Accelerated Environmental Aging Effects and In-Situ Functional Testing of Commercial Photovoltaic Modules

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Introduction and Motivation

- Degradation in PV modules is commonly investigated through methods such as stress tests and field-based life-cycle analysis.
- Accelerated lifecycle testing provides more rapid evaluation of module operational and performance evolution under field-consistent application environments.
- The present program, performed in cooperation with Tucson Electric Power, evaluates commercial solar module temperature and time-dependent performance under accelerated lifecycle test conditions (temperature, humidity, irradiance) typical of Tucson, AZ over a full year.

Experimental Details

Environmental Testing Chamber

- Custom Envirotronics chamber
- Internal workspace of 99" L x 85" W x 83.75" H
- Temperature range of -30°C to +85°C ± 1.1°C
- Relative humidity range of 20% to 95% ± 5% via integrated steamer and/or atomizer.

Solar Irradiance

- Four Atlas metal halide arc lamps provide calibrated solar-spectrum irradiance over a 2.0m x 1.3m area with an average irradiance of 1000 W/m^2 over the module.
- Irradiance measured throughout test period via two pyranometers mounted on top and bottom edges of module.

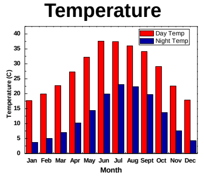
Photovoltaic Module

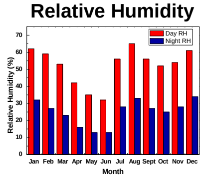
- Module under examination is Hanwha SolarOne HSL72P-PA-0-295K
- 1.985m L x 0.999m W
- 72 poly-Si cells with a total cell area of 1.752m^2
- STC Ratings: V_{oc}=45.0 V, I_{sc}=8.67 A, V_{mp}=36.3 V, I_{mp}=8.14 A, η = 15.3%
- Temp. Coeffs: P (-0.43%/°C), V (-0.31%/°C), I (+0.05%/°C)

In-situ Performance Measurement

- Current-voltage characteristics measured at 30 minute intervals throughout testing period. Open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), voltage and current at the maximum power point (V_{mp}, I_{mp}), fill factor (FF), maximum power output (P_{max}) measured/computed in-situ.
- Environment (ambient) temperature and module front and backside temperature also monitored throughout test cycle.

Environmental Lifecycle Conditions

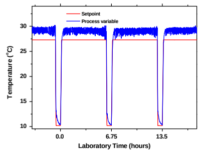


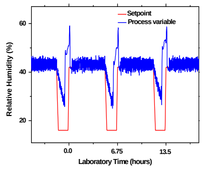


- Monthly average day- and night-time temperatures and relative humidities, combined with average monthly hours of peak solar irradiance in Tucson, AZ were used to define environmental conditions for accelerated lifecycle testing [1].
- Primary degradation processes assumed to occur during daytime soak period. Night duration held at 0.75 hours throughout test period.

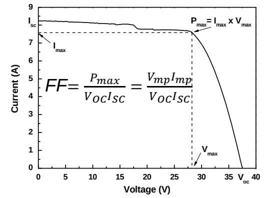
Environmental cycling: month of April

- Excerpt from month of April showing representative three day-night environmental cycles. Ambient temperature closely approximates setpoint while inherent limitations of chamber to follow rapid changes in RH between day and night evident due to corresponding changes in temperature and dewpoint conditions.
- Effective time acceleration of 3.6X.





Results: Environmental Effects on Module Performance



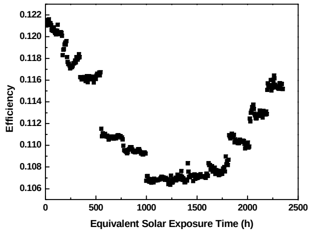
$$FF = \frac{P_{max}}{V_{OC} I_{SC}} = \frac{V_{mp} I_{mp}}{V_{OC} I_{SC}}$$

$$\eta = \frac{P_{max}}{EA}$$

E = irradiance
A = cell area

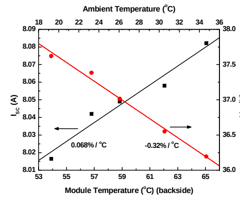
- Representative I-V curve from April
- Key performance metrics indicated.

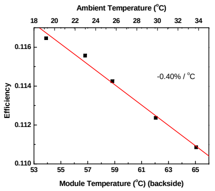
Lifecycle data: Efficiency = f(Temp and Time)



- Module performance variation with environment cycling and accumulated solar exposure integrates both temperature-dependence of efficiency for the module as well as time-dependent degradation in module performance that is associated with aging effects.

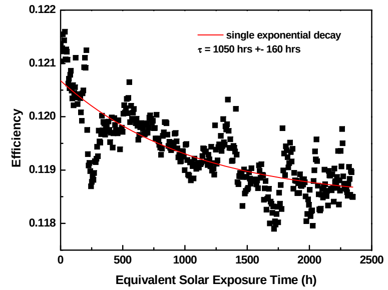
Module Temperature Response





- Temperature-dependent module performance can be extracted from the total time-temperature degradation behavior to examine time-dependent aging.
- The experimentally determined temperature coefficients for I-V metrics were found to be consistent with manufacturer's module specifications [2].

Efficiency Degradation - Time only



- Temperature coefficients can be used to correct for month-to-month variation in module daytime temperature and extract time dependence of module degradation.
- Results indicate a 2.1% relative degradation in module efficiency over the 12 month accelerated lifecycle test.

Conclusions

- Accelerated lifecycle testing of commercial solar module integrated time, temperature, humidity and solar irradiance effects approximating Tucson, AZ climate conditions was performed.
- In-situ monitoring of module function and ambient conditions confirmed module temp response.
- Module efficiency evolution with lifecycling was analyzed to isolate temperature and time-related contributions – time-dependent degradation (aging effect only) in efficiency of 2.1% (relative) was observed after the first 12 month period (Jan – Dec climate conditions).
- Results consistent with typical first-year, field-based degradation observed for new polycrystalline Si modules under similar conditions [3].

References

[1] NREL. "30-Year Average of Monthly Solar Radiation." Internet: http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/sum2/state.html, 1990 [Oct., 2012].
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[3] Makrides G, Zinsser B, Georghiou GE, Schubert M, Werner JH. Degradation of different photovoltaic technologies under field conditions. Proceedings of the 35th IEEE PV Specialists Conference, Honolulu, HI, USA, 2010; 2332–2337. DOI: 10.1109/PVSC.2010.5614439

Acknowledgements

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