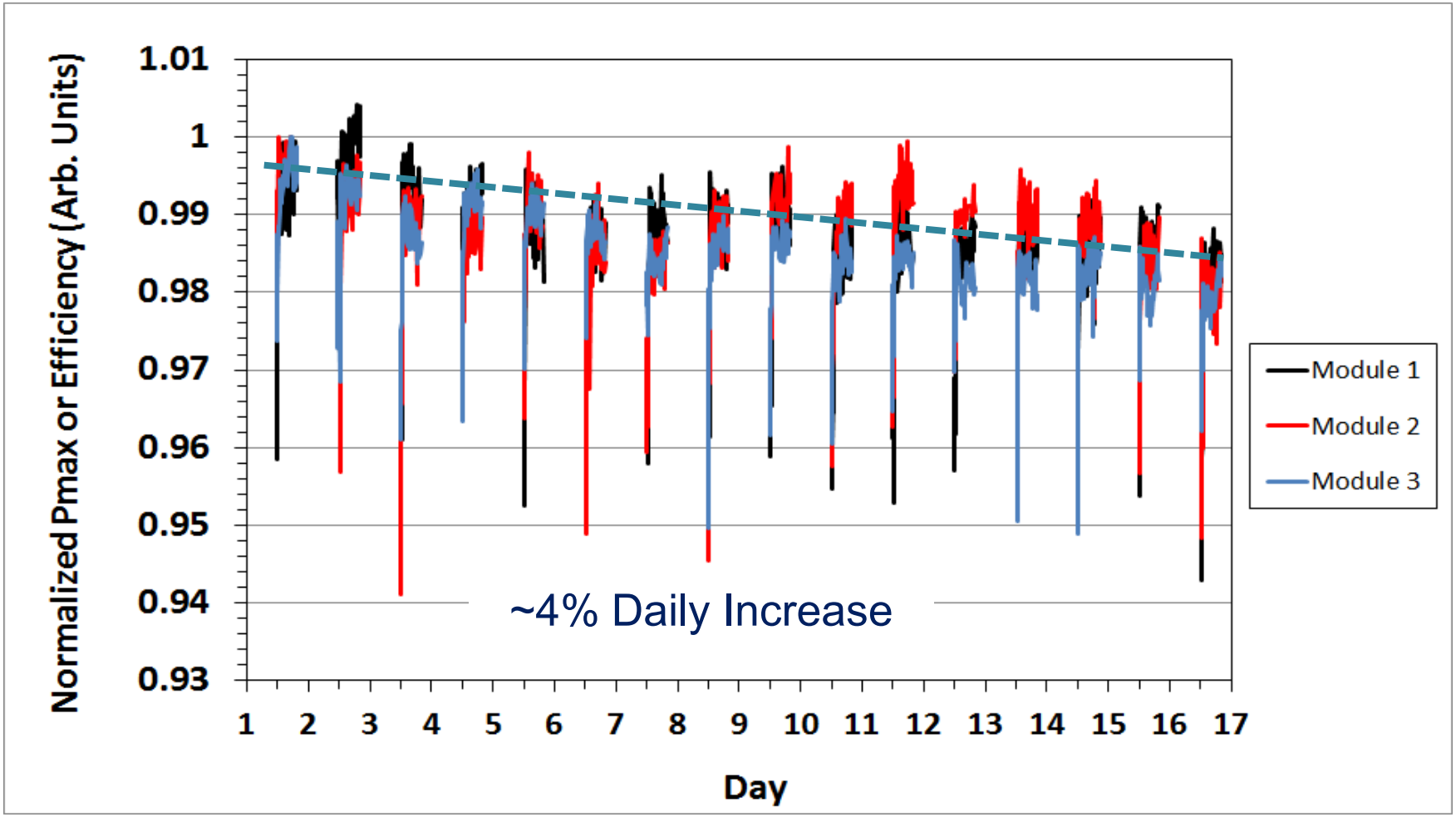
Test 1 Results: Normalized Efficiency



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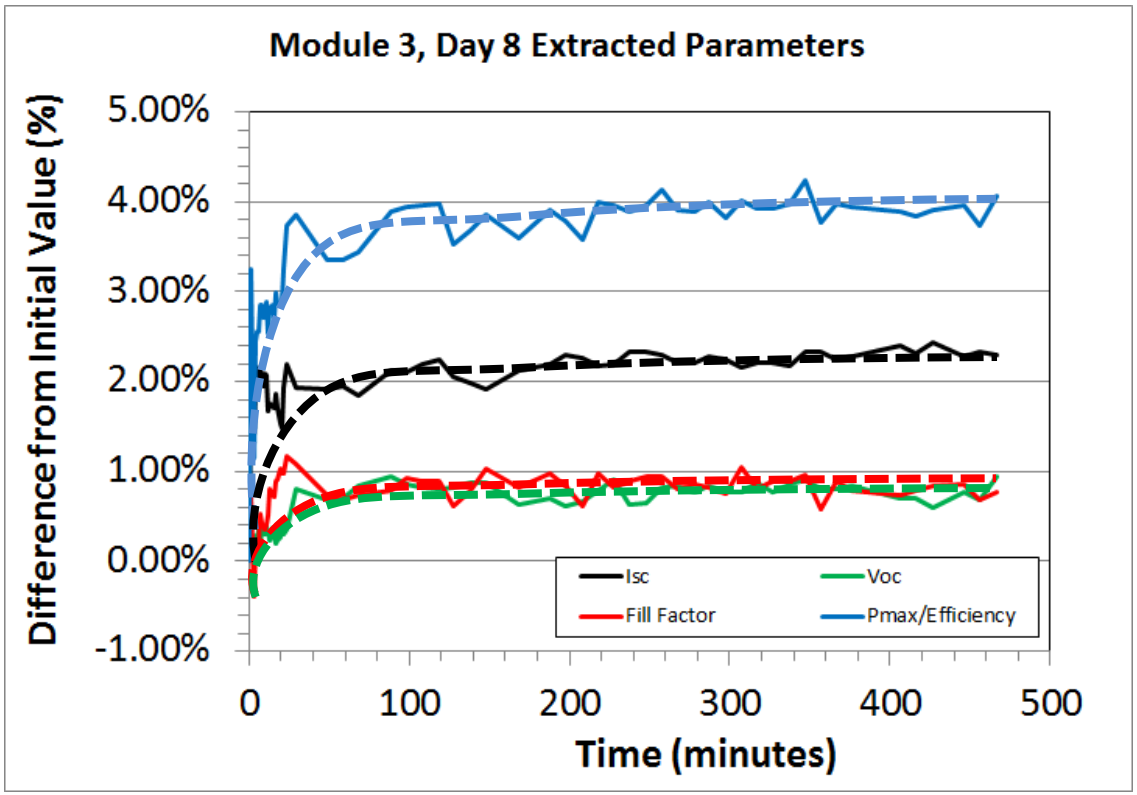
What is happening on a shorter time scale?



- Trends
  - FF -> FF * 1.01
  - Isc -> Isc * 1.02
  - Voc -> Voc * 1.01
  - Pmax -> Pmax * 1.04

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Test 1 Conclusions

- All 3 module types seemed to undergo an approximately 3%-5% relative increase in efficiency within one hour of light exposure.
- Modules seemed to fully relax during 16 hours in the dark.
- After 16 days the modules had experienced an approximately 1%-2% loss in stabilized efficiency from their initial value.

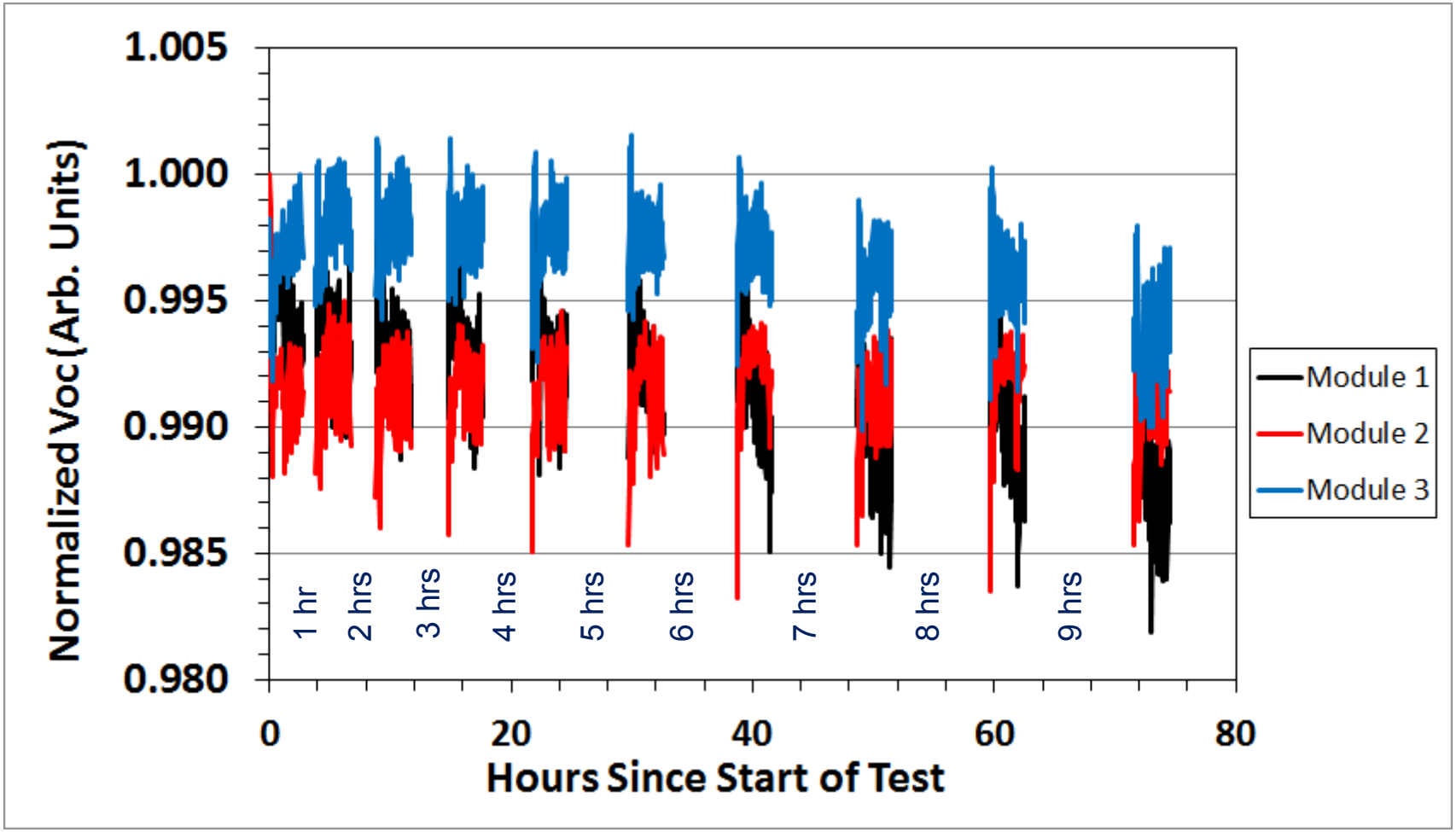
Test 1 Questions Raised

- After preconditioning, how long can modules remain in the dark before needing to be preconditioned again?
- How many cycles needed for long-term stabilization?
- How would this phonemenon change with module temperature? Irradiance Intensity? Electrical bias condition? Etc.?
- Are we correctly quantifying the effect? Could we be missing something in our test methodology?

Test 2 Details

- Goal: Determine dark relaxation time
- Test Details:
  - Modules held in the dark 7 days prior to start
  - Each cycle: 2.5 hrs light exposure + variable time in the dark
    - 1 hour dark time, then 2 hours, etc., up to 9 hours
- All other details as in Test 1

Test 2: Normalized Voc



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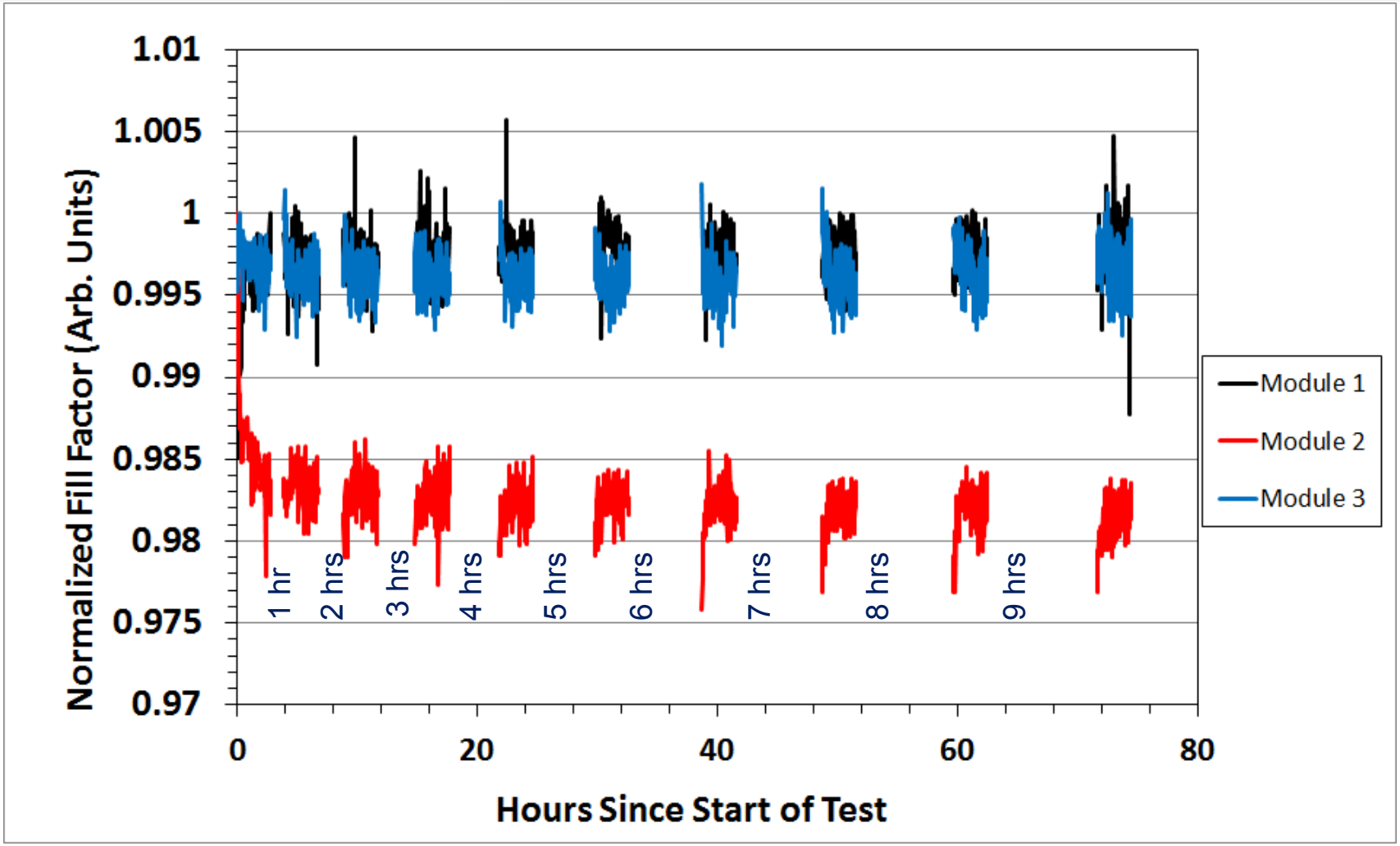
Test 2: Normalized FF



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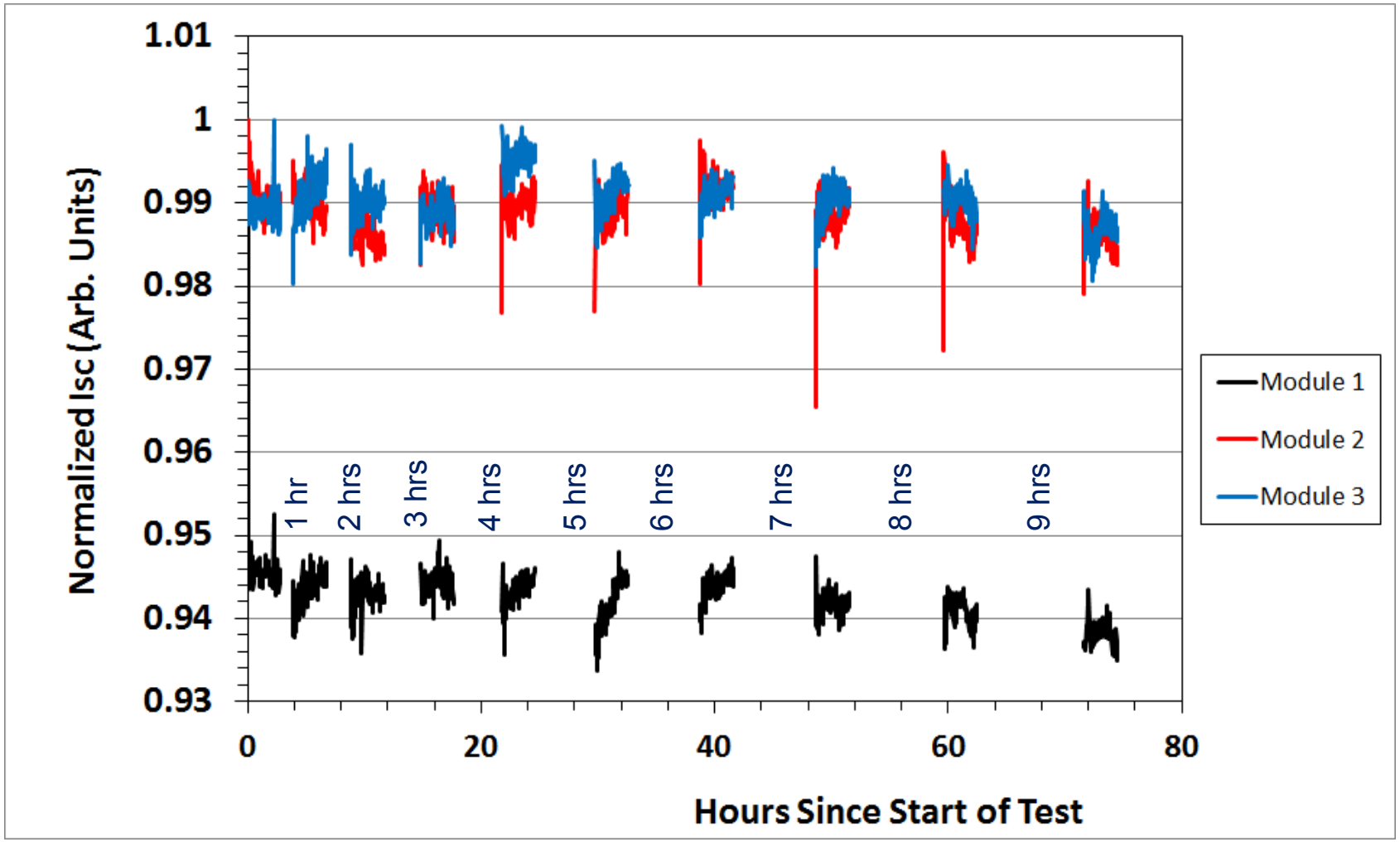
Test 2: Normalized Isc



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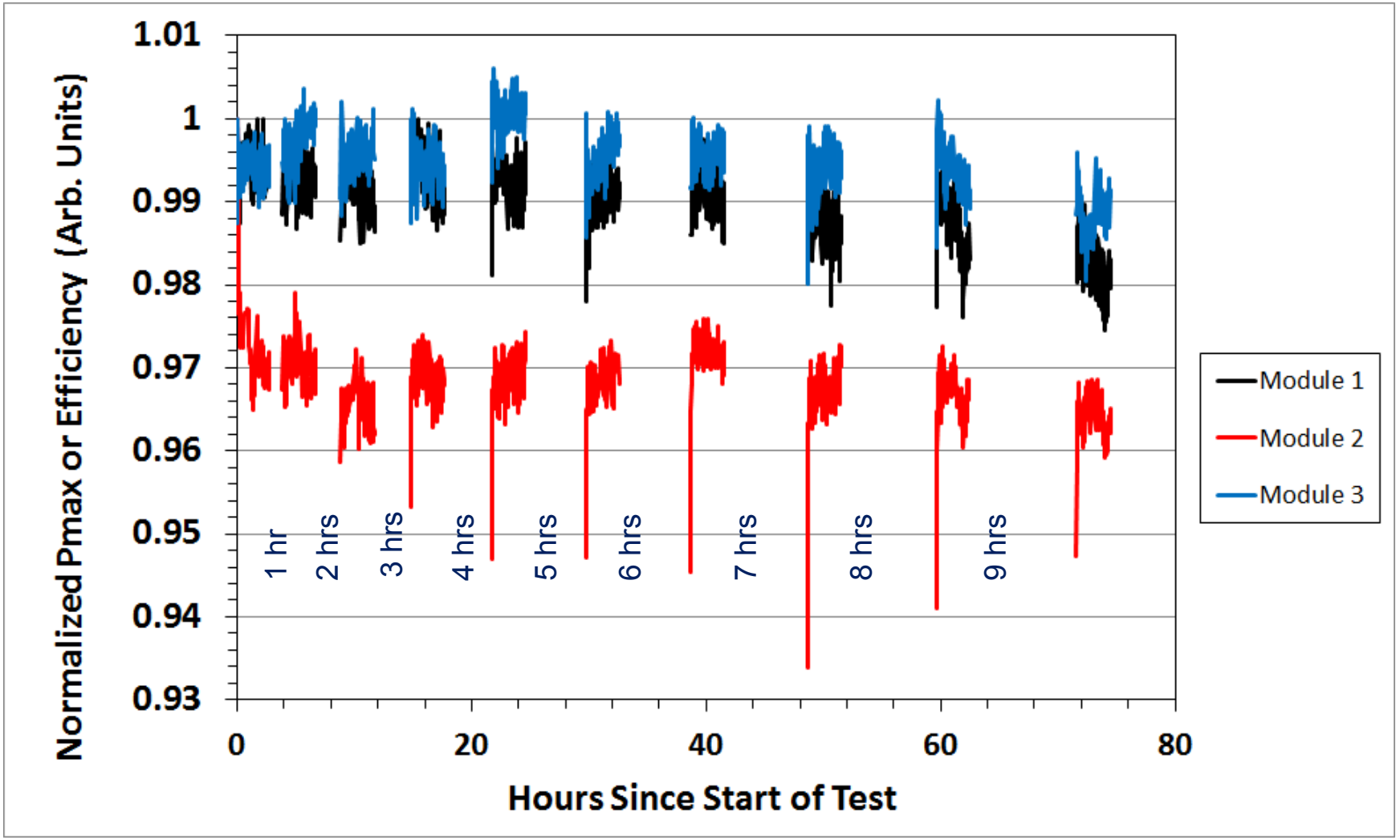
Test 2: Normalized Pmax/Efficiency



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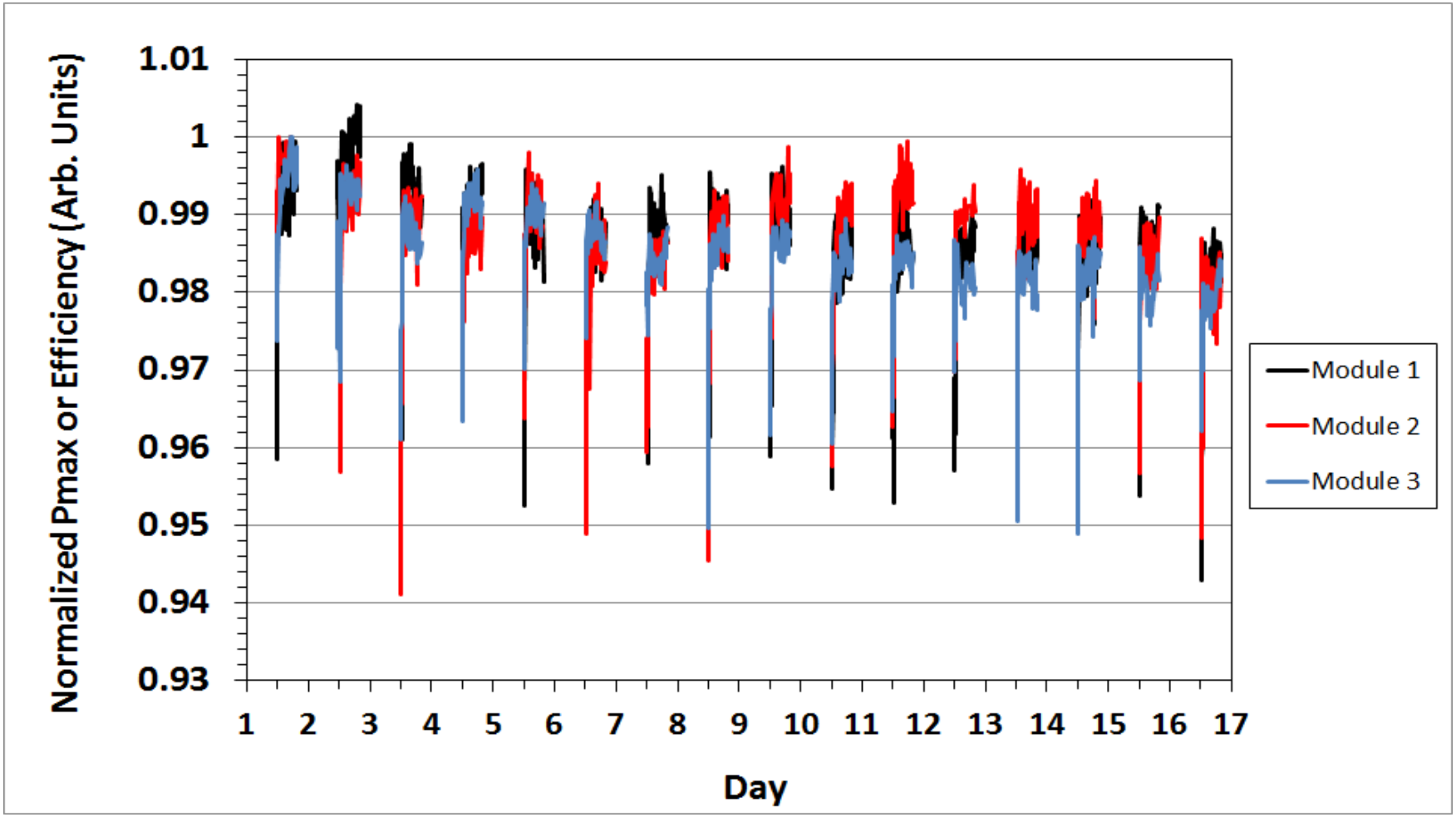
Compare to Test 1 Results



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Test 2 Conclusions

- Module 2 appeared to fully relax after >3 hrs in the dark
- Modules 1 and 3 fully relaxed after 16 hours in the dark (from Test 1) but shorter time scale not definitively determined

Future Work

- Quantify preconditioning extent and time scale for different temperatures
- Investigate effect of different electrical bias conditions on preconditioning (and dark relaxation) behavior
- Repeat study with additional module types

We welcome questions, comments, and suggestions.

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