

Long Term Performance of CIGS Modules in Multiple Environments

Kristopher Toivola, Paul Robusto, Bill Kessler

Introduction

Outdoor module testing is critical for long term performance monitoring and validating accelerated laboratory testing results.

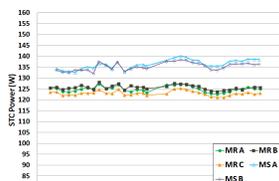
MiaSole has tested modules for multiple years in four Climate Zones:

- 1.) Desert - Arizona
- 2.) Mediterranean - California
- 3.) Continental - Ohio
- 4.) Tropical - Florida



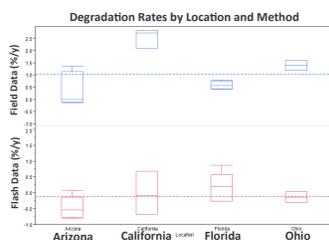
Test install at Florida Site

Arizona Location Example



| Location | Module | Months in field | Change in Pmax (%) | Degradation Rate per year from flash tests(%) | Degradation Rate per year from regression of field data (%) |
|----------|--------|-----------------|--------------------|---|---|
| Arizona | MRA | 34 | -2.00 | -0.71 | -0.69 |
| | MRB | 34 | -1.51 | -0.53 | -0.01 |
| | MRC | 34 | -2.30 | -0.81 | -0.13 |
| | MSA | 33 | -0.16 | -0.06 | -1.37 |
| | MSB | 33 | -0.94 | -0.34 | 0.89 |
| Average | | | | -0.47 | 0.41 |

Degradation rates for all sites:



Average degradation rate for all modules determined by field regressions was +1.03%/year, and average degradation rate from spire flash data was -0.12%/year.

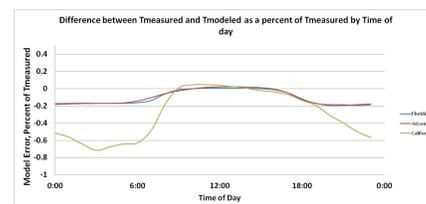
Temperature Model

Sandia Temperature model used as basis for our temperature regressions

$$T_{Module} = Irradiance * (e^{a+b*Windspeed}) + T_{Ambient}$$

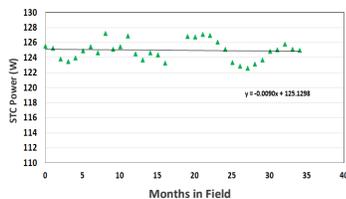
Temperatures model accurate during peak power producing hours:

- California: -0.17C
- Arizona: -0.16C
- Florida: -0.46C



The percent difference between model temperature and measured temperature is very small during peak power producing hours (8am and 6pm). Model over predicts temperature at night as it does not account for irradiative losses.

Extracting Degradation Rates

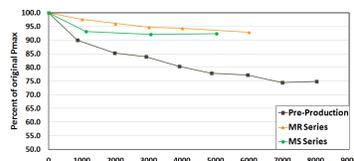


Module field performance was translated to Standard Test Conditions:

$$STC P_{Max} = P_{Max} * \left(\frac{1000 W/m^2}{Irradiance} \right) * (1 + T_{Coef} * (25 - T_{measured}))$$

Degradation rates determined by linear regression of results, and compared to before and after Spire flash measurements

Accelerated Testing Performance and Outdoor Results



| Average Degradation Rates | Degradation Rate per year from flash tests(%) | Degradation Rate per year from regression of field data (%) |
|---------------------------|---|---|
| Pre-Production | -1.20 | -0.86 |
| MR | 0.00 | 0.50 |
| MS | -0.23 | 1.49 |

Degradation rates improve from preproduction to MR and MS production modules

Similar improvements shown in Damp Heat 85C/85% relative humidity testing

Conclusion

- ▶ MiaSole CIGS modules were tested in multiple climates for several years
- ▶ Degradation rates determined by both flash testing and outdoor regression were low and in good agreement
- ▶ Improvements in degradation rates from pre-production modules also evident in long term Damp Heat results
- ▶ Temperature module confirmed accurate with long term outdoor data

Kristopher Toivola
ktoivola@miasole.com