Use of Pyranometers to Estimate PV Module Degradation Rates in the Field

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Introduction

- Pyranometers are used to monitor PV system performance in the field.
- Data from these instruments are sometimes used to calculate the decrease in PV module efficiency over time.
- A wide variety of PV module degradation rates are reported. The accuracy of these results is frequently limited by the uncertainty in the irradiance measurements.

Uncertainties can be reduced by using the following steps.

1. Put the pyranometer in the plain of array (POA) of the module
2. Measure module temperature
3. Calibrate the pyranometer at the beginning and the end of the testing and at yearly intervals
4. Ensure the instrument is cleaned regularly to prevent soiling that degrades instrument performance
5. Keep a log on calibrations and maintenance
6. Understand and characterize systematic errors associated with the pyranometer
7. Make relative comparisons instead of absolute comparisons
8. Obtain comparisons under similar circumstances under near cloudless skies
   - Solar incident angles, temperature, and seasons
9. Adjust responsivity of pyranometer to account for the degradation rate of the pyranometer's responsivity
10. To determine the length of time necessary to obtain a statistically valid degradation rates perform an initial uncertainty analysis of the measurements such as is done in the example section

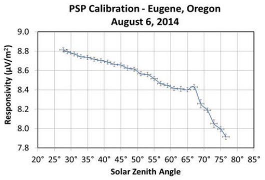
Objectives

- Develop a rigorous and accurate relative comparison methodology to evaluate the annual decrease PV module efficiency using PV performance data and POA irradiance data
- Identify limitations of the methodology
- Estimate the time period necessary to accurately determine the PV module performance degradation rate

Irradiance Measurement Uncertainties

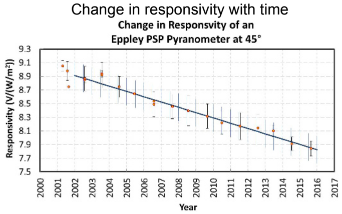
There are several systemic issues associated with pyranometer-based irradiance measurements.

Deviation from true cosine response



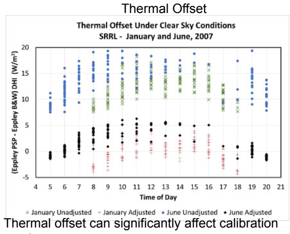
Calibrating a pyranometer in 2 degree bins have an uncertainty of ±0.5% while over a 30 to 60 degree SZA range, the uncertainty is more like ±2.5%.

Change in responsivity with time



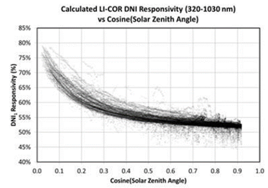
The responsivity of this pyranometer decreases by about 0.8% per year. The instrument in located in the high desert of eastern Oregon. Side by side calibration with a similar reference instrument yields the best estimate of degradation.

Thermal Offset



Thermal offset can significantly affect calibration results

Effects of changing spectral distribution of irradiance



The responsivity of the LI-COR pyranometer changes over the day

Example – Calculation of Irradiance Uncertainty

Table 1: Estimated best case irradiance uncertainties

Source of uncertainty	% Uncertainty
Calibration uncertainty at a given angle	± 0.5%
Uncertainty in changing responsivity over time	± 0.2%
Spectral response	± 0.02 – 0.3%
Thermal offset response	± 0.2 – 0.4%
Miscellaneous	± 0.1%

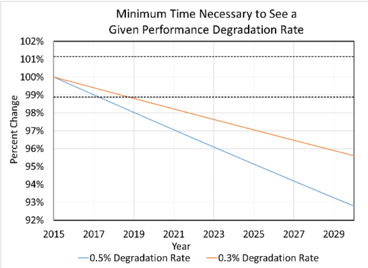
Adding uncertainties in quadrature – Under the best conditions

Combined uncertainty = $((0.5)^2 + (0.2)^2 + (0.02)^2 + (0.3)^2 + (0.1)^2)^{½}$ = 0.59%

Expanded uncertainty at 95% level = 1.96 * 0.59 = 1.16%

Conclusion

Obtaining PV module degradation rates in the field with pyranometer measurements requires several years because there are inherent uncertainties in the irradiance measurements.



The time period required to identify a given rate of decrease for PV module performance increases as module degradation rate decreases. The dashed lines show the uncertainty taken from the example for relative irradiance measurements.

The uncertainty of the irradiance measurements increases significantly if the pyranometer is not regularly cleaned and calibrated. The uncertainty in the module performance also increases significantly if the model is not cleaned. Without cleaning, the comparison yields the degradation rate due to soiling as well as decrease in efficiency.

This example above is for an idealized situation. The uncertainty of the irradiance measurements is dependent on the type of instrument used and the characteristics of the instrument. Using relative measurements can minimize systematic errors in irradiance measurements.

References

[1] F. Vignola, J. Michalsky, and T. Stoffel, 2012. Solar and Infrared Radiation Measurements, CRC Press, Boca Raton, Florida
[2] M. Sengupta, A. Habte, S. Kurtz, A. Dobos, S. Wilbert, E. Lorenz, T. Stoffel, D. Renné, C. Gueymard, D. Myers, S. Wilcox, P. Blanc, and R. Perez, 2015. Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications, Technical Report, NREL/TP-5D00-63112, February 2015
[3] S. Wilcox, S. Andreas, I. Reda, and D. Myers, 2002. Improved methods for broadband outdoor radiometer calibration (BORCAL). 12th Atmospheric Radiation Measurement (ARM) science team meeting proceedings, St. Petersburg, Fl.
[4] Aron Habte, Manajit Sengupta, Afshin Andreas, Stephen Wilcox, Thomas Stoffel, 2016. Intercomparison of 51 radiometers for determining global horizontal and direct normal irradiance measurements, Solar Energy,
[5] Wilcox, S., Myers, D., Al-Abbadi, N., Bin Mahfoodh, M., "Using irradiance and temperature to determine the need for radiometer calibrations" in Forum 2001 Solar Energy, the Power to Choose. 2001. Washington D.C.
[6] Vignola, F., Long, C., Reda, I., 2008. Modeling IR Radiative Loss from Eppley PSP Pyranometers, proceeding SPIE conference, San Diego
[7] L. Riihimaki, F. Vignola. 2008. Establishing a Consistent Calibration Record for Eppley PSPs, Proc. of the 37th ASES Annual Conference, San Diego, California, 2008.
[8] F. Vignola, Zachary Derocher, Josh Peterson, Laurent Vuilleumier, Christian Félix, Julian Gröbner, Natalia Kouremeti, 2016. Effects of changing spectral radiation distribution on the performance of photodiode pyranometers, Solar Energy, 129, 2016, pp 224-235.
[9] F. Vignola, Josh Peterson, Rich Kessler, Fuding Lin, Bill Marion, Allan Anderberg, Fotis Mavromatakis, 2014, PV module performance after 30 years without washing, Proc. Solar 2014, InterSolar North America, San Francisco, CA.
[10] F. Vignola, Jim Krumsick, Fotis Mavromatakis, Robert Walwyn, Measuring Degradation of Photovoltaic Module Performance in the Field, *Proc. Solar 2009*, American Solar Energy Society, Buffalo, NY, (2009)

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