ATONOMETRICS

Best Practices in Irradiance Measurement for PV Arrays
A Brief Literature Survey

Introduction

In this white paper we summarize the results from several references which directly address the issue of irradiance measurements for PV arrays. Several of the publications reviewed provide data comparing PV array performance assessments made using irradiance measurements from both PV reference devices and thermopile pyranometers. The results strongly highlight the advantages of PV reference devices.

Direct Comparison of PV Reference Devices and Thermopile Pyranometers for PV Array Monitoring.

In 1995 The Bern University of Applied Sciences, the Commission of European Communities Joint Research Center, and The Fraunhofer Institute for Solar Energy (ISE) published a study comparing the results of long-term PV array monitoring with a PV reference device and a thermopile pyranometer [1]. The following conclusions are taken directly from their publication:

> **Scatter plots of hourly array output vs. irradiance have a much better diagnostic value (as an indicator of how well the available solar energy has been used by the system) when irradiance is measured with a *reference cell, having a spectral response similar to that of the modules.* Therefore cristalline [*sic*] reference cells should be used for cristalline [*sic*] PV arrays…If a pyranometer…is used instead, spectral mismatch may introduce additional scatter into these plots, and it is impossible to decide whether the observed scatter is due to a weakness in system operation or to spectral effects** [1]**.**

They also published data showing the correlation between measured irradiance (with a PV reference device and thermopile pyranometer) and normalized PV array power output. Their results, after reformatting, are shown below in Figures 1 and 2. We note that the authors provided no details regarding temperature corrections to calculated output power. A lack of temperature correction would explain the low PV array power output at high irradiances shown in Figure 2.

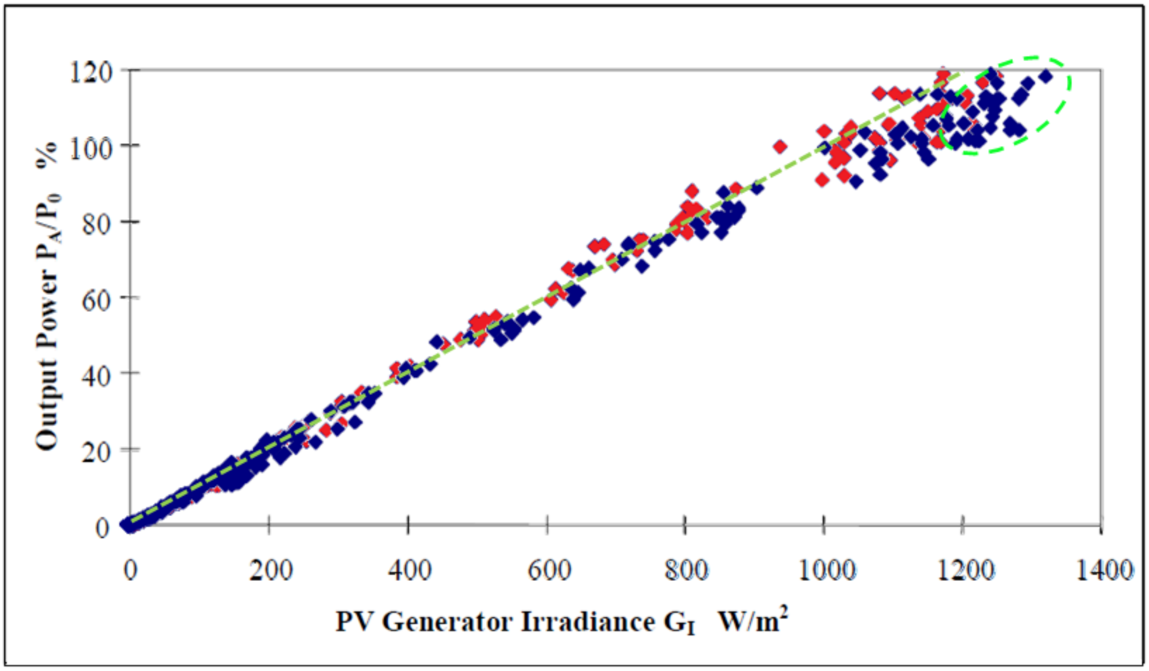

Figure 1: Hourly correlation data for the month of January, 1995, between solar irradiance as measured with a PV reference device (red diamonds) and a thermopile pyranometer (blue diamonds) from Ref. [1]. Dashed line shows a 1:1 output. The circled area highlights deviations in thermopile pyranometer data.

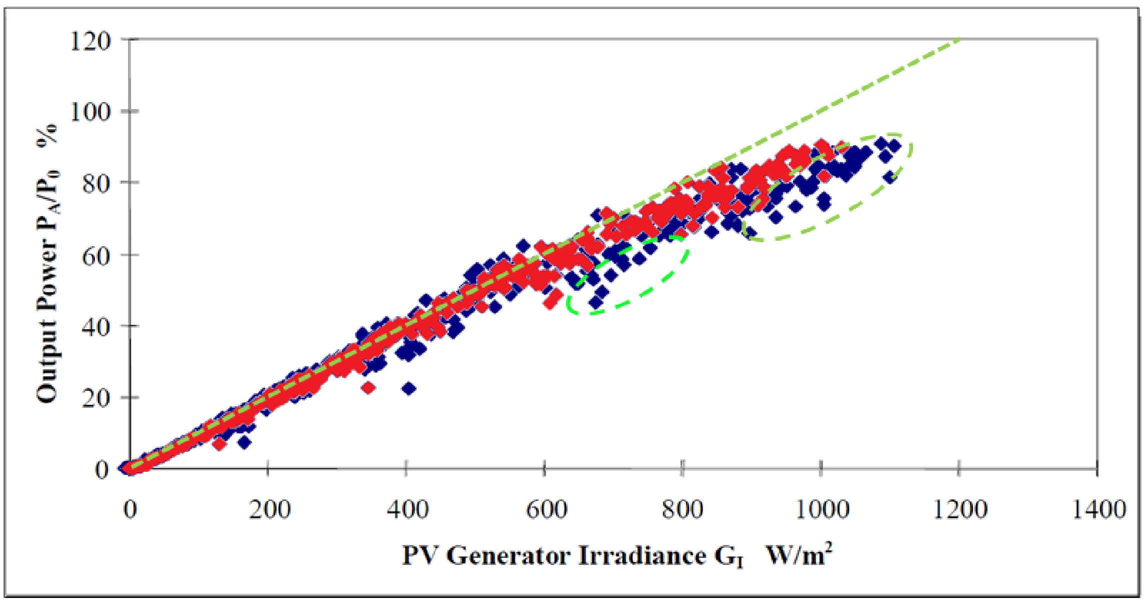

Figure 2: Hourly correlation data for the month of January, 1995, between solar irradiance as measured with a PV reference device (red diamonds) and a thermopile pyranometer (blue diamonds) from Ref. [1] Dashed line shows a 1:1 output. The circled areas highlight deviations in thermopile pyranometer data

PV Plant Power Ratings with PV Reference Devices and Thermopile Pyranometers

In 2009 a review of three PV power plant power rating methods was published by SunPower, the San Francisco Public Utilities Commission, BEW Engineering, Sandia National Laboratories, NREL, First Solar, and NextEra Energy Resources [2]. The authors specifically examined the issue of PV plant power rating performed with PV reference devices and thermopile pyranometers. The following excerpt is taken directly from their work:

> **Relative to irradiance measured with a thermal pyranometer, solar irradiance determined with a properly calibrated and packaged reference cell results in less scatter in regression analysis because spectral, AOI [Angle of Incidence], and diffuse irradiance effects are implicitly compensated…In principle there should be no seasonal or air mass related spectral effects in the data** [2]**.**

In addition to the spectral, AOI, and diffuse irradiance effects the authors listed above, they went on to elaborate that the "time constant of the reference cell is matched to the PV array eliminating scatter when the light is rapidly varying [2]."

PV Plant Monitoring: Higher Quality Data and Fewer Nuisance Alarms with PV Reference Devices

In 2007 PowerLight Corporation submitted a subcontract report to the National Renewable Energy Laboratory summarizing their progress toward the reduction of installed cost for commercial roof-top PV systems [3]. A portion of their project examined the effects of system monitoring with PV reference devices vs. thermopile pyranometers. After installing PV reference devices and thermopile pyranometers at 5 sites and monitoring the installations, PowerLight found that the PV reference devices produced a "steadier" [3] calculation of Performance Index, defined as the ratio of actual power produced to predicted or expected power produced [4]. Figure 3, reproduced from data given in the report, shows a comparison between the daily Performance Index as calculated with a PV reference device and a thermopile pyranometer. Note the unphysical regions where the Performance Index as calculated with the pyranometer clearly exceeds 100%.

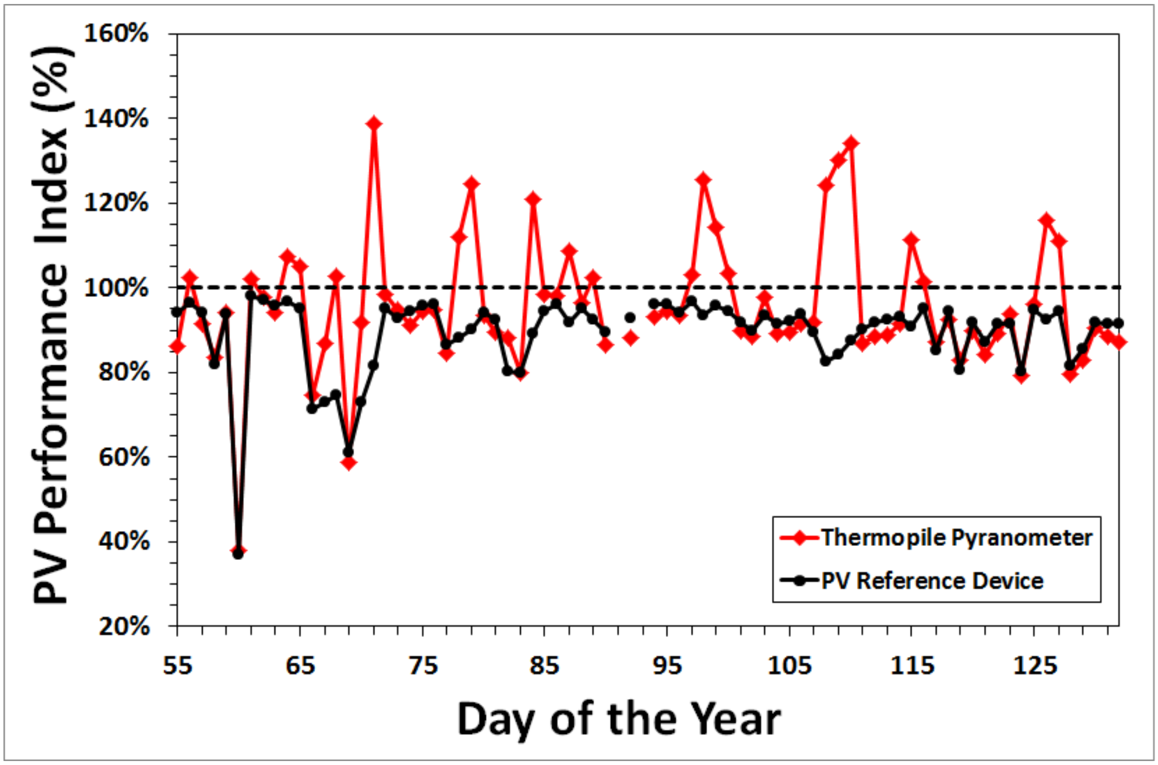

Figure 3: PV system Performance Index as calculated with pyranometer insolation data (red diamonds) and PV reference device insolation data (black circles). Note the regions where the use of the pyranometer clearly introduced error into Performance Index calculations, showing values greater than 100%.

PowerLight also defined and tested six performance alert algorithms to generate alert tickets for PV system performance issues. After using both pyranometer and PV reference device-generated data to test their alert algorithms, they concluded that the use of PV reference devices instead of thermopile pyranometers resulted in 37% fewer nuisance alarms [3].

Irradiance Measurement Uncertainty: Pyranometers vs. PV Reference Devices

In June, 2012, Atonometrics co-authored a paper with the head of NREL's cell and module calibration lab, examining how best to measure irradiance for evaluating PV array performance [5]. In that work we quantified typical, clear-sky irradiance measurement uncertainties in the amount of light available to PV modules for power generation (*i.e.*, the broadband irradiance adjusted for spectral, angle of incidence, diffuse light, and other effects). We found that typical uncertainties in this quantity for measurements made with thermopile pyranometers to be on the order of ±5.2%, while analogous measurement uncertainties for PV reference devices are on the order of ±2.4% [5]. The results of the paper are summarized in Figure 4, shown below:

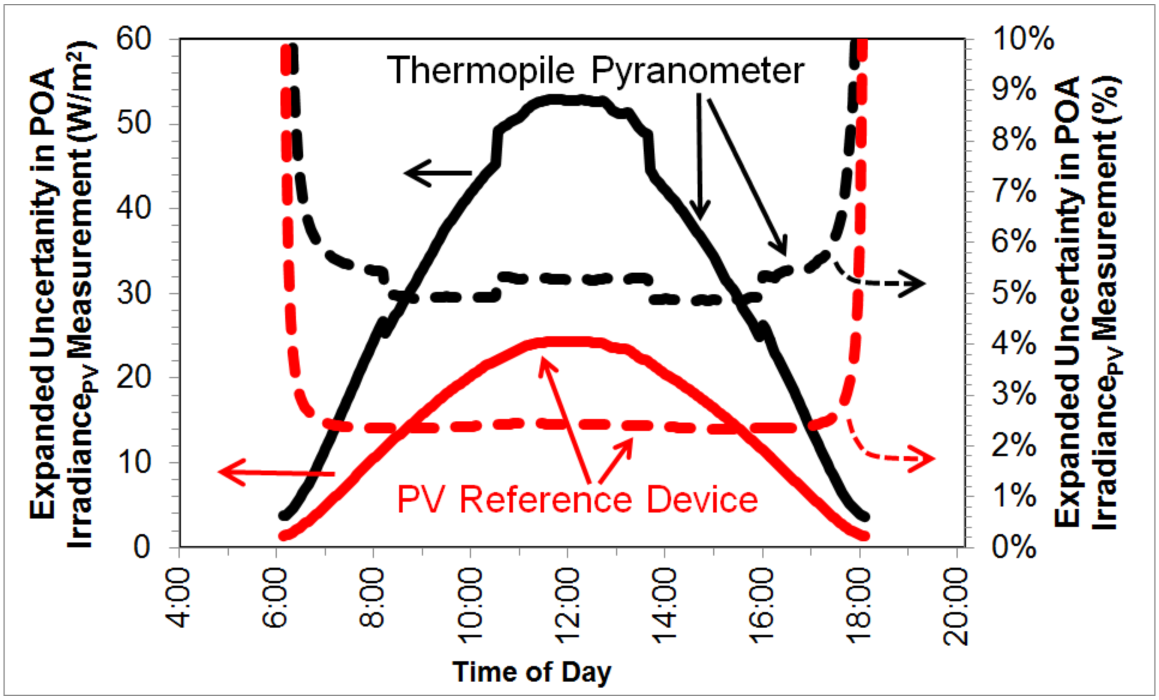

Figure 4: Typical, clear-sky expanded uncertainties in plane of array irradiance measurements made with a thermopile pyranometer and a PV reference device. The left y-axis corresponds to the solid curves and gives the uncertainties in units of W/m^2, while the right y-axis corresponds to the dashed curves and gives the uncertainties in percentages of the measured irradiance.

Bibliography

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[5] L. Dunn, M. Gostein, and K. Emery, “Comparison of Pyranometers vs. PV Reference Cells for Evaluation of PV Array Performance,” in *Proceedings of the 38th IEEE Photovoltaic Specialists Conference*, Austin, TX, 2012.