



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Bureau
International des
Poids et
Mesures



Accurate and Traceable Measurements for Photovoltaic (PV) Systems: Ensuring Electrical and Power Performance and Quality

INMETRO maintains a comprehensive metrology programme to support the reliability of solar energy systems, including the calibration of reference solar cells and power quality instruments, as well as technical support for accredited photovoltaic (PV) testing laboratories

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The Challenge

Brazil has experienced rapid growth in solar photovoltaic (PV) adoption over the past decade, driven by national policies such as energy auctions and distributed generation incentives. Solar energy is now one of the fastest-expanding sources in the country's electricity mix, contributing to national goals of diversifying energy supply and meeting climate commitments. Solar energy now accounts for approximately 25 % of the national electricity matrix, with installed capacity exceeding 44 GW. However, this expansion has also revealed three critical challenges for Brazilian metrological infrastructure: 1) prevention of fake power ratings, 2) assurance of PV inverter power quality, and 3) metrological traceability through new calibration services for Brazilian testing laboratories.

First, the circulation of solar PV panels that claim exaggerated or false power ratings has become a significant concern for Brazil's energy infrastructure. Many imported modules claim higher efficiency than they deliver, leading to underperformance in households, businesses, and utility-scale projects. This undermines consumer trust, creates financial risks for investors, and threatens Brazil's ability to meet its renewable energy targets. Further, the widespread integration of PV inverters poses technical challenges for proper grid integration, including harmonic distortion and voltage fluctuations (i.e., flicker). Beyond grid stability, these phenomena can affect human health, as excessive flicker can cause eye strain, fatigue, visual discomfort, and even convulsions in people, especially those who are photosensitive.

Metrology can address this challenge by establishing standardized, metrologically traceable testing of PV modules' performance (i.e., solar panels). Brazil's National Metrology Institute (NMI) and accredited laboratories are primed to ensure that panels meet declared specifications. This strengthens compliance in energy auctions, protects consumers in distributed generation, and builds confidence in the renewable energy market. Such testing infrastructure is specified by the regulation of PV modules and their components, established by Inmetro Ordinance No. 140/2022,¹ later complemented by Inmetro Ordinance No. 515/2023,² which mandates safety and performance certification for modules above 5 Wp, inverters, and batteries, setting a minimum quality and reliability level for equipment placed on the national market.

¹ Inmetro Ordinance No. 140/2022: Requisitos de Avaliação da Conformidade para Equipamentos de Geração, Condicionamento e Armazenamento de Energia Elétrica em Sistemas Fotovoltaicos: <http://sistema-sil.inmetro.gov.br/rtac/RTAC002957.pdf>

² Inmetro Ordinance No. 515/2023: alters Ordinance 140/2022: <http://sistema-sil.inmetro.gov.br/rtac/RTAC003010.pdf>

This regulatory framework also relies on a consolidated laboratory infrastructure that currently comprises only ten accredited calibration laboratories and eight accredited testing laboratories within the PV supply chain. These testing laboratories currently base their measurements on robust, metrologically traceable standards. A calibration service for reference solar cells will require full metrological traceability to national radiometric standards and alignment with international PV standards. Further, the PV inverters will need to be tested in accredited laboratories to comply with specific power quality emission limits (IEC 61000 series), including harmonic measurements as per IEC 61000-4-30³ and flicker interference with flickermeters as per IEC 61000-4-15.⁴ To support such measurements, there is a need to broaden the scope of power harmonics measurements and to calibrate flickermeters, a new service not yet available in Brazil.

The opportunity is clear: accurate measurement and certification of PV panels and inverters will not only prevent fraud but also accelerate Brazil's transition to clean energy, making this a nationally relevant case study with sectoral impact across energy, industry, and sustainability.

The Solution

To address these challenges, INMETRO worked with the General Coordination for Laboratory Accreditation (CGCRE) to establish ISO/IEC 17025-accredited testing laboratories and to introduce metrologically traceable calibration services for solarimeters, pyranometers, reference PV modules, and power quality meters for PV inverters. This was followed by the implementation of certification programmes requiring manufacturers and importers to submit panels and inverters for testing before commercialization. In addition to these accredited laboratories, Inmetro's Inspection Division established its own testing laboratory, as the responsible unit for market surveillance in Brazil, to evaluate the power output of PV systems. Items that failed to meet declared performance (i.e., possessing 'fake power') are barred from auctions and consumer markets. All calibration measurements complied with consolidated standards, such as the Brazilian Association of Technical Standards (ABNT) NBR IEC 61.215-2,⁵ to ensure accuracy and comparability. See **Figure 1** for an overview of Inmetro's metrology programme to provide reliable solar energy for Brazil.

³ IEC 61000-4-30: Testing and measurement techniques - Power quality measurement methods

⁴ IEC 61000-4-15: Electromagnetic Compatibility (EMC) – Flickermeter – Functional and Design Specifications.

⁵ Brazilian Association of Technical Standards (ABNT) NBR IEC 61.215-2 Módulos fotovoltaicos (FV) para uso terrestre – Qualificação de projeto e aprovação de tipo – Parte 2

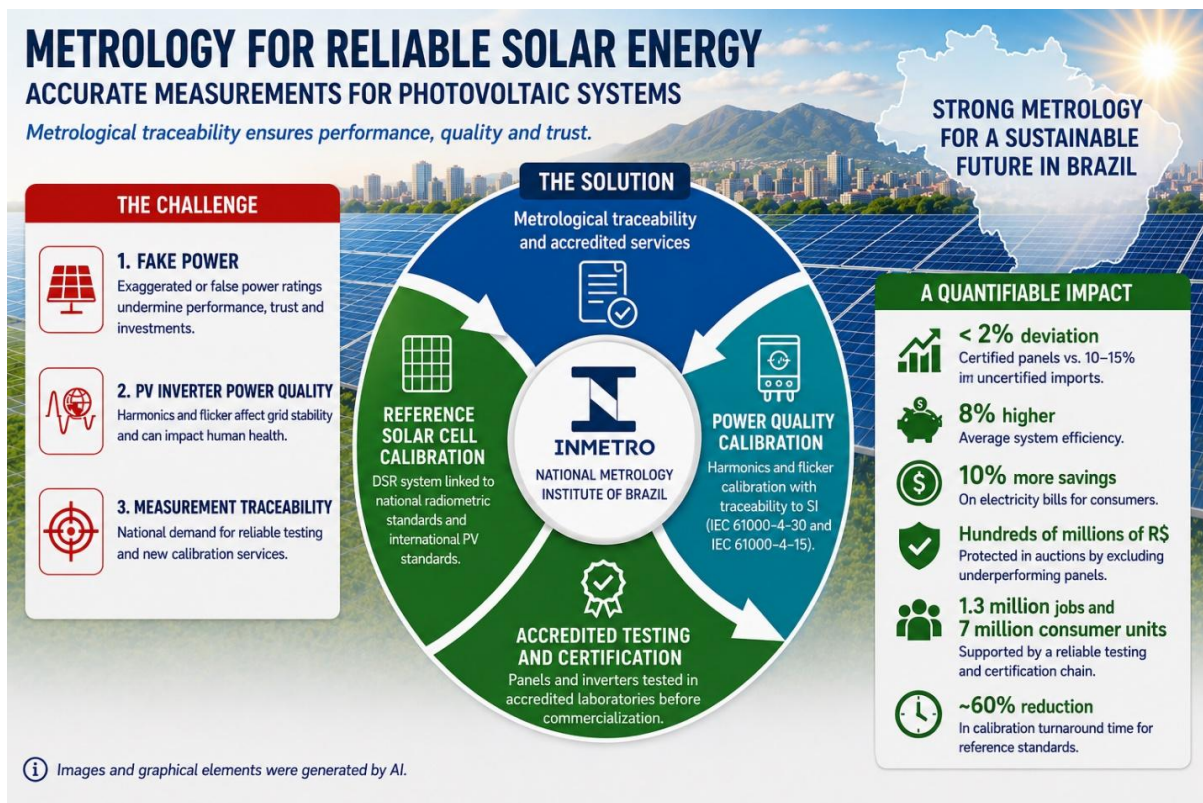


Figure 1. An overview of Inmetro’s metrology programmes to provide reliable solar energy for Brazil, summarizing the challenges, the solutions and the quantifiable impacts.

In 2026, INMETRO designed and implemented an experimental differential spectral responsivity (DSR) system to calibrate reference solar cells, linking their spectral irradiance responsivity directly to the electric substitution cryogenic radiometer as the national primary optical power scale through standard photodetectors. The system comprises a custom Czerny–Turner monochromator with automated wavelength and slit control, a stabilized auxiliary LED illumination system, active temperature control of the reference cell at 25 °C, and characterization of beam spatial uniformity over the active cell area. The calibration is performed in two main steps: 1) measurement of the relative spectral responsivity of the reference cell by comparison with a nationally calibrated photodetector using modulated monochromatic radiation (DSR mode), followed by 2) an absolute spectral irradiance measurement at 546.1 nm with a homogenized integrating-sphere setup to convert the relative curve into absolute spectral responsivity in irradiance mode. Measurement protocols, linearity checks, and uncertainty evaluation were established in accordance with IEC 60904-4:2019,⁶ ensuring full metrological traceability to SI units.

⁶ IEC 60904-4:2019, Photovoltaic devices - Part 4: Photovoltaic reference devices - Procedures for establishing calibration traceability.

The DSR system measured the relative spectral responsivity of a silicon reference solar cell over 320 nm to 1100 nm, with good repeatability and reproducibility. Spatial non-uniformity of the irradiance field over a 20 mm × 20 mm test area was measured at approximately 0.75 %, comparable to class A+ solar simulators (non-uniformity < 1 %), thereby supporting high-quality irradiance-based calibration. The measured responsivity spectra of reference solar cells agreed with available calibration certificates within expanded uncertainties (normalized error < 1), thus validating the INMETRO DSR system and its metrological traceability chain, illustrated in **Figure 2**.

In addition, in 2025, INMETRO expanded its PV panel testing capabilities to address the metrological traceability of power quality measurements conducted by PV system testing laboratories. This included increasing the operational ranges for single-phase harmonic current measurements ($I < 80$ A) and officially implementing a new calibration service for voltage flickermeters. This intervention now provides high-accuracy traceability to the International System of Units (SI) for these parameters. By establishing this metrological foundation, INMETRO has enabled national laboratories to perform standardized compliance testing of PV inverters in accordance with international IEC standards.

A Quantifiable Impact

As a result, consumers who used distributed generation as their energy source saved up to 10 % more on their electricity bills when certified panels delivered the expected output.

Solar panel testing also identified specific products with inflated power ratings, thereby protecting consumers and investors. Energy auctions have also avoided losses estimated at hundreds of millions of reais by excluding underperforming panels, since after the non-conformities of the photovoltaic modules are confirmed, INMETRO cancels the product registrations, preventing their commercialization. The solar panel certification process increased trust in PV technology, encouraging adoption across distributed generation and utility-scale projects and thereby providing market confidence. The integration of this metrology-based programme with policy enforcement energy auctions ensured systemic compliance and alignment with Brazil's renewable energy expansion.

The recently established INMETRO calibration service of reference solar cells also addresses a critical metrological gap for PV testing laboratories by providing accurate, metrologically traceable measurements of solar irradiance and PV device performance, thereby strengthening the reliability of test results and enhancing the effectiveness of Brazil's PV technical regulations. The project's achievements represent a breakthrough for the PV sector in Brazil through capacity building in metrology at INMETRO. This impacts not only the direct calibration cost but also the indirect costs associated with the time required to temporarily export the reference cells. Offering a local calibration service makes metrological traceability accessible to all ten accredited and designated laboratories responsible for efficiency tests on PV modules and panels, as well as for conformity testing and market regulator agents.

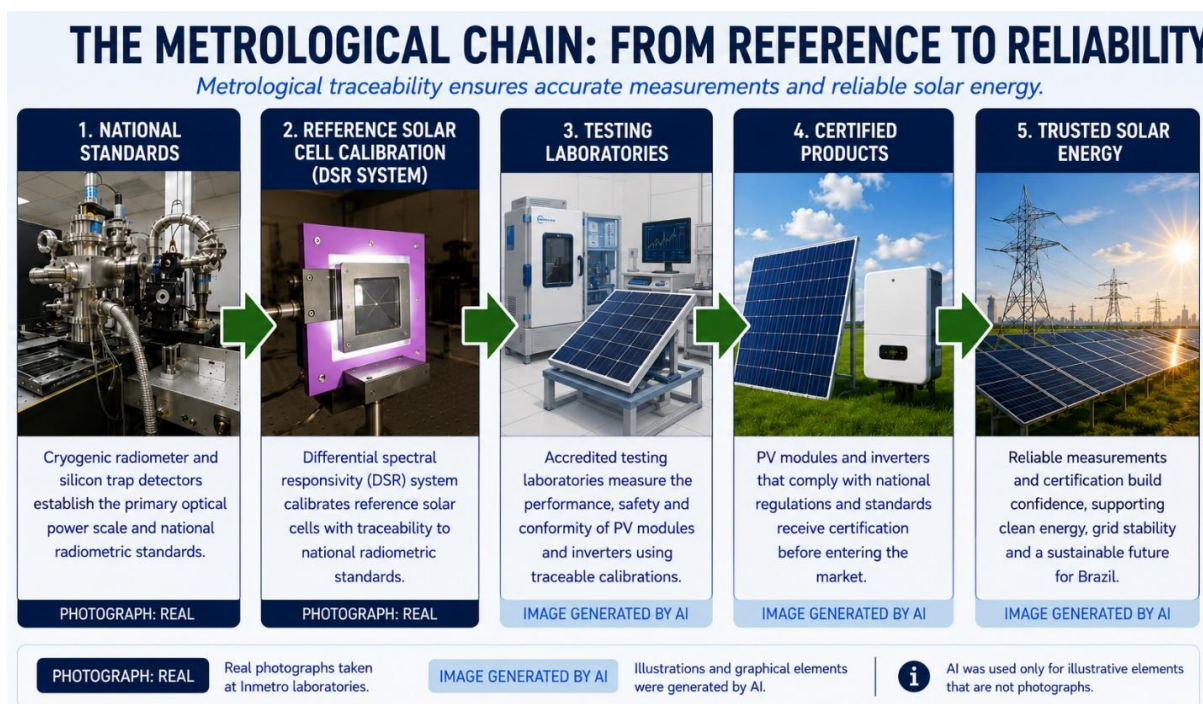


Figure 2. Metrological chain supporting PV measurements in Brazil, from national radiometric standards to trusted solar energy.

This project also consolidated the national testing and certification chain for PV inverters. The overall solar industry in Brazil, with 1.3 million jobs and 7 million consumer units, is directly supported by such laboratory infrastructure. By providing a primary reference for flickermeters, INMETRO now meets 100 % of the national demand for metrological traceability for flicker, supporting a network of eight accredited laboratories for flickermeters (including three specifically focused on PV inverters). Key outcomes include removing technical barriers to trade for hundreds of PV technology providers and ensuring that approximately 1 000 grid-tied inverter models meet the mandatory requirements of national regulations (Ordinance 140/2022).⁷ Furthermore, the intervention reduced the calibration turnaround time for reference flickermeters by an estimated 60 %, eliminating international logistics and customs burdens for the domestic industry. As stated by Cepel, an electrical energy research institution, one of Inmetro’s clients:

“We are interested in continuing to perform these calibrations, primarily because, within the Brazilian network, INMETRO is the only laboratory that carries out flicker calibration. This is a parameter of utmost importance in photovoltaic inverter testing.”

⁷ Inmetro Ordinance No. 140/2022: Requisitos de Avaliação da Conformidade para Equipamentos de Geração, Condicionamento e Armazenamento de Energia Elétrica em Sistemas Fotovoltaicos: <http://sistema-sil.inmetro.gov.br/rtac/RTAC002957.pdf>

In conclusion, the implemented calibration services for reference solar cells and power quality meters will enable a complete metrological traceability chain for PV panel and inverter testing in Brazil, with a direct impact on the PV sector, thereby strengthening conformity assessment, improving the reliability of efficiency ratings, and supporting the sustainable growth of the solar energy sector, preserving grid stability and population well-being, and preventing eye-related health problems. Addressing the increasing demand for a smooth transition towards an even greener energy matrix, Inmetro's metrological capabilities and services for testing photovoltaic panels and inverters will underpin a reliable solar energy sector, facilitate the nation's financial investments in this sector, and contribute to sustainable energy production.

This case study has demonstrated a significant economic impact by reducing risk for investors and consumers by ensuring PV systems deliver the promised output. This metrological intervention has also increased social awareness and confidence in renewable energy, accelerating household and institutional adoption. Furthermore, this supports Brazil's clean energy transition, reduces reliance on fossil fuels, and contributes to environmental protection and climate goals. In addition, this ensures that the transition to clean energy remains grid-compatible and protects the health of citizens nationwide, avoiding eye-related health problems like fatigue, headaches and convulsions caused by flicker grid interference from non-compliant equipment.

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