Linearity Testing of Photovoltaic Cells

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Introduction

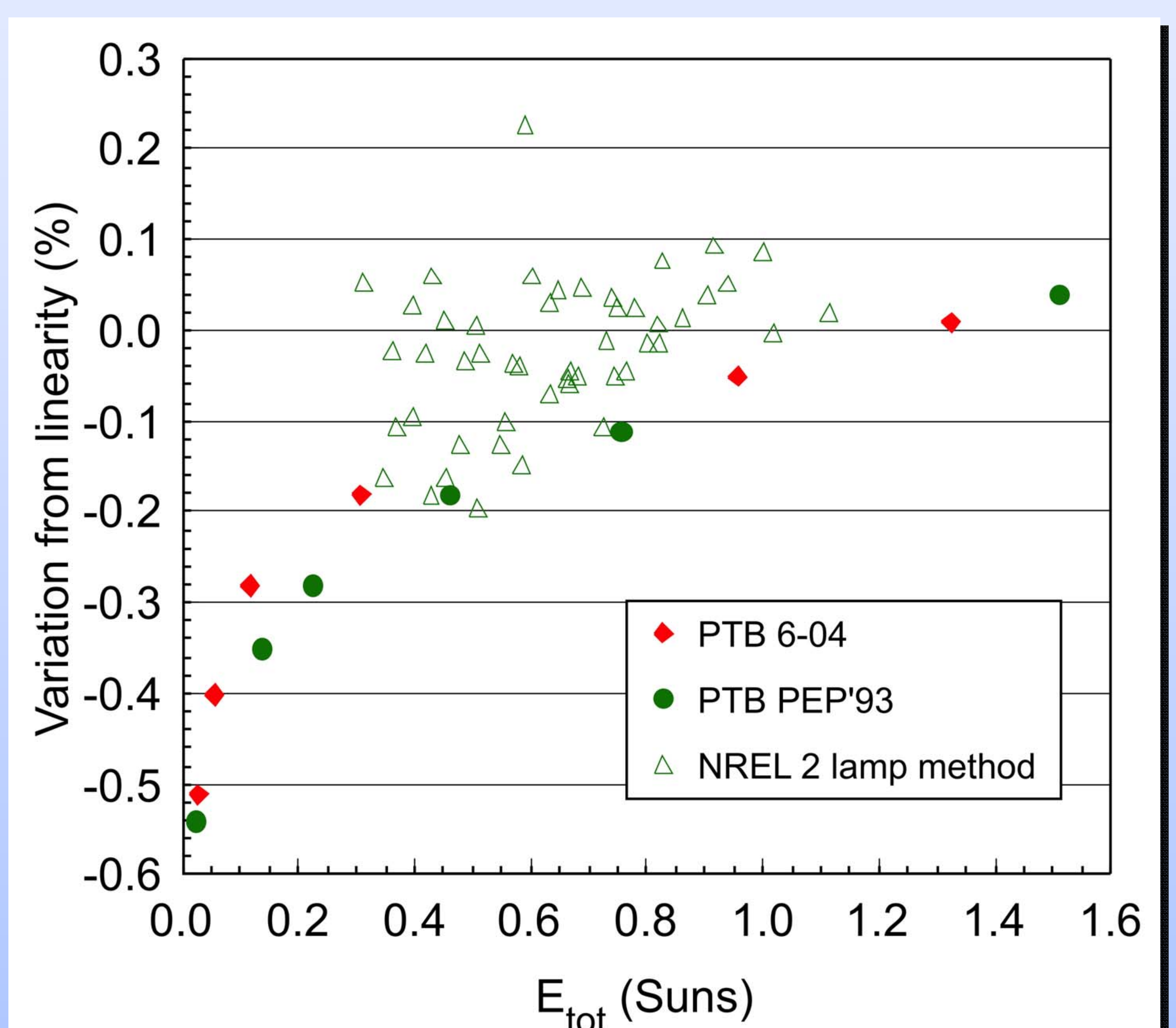
International PV standards require that the short-circuit current or response of the reference device be linear with total irradiance. Accredited calibration laboratories can not assume that their reference device is linear unless another accredited laboratory has performed the measurement. The NREL PV performance laboratory is ISO 17025 accredited for primary reference cell, secondary reference cell and secondary module calibrations. Limited labor resources necessitated the development of a technique to determine linearity without taking significant labor or technical skill.

The two-lamp method is insensitive to the spectrum of the light or spatial nonuniformity changing as the irradiance is varied. It does assume that the temperature does not change with irradiance and that the light-source spectrum resembles the solar spectrum. This requirement is only because nonlinear mechanisms in the photo-current are wavelength dependent. A laser for example may show the same device as linear or very nonlinear with irradiance depending on the wavelength. The two-lamp method assumes that the lamp intensities when individually irradiating the sample are the same as when both lamps irradiate the sample. The presence of room light only limits the lowest irradiance that can be evaluated. Unlike other methods, the two-lamp method does not allow the current to be corrected for nonlinear effects. The most appealing aspect of the two-lamp method when compared with other methods for a high-volume calibration laboratory is that it is fast and does not require operator intervention to change the irradiances and is difficult for the operator to make mistakes that would affect the outcome.

Short-Circuit Nonlinearity with Irradiance for Two Lamp Method Compared with Differential Responsivity

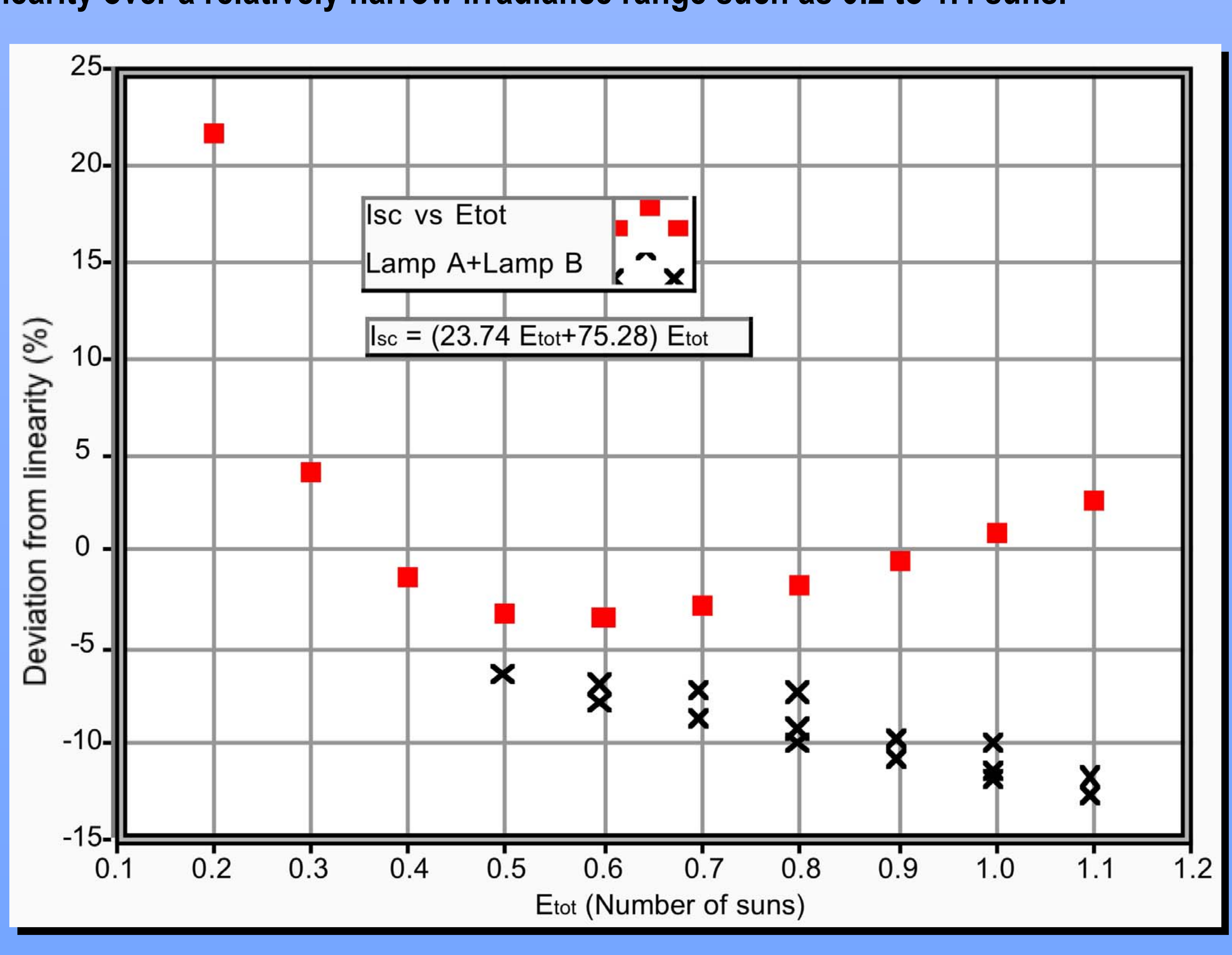
Osterwald, S. Anevsky, A.K. Barua, J. Dubard, K. Emery, D. King, J. Metzdorf, F. Nagamine, R. Shimokawa, N. Udayakumar, Y.X. Wang W. Zaaiman, A. Zastrow, J. Zhang, "The Results of the PEP '93 Intercomparison of Reference Cell Calibrations and Newer Technology Performance Measurements: Final Report" NREL tech. rep. NREL/TP-520-23477 (March 1998); *Proc. 26th IEEE PVSC*, 1209 (1997)

S. Winter, J. Metzdorf, S. Brachmann, K. Emery, F. Fabero, Y. Hishikawa, B. Hun, H. Müllejans, A. Sperling, W. Warta, "The Results of the Second World Photovoltaic Scale Recalibration," Proc. 31st IEEE PVSC, 1011 (2005)



Compare Methods by Exact Calculation

The two-lamp method and the more traditional approach of measuring the irradiance E_{tot} and short-circuit current, I_{sc} are compared using a quadratic function designed to give a 1-sun I_{sc} of 100 mA and a standard deviation of 2% over a 0.3 to 1.4 sun irradiance range. The exact calculation demonstrates that a standard deviation of 2% does not ensure that the maximum deviation is less than 2%, as suggested in ASTM standard E1143 or IEC standard 60904-10. Differences between the two-lamp method and traditional measurements are a function of the nonlinearity. Because of these differences, the two-lamp method is limited to determining the nonlinearity over a relatively narrow irradiance range such as 0.2 to 1.4 suns.



Apparatus

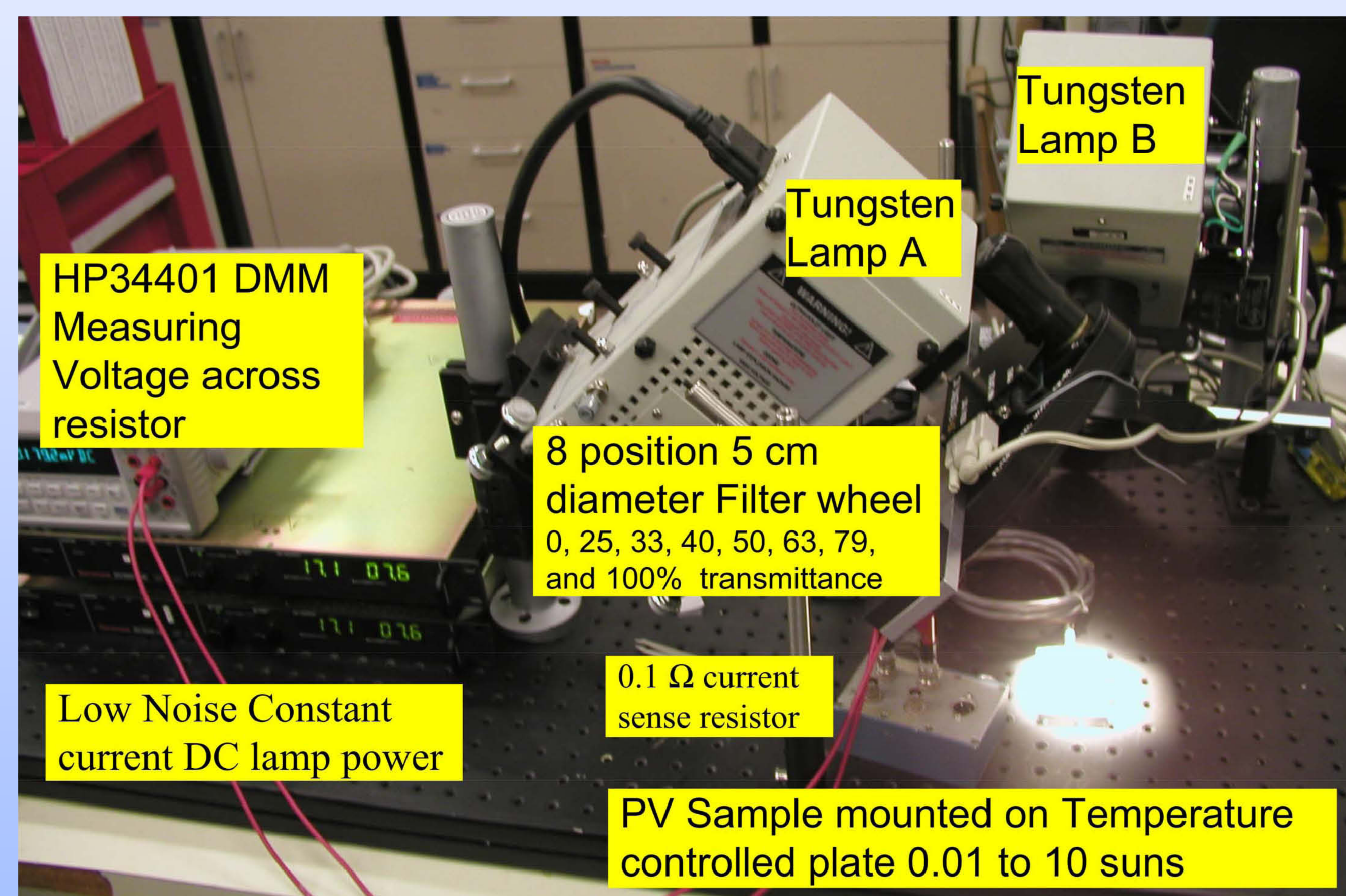
- The light box enclosing the system was removed for the photograph and is not essential
- 8-position filter wheel, 50 cm clear aperture, RS-232 controlled
- Metallic 50-cm-diameter neutral-density filters — 25, 33, 40, 50, 63, and 79% transmittance, with transparent and opaque positions
- The minimum irradiance that the linearity measurement can be made is determined by the background irradiance and noise in the current measurement
- The software automatically adjusts the power supply current to the lamps until the maximum desired light level is reached. For 1-sun reference cells this value is typically 1.4 suns. The program waits for the lamps to stabilize and then rotates the wheels through the 64 combinations of positions. The data is saved and plotted in the groups standard format.
- The filter wheel is placed so that no light from the lamp leaks out the sides.
- Lamp irradiance or cell temperature drift is an error. High speed shutters between each lamp and filter wheel allow the 3 required measurements for each data point to be reduced to the shutter speed and time to read the meter because the filter wheels do not need to rotate. This also would free up another position on the filter wheel giving 7 filters and one transparent position. The major issue would be the additional expense of hardware and software to control the shutters.

In a Linear System the Superposition must be valid

$$I_{sc}(E_{Lamp\ A} + E_{Lamp\ B}) = I_{sc}(E_{Lamp\ A}) + I_{sc}(E_{Lamp\ B})$$

or as a percentage deviation from linearity and correcting for room light, E_{room}

$$D_{lin} = 100\ [\{I\,(E_{Lamp\ A} + E_{Lamp\ B}) - I(E_{room})\} / \{I\,(E_{Lamp\ A}) + I\,(E_{Lamp\ B}) - 2\ \ I(E_{room})\} - 1]$$



Nonlinear Example

Measurement of a reference cell using a commercial detector with filters chosen to match amorphous silicon or organic PV spectral responsivities. Most commercial detectors saturate at 1-sun.