Calibration Assessments for a Sustainable Economy – Assessing Solar Irradiance Meter Calibrations

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Introduction

- By the end of 2024, the US installed 219 GW of solar power and 64% of all new electricity generation capacity came from solar
- It is estimated that between 2025 and 2034, South America will add 160 GW of solar capacity
- Millions of solar panels will be installed
- Commissioning requires quick and accurate evaluation of the performance of solar panels

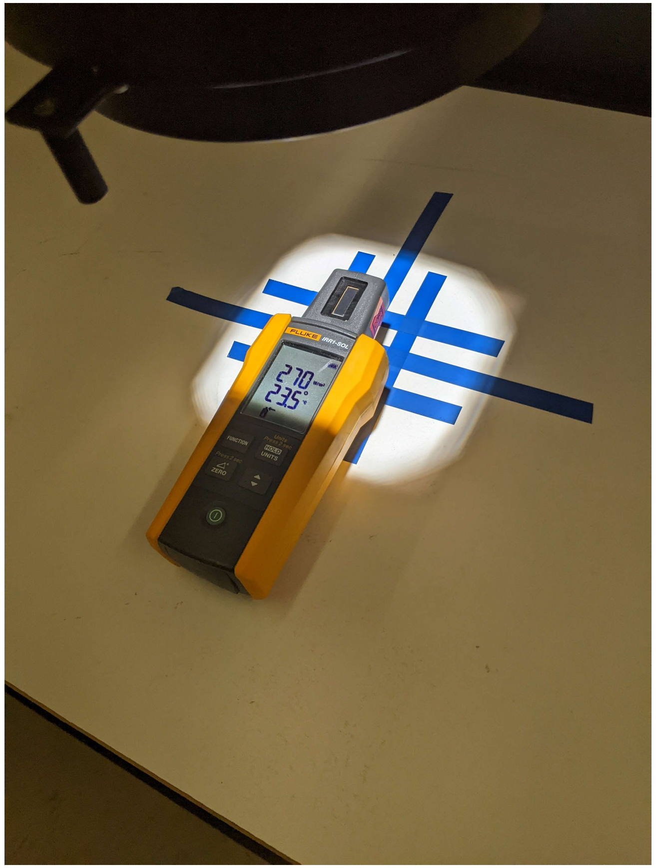
Key measurements of solar panels

- Digital Multimeter – Measures Short circuit current (I_{sc}) and Open circuit voltage
- I-V Curve Tracers – evaluate PV module performance from maximum current to maximum voltage
- For I-V Curve Tracer data to be useful, surface temperature of the panels and irradiance incident on the panels must be measured
- Irradiance measurement is crucial to:
  - Diagnose underperformance issues
  - Optimize tilt and orientation of panels
  - Validate the expected energy output against actual performance
- Also used for site selection and feasibility studies for investment/install

Solar Irradiance Meters

- Used to measure power of solar radiation per unit area
- Expressed in Watts per square meter (W/m^2)
- Placed on the solar panels being evaluated
- Must be calibrated for a range of at least 400 W/m^2
- Calibrated at a single solar spectrum
  - Usually ASTM G-173 AM1.5G (global irradiance when the solar spectrum passes through 1.5 standard atmospheres)
  - Measuring irradiance at different times of day, year, location, atmospheric conditions are sources of measurement variation, but are not significant above 400 W/m^2
- Performance requirements are defined in ISO/IEC 62446-2, Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance

Assessing Irradiance Meter Calibration



- This presentation provides guidance on critical assessment points for assessing an Irradiance Meter Calibration Laboratory
- There are many other portions of ISO/IEC 17025 that are not addressed in this presentation that are required for every assessment, which are left to the accreditation body
- The accreditation body needs to ensure the technical competency of the assessor. They should have experience in performing these calibrations or have transferrable skills such as radiation thermometry

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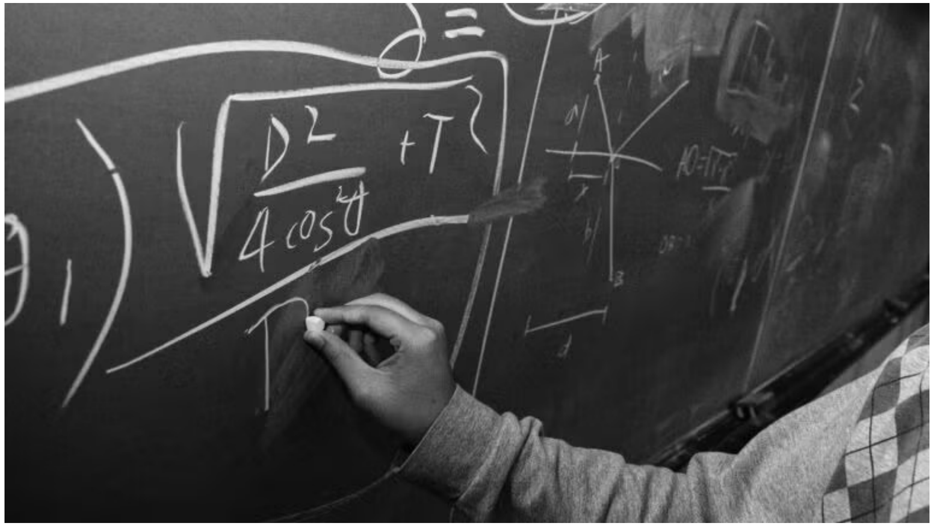
Personnel Requirements

- Education best practices:
  - A degree in Physics, with an emphasis in radiometry
  - Meteorology - Atmospheric science
  - Civil/Environmental Engineering – Renewal Energy Engineering
  - Electrical Engineering – with an emphasis in RF
- Training: in the operation and calibration of required instruments such as pyranometers, pyrheliometers, or solar radiation meters
- Data and Analysis Skills: Proficiency in data analysis techniques and understanding its implications, higher math and statistics skills



Facilities and Environmental Conditions

- Two schools of thought for Calibration
- Internal laboratory
  - Standard Temperature and Humidity Control (e.g. 23 +/- 3 C, less than 80% RH)
  - Restrictions on stray light
- External laboratory
  - Operate during the time that the equipment is rated for
  - Have to wait for the right day and conditions
  - A lot less control over the spectrum

Equipment

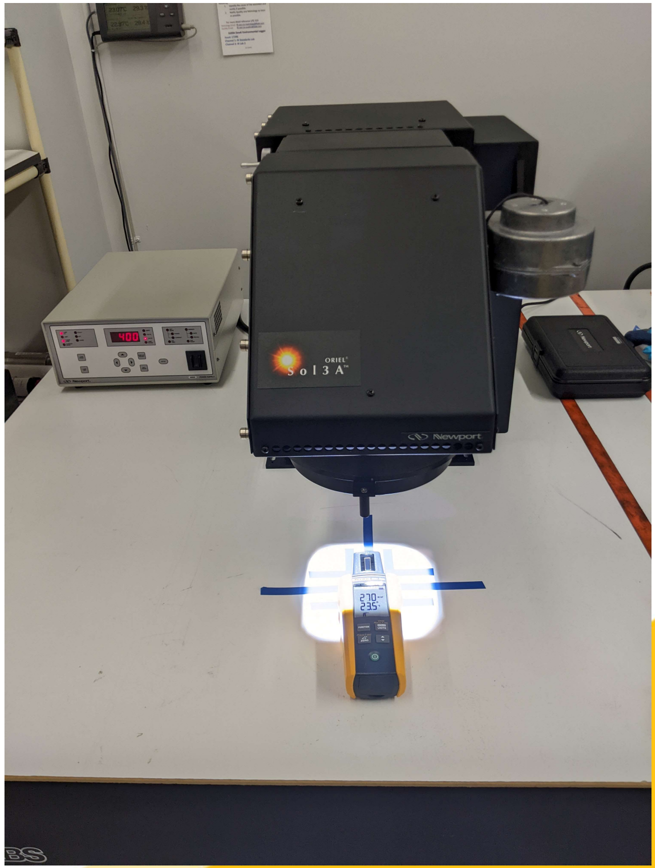
- Internal laboratory
  - Light Source (Solar Simulator)
    - Spectral Output – Xenon lamp or tunable LED and optical filters to approximate the sun's spectrum
    - Temporal Stability: the amount of light source intensity variation in a defined period, usually a minute
    - Spatial Uniformity: a defined working distance and 2-D zone, perpendicular to beam axis, where defined axis remains within a certain percentage of center intensity (e.g. 50 x 100 mm zone and 2% intensity stability)
  - Reference Solar Cell
  - Ammeter
  - Ohmmeter or voltmeter
- External laboratory
  - Sun – Need time of year, angle, lack of clouds for successful measurements
  - 2 axis tracker system, to remain at a normal angle to the sun
  - Reference Solar Cell or Pyranometer, ammeter, ohmmeter or voltmeter

Metrological Traceability

- Ammeter, ohmmeter and voltmeter can have accredited calibrations through appropriate laboratory
- Reference solar cell: Calibration at an NMI or accredited reputable organization such as the U.S. National Renewable Energy Laboratory
  - Calibrated to ASTM E948-16 Standard Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight
- If reference lab not accredited, evaluate as per ILAC P10:07:2020
- Solar Simulator: Is characterized by reference solar cell

Methods

- Reciprocity Method
  - Reference solar cell imparts traceability and determines stability of Solar simulator
  - Minimize ambient lighting and temperature variation of the Device Under Test (DUT) and reference solar cell
  - Minimize the time under the solar simulator to avoid heating of DUT and Reference Solar Cell
  - Time per measurement largely depends on the stabilization time of the electronic instruments, DUT and reference solar cell can respond in nanoseconds
- Key light Source Specifications
  - ISO/IEC 60904-9
  - JIS 8904-9
  - ASTM E927-10



Evaluation of Measurement Uncertainty

- Long Term Stability of reference solar cell (B) - During a full calibration period, this is the maximum the reference solar cell is expected to drift
- Calibration Uncertainty of reference solar cell (B) - The uncertainty in the calibration of the reference solar cell's proportionality factor to convert I_{sc} to irradiance
- Ammeter Instrumental Measurement Uncertainty (B) - The accuracy and long-term stability of the ammeter used to measure the I_{sc} of the reference solar cell
- Short Term Stability of the Light Source (A or B) - Maximum fluctuations in the light sources output over the time period of a single test point in the DUT's calibration
- Ambient lighting (B) - The maximum error introduced by light sources other than the primary light source incident on the DUT and reference solar cell (e.g. ambient fluorescent lighting and lamps)

Evaluation of Measurement Uncertainty

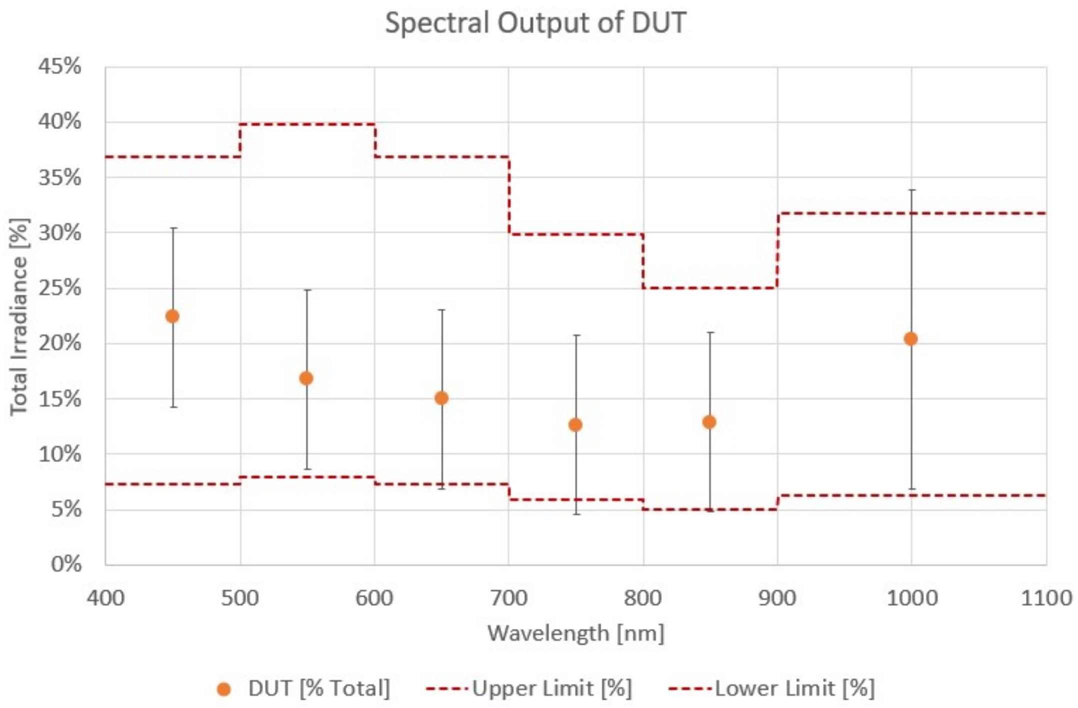
- Uniformity of light source (A or B) - Maximum deviations in the spatial uniformity in a plane that is perpendicular to the beam axis. This is to account for variances in placement of the reference solar cell and DUT, as well as differences in the physical size of the reference solar cell and DUT
- Spectral Mismatch (A or B) - Maximum calculated error due to differences in the spectral response of the reference solar cell versus the DUT, coupled with the light sources maximum expected deviation from the intended output spectrum (e.g. AM1.5G)
- Repeatability (A) – Variation in successive measurements
- Resolution of the DUT (B) – Uncertainty due to finite resolution of the DUT
- Resolution of reference (B) – Uncertainty due to resolution of the ammeter

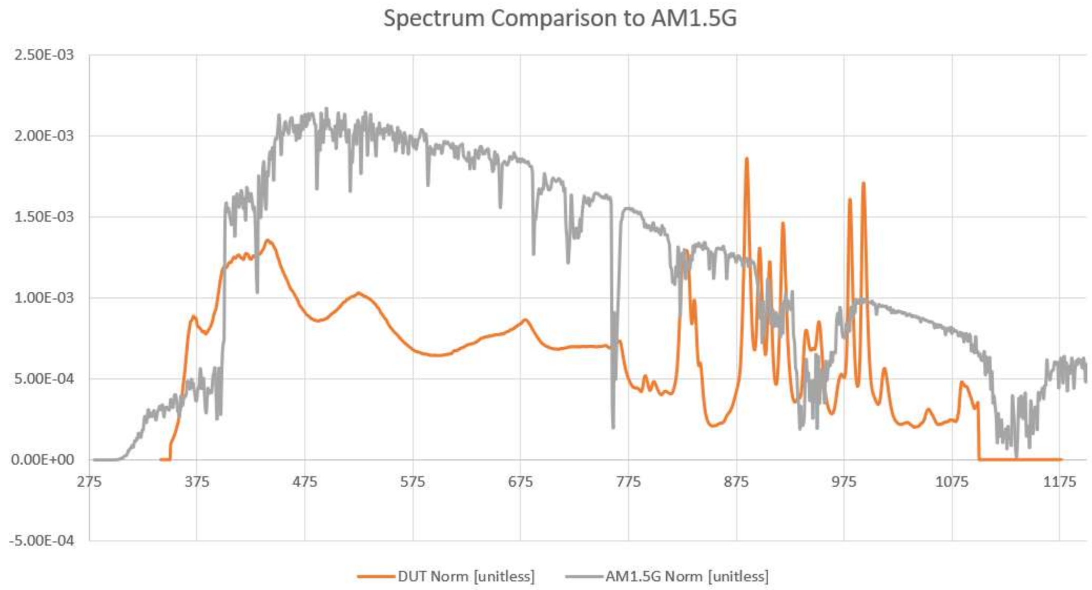
Evaluation of Measurement Uncertainty

- Thermal Stability of DUT (A) - If the temperature of the DUT is not being measured, then what is the maximum variation in the DUT indication as it heats up from varying ambient conditions and exposure to the light source. If the temperature of the DUT is being measured, then this captures the accuracy and long-term stability uncertainty in the temperature measurement device, either ohmmeter or voltmeter. In addition to the temperature measurement device, uncertainty in the temperature coefficient may also be accounted. Resolution of the ohmmeter or voltmeter may also be considered but is often negligible.
- Thermal Stability of Reference (A) - If the temperature of the reference solar cell is not being measured, then what is the maximum variation in the reference solar cell indication as it heats up from varying ambient conditions and exposure to the light source. If the temperature of the reference solar cell is being measured, then this captures the accuracy and long-term stability uncertainty in the temperature measurement device, either ohmmeter or voltmeter. In addition to the temperature measurement device, uncertainty in the temperature coefficient may also be accounted. Resolution of the ohmmeter or voltmeter may also be considered but is often negligible

Ensuring Validity of the Results

- Control Charting of the reference solar cell – prone to drift
- Measuring the spectral output of the solar simulator – The spectrum can change as the bulb ages





Reporting the Results

- The calibration certificate should report the spectrum used (ASTM G-173 AM1.5G, AM1, AM0, etc.)

Calibration Data					
	Nominal	Measurement	Limts of Error		Expanded Uncertainty
Parameter	Value	Result	Lower Limit	Upper Limit	k=2
Solar Irradiance @ AM1.5G					
0 W/m²	0.2 W/m²	0 W/m²	-2	2	0.67
200 W/m²	198.9 W/m²	198 W/m²	194	204	2.3
400 W/m²	399.5 W/m²	398 W/m²	391	408	3.9
600 W/m²	599.3 W/m²	597 W/m²	587	612	5.5
800 W/m²	800.4 W/m²	796 W/m²	785	816	7.2
1000 W/m²	1000.4 W/m²	995 W/m²	981	1020	8.8

Conclusion

- Calibration of Solar Irradiance meters is becoming key to the successful deployment of renewable energy
- Regular testing and maintenance are crucial for optimal performance
- The demand for calibration laboratories to perform accredited calibrations increase the need for both the laboratory and the accreditation bodies to learn this new technology
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