Technical procedures for guaranteeing performance and conformity in photovoltaic modules

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Abstract

The article addresses the importance of standardizing tests to ensure the performance and compliance of photovoltaic modules, based on INMETRO Ordinance 140. Visual inspection, maximum power, electrical insulation, and electroluminescence tests were performed on 20 555 W crystalline silicon modules. The results showed that 65% of the modules had minor damage, such as scratches and stains, related to transportation or manufacturing defects, although all met the electrical insulation criteria. In the maximum power test, it was observed that no module reached the specified nominal value, evidencing the performance drop of conventional modules. The electroluminescence test revealed internal defects—microcracks, stains, and dark spots—absent in traditional tests, indicating possible structural weaknesses. These results reinforce the need to incorporate electroluminescence testing into technical standards, with a view to improving the reliability, traceability, and quality of photovoltaic modules, as well as contributing to increased durability and efficiency of solar systems.

Keywords: Standardized tests, photovoltaic modules, performance quality, electroluminescence testing, technical standards.

1. Introduction

Environmental restrictions and the continuous increase in energy consumption, driven by population growth and rapid urbanization, have led to a growing demand for cleaner and more efficient energy sources (SARAVANAN; BABU, 2016). In this context, photovoltaic systems stand out as a strategic alternative, supported by technological advances, incentive policies, and the global need to reduce greenhouse gas emissions (DRISSI et al., 2017).

The standardization of performance tests establishes standardized procedures to ensure the functionality and reliability of photovoltaic modules, providing security to investors and consumers, both in conventional technologies (such as those based on silicon) and in emerging technologies (such as perovskite and OPV). Among the most widely used standards for evaluating photovoltaic modules is IEC 61215, which defines a set of essential tests, including visual inspection, maximum power measurement, and electrical insulation testing. This international standardization, as described in IEC 61215-1 and IEC 61215-2, enables objective comparisons between different technologies and manufacturers, as well as serving as a technical basis for analyzing performance degradation over time.

In the national context, INMETRO Ordinance No. 140 establishes the Technical Quality Regulation and Conformity Assessment Requirements for equipment used to generate, condition, and store electrical energy in photovoltaic systems. Among the devices covered by this regulation, photovoltaic modules undergo a conformity assessment process that includes visual inspection tests, initial stabilization, determination of maximum power, verification of electrical insulation, and insulation testing under humid conditions.

There is a notable similarity between the procedures required by the two standards, with national regulations covering a greater number of tests, aiming to increase reliability in equipment validation. Both procedures, however, ensure the conformity of photovoltaic modules through electrical characterization tests under standard test conditions, detailed visual inspections, and electrical insulation tests. These steps allow for the detection of visible and non-visible defects, especially those that may arise during the transport and handling of the modules. The adoption of standardized procedures, with proper alignment between national and international standards, promotes data

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traceability, increases transparency in specifications, and ensures interoperability between components. These factors together contribute to increased system reliability and investment security in the photovoltaic sector.

In large-scale projects, pre-installation testing plays a key role, as undetected faults can significantly compromise overall system performance and lead to significant economic losses. Thus, prior standardization of these tests is essential to ensure both the operational efficiency and longevity of photovoltaic systems.

However, electroluminescence testing is absent from both standards and is not included as an essential test for determining equipment characteristics. Although this test is currently performed on a complementary basis, it is considered fundamental when analyzed in conjunction with the results of other tests. Through electroluminescence, it is possible to directly assess the condition of photovoltaic cells, identifying initial defects that often do not yet manifest themselves significantly in other tests. Thus, electroluminescence testing allows for the early detection of faults that can compromise the performance of modules in the first months of operation. In addition, its results can be used in studies aimed at reducing the rate of equipment degradation, contributing to the development of more robust and durable modules.

In this context, in 2025, the Brazilian Association of Technical Standards (ABNT) developed the ABNT NBR 17258 standard, which establishes the criteria for electroluminescence inspection in photovoltaic modules. This national standard defines specific recommendations for tests applied to crystalline silicon modules, presenting in detail the standardization of procedures and the determination of quality standards for cells and their interconnections.

Considering the relevance of the creation of this standard, it is pertinent to discuss the integration of this test into the standardized evaluation protocols currently in use. The incorporation of electroluminescence into existing standards would enable a more thorough and comprehensive analysis of module performance, covering aspects that conventional tests alone are unable to identify.

Given this scenario, experimental analysis of photovoltaic modules using different testing methods is essential to understand the efficiency of characterization processes and the ability of each test to identify structural or electrical faults. The combined application of visual inspection tests, maximum power determination, and electrical insulation allows for verification of module compliance with current standards, providing a technical overview of the physical integrity and electrical performance of the equipment. However, the inclusion of electroluminescence testing significantly increases the accuracy of this assessment, as it enables the detection of internal anomalies that are not noticeable by traditional methods, such as microcracks, partial disconnections, and internal shading regions in the cells.

Thus, this work aims to present and compare the results obtained from visual inspection, maximum power, and electrical insulation tests on a set of 20 photovoltaic modules, discussing the relevance of electroluminescence testing as a complementary diagnostic tool. Based on this analysis, we seek to demonstrate the importance of incorporating it into conformity assessment standards, highlighting how its application contributes to the early detection of defects, the improvement of manufacturing processes, and the increased reliability of photovoltaic systems in operation.

2. Methodology

2.1. Experimental Procedure

To ensure the quality of photovoltaic module performance, standardized procedures must be used to assess their condition. Thus, standardized tests were performed in accordance with INMETRO Ordinance 140, which defines performance requirements for equipment approval. Figure 1 shows the flowchart that represents, in an orderly manner and in accordance with the ordinance, the tests to guarantee the performance of the equipment.

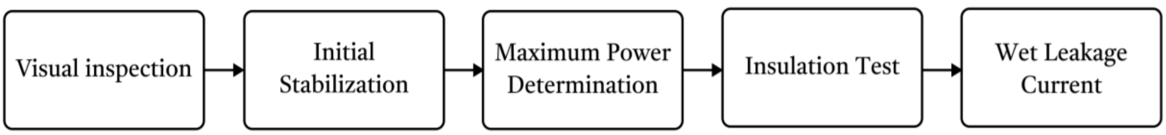


Figure 1: Flowchart of tests to guarantee performance (Adapted from INMETRO, 2022).

The tests were conducted in a controlled laboratory environment, without interference from external lighting and following the recommendations provided to ensure the reliability of the data obtained and, consequently, of the analysis performed according to the results obtained. A sample of 20 photovoltaic modules that had never been placed in operating conditions was used, with original characteristics, without the impact and effects that field operation causes on the equipment. The modules are identical, made of crystalline silicon, with 555W of nominal power specified by the manufacturer.

The equipment used to perform the tests was defined considering the minimum requirements established by the standard. A 5500K white light was used to perform the visual inspection test, with an illuminance of approximately 1600 lm/m² on the module plane. The equipment was positioned vertically so that the incident light was direct in relation to the module plane, which is ideal for complete visualization of the equipment.

The maximum power test, in turn, was performed in accordance with Standard Test Conditions (STC), which establish a standard temperature of 25°C, an irradiance under the test plane of 1000W/m², and an air mass of AM 1.5. The equipment used to measure the IxV curve was the HighLight 3 solar simulator, classified as Class A+++ according to the requirements for spectral matching, irradiance non-uniformity on the test plane, and temporal instability, as defined in IEC 60904-9 - Classification of solar simulator characteristics. Thus, the test was performed using an electronic load with an acquisition rate of 10 kHz and a flash of 100 ms, with the IV curve synthesized by measuring voltage and current with four wires. Each measurement was repeated three times, with the result calculated as the average of the recorded values.

In the insulation test procedure, it was necessary to use an insulating surface to perform the tests. A megohmmeter configured to apply voltage according to the module category for 2 minutes was used. With the area properly protected and the connections established, the test was performed and the results stored in the equipment for post-test analysis.

Finally, the electroluminescence test was performed using a DC power supply configured according to the voltage, current, and power requirements specified in IEC TS 60904-13, which defines the electroluminescence test procedure for silicon modules. The camera used was a commercial camera adapted and with a filter adjusted to capture images in the light spectrum emitted by silicon. The camera is configured according to the environmental conditions where the test is performed, in this case, with an ISO of 160, 2 seconds of exposure time, and a lens aperture of f/2.8.

3. Results

In accordance with the procedures described, it was possible to analyze the results obtained, using the requirements established in INMETRO Ordinance 140 of 2022 and standards IEC61215 and IEC60904 as parameters to diagnose which modules would be rejected or approved. Initially, the inconsistencies identified in the visual inspection test, shown in Figure 2, were observed. Minor damage to the glass resulting from impacts was the most frequent type of defect, followed by scratches on the frame. Such defects may be associated with the transportation and handling of the modules. A yellowish surface was identified on the back of the photovoltaic module, which may be associated with the interaction between the material on the back of the module and the packaging used during storage, possibly due to prolonged contact with the cardboard layer, which resulted in a change in color.

According to the national regulatory resolution, for a photovoltaic module to fail the visual inspection test, there must be physical damage such as a broken, warped, or cracked surface, bubbles, delamination, broken interconnections, joints, or terminals, among other defects. Even though 65% of the modules analyzed showed minor impacts on their structure, no module failed the visual inspection test.

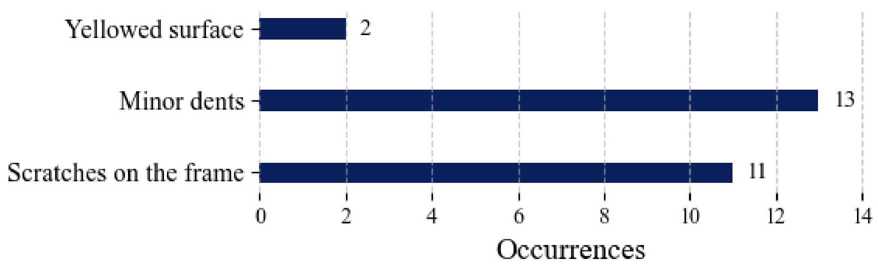
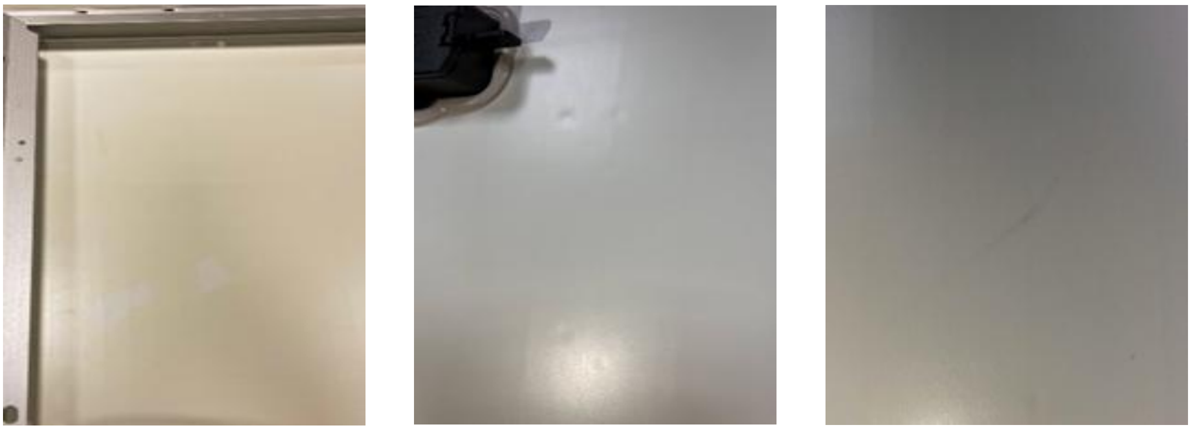


Figure 2: Index of occurrences recorded during visual inspection tests.

The empirical evidence of the occurrences quantified in Figure 2 is presented through the detailed photographic records in Figure 3, in which Figure 3.a illustrates the yellowed surface, Figure 3.b documents the smaller dents, which represent the highest occurrence rate, and Figure 3.c shows the scratch on the rear structure of the module. It can be observed that the yellowing on the structure has the characteristics mentioned above, being very similar to the coloration caused by contact with the packaging material, with some points on the surface that do not contain the different coloration. The minor dents and scratches on the structure, in turn, may be related to manufacturing problems in the parts, but mainly to transportation problems.



(a) (b) (c)

Figure 3: Photographic evidence of damage recorded during visual inspection.

In the maximum power test, the maximum power results obtained are shown in Figure 4. It can be seen that no modules had a power greater than or equal to that estimated by the manufacturer, meaning that all the modules analyzed were below the expected power value. According to IEC 60904-1, which defines the maximum power test requirements followed by the Ordinance, the condition for approval of a photovoltaic module in the maximum power test is to have between 100% and 105% of the nominal power value specified in the manufacturer's data sheet. This requirement means that the entire sample analyzed is discarded.

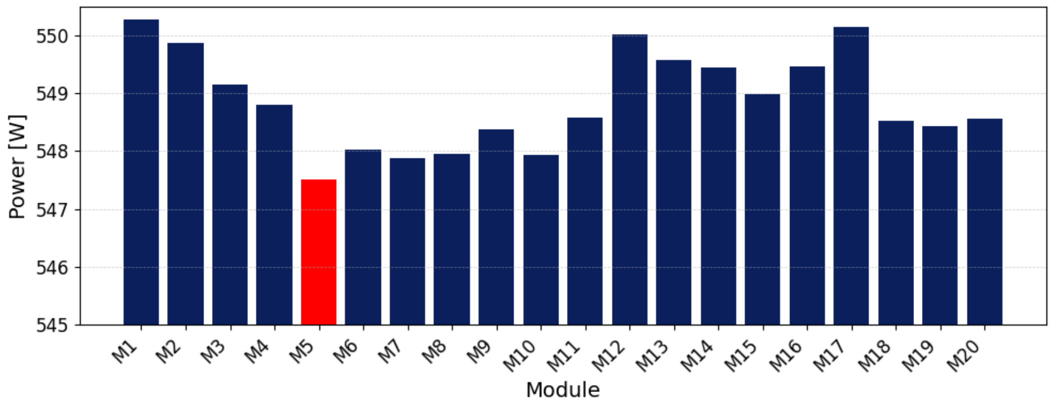


Figure 4: Maximum power test of the modules.

When comparing the current and voltage parameters measured and displayed in Table 1, a difference in these parameters can be seen according to the equipment's standard values. Looking at the data for module 5 (M5), which was the module with the lowest power among those measured, there is a 3.27% divergence from the standard short-circuit current, as well as a 1.81% divergence from the maximum power current. On the other hand, it is possible to observe that even with the divergence between the values obtained, the IxV curve of these overlapping devices does not show significant divergences between the values displayed graphically. This is shown in Figure 5, and therefore it is essential to verify the data individually for each device, allowing for a more accurate analysis and a true diagnosis.

Table 1: Results of the electrical characteristics of the modules compared with those declared by the manufacturer.

ID	POWER [W]	POWER [%]	Vmpp [V]	Vmpp [%]	Impp [A]	Impp [%]	Voc [V]	Voc [%]	Isc [A]	Isc [%]
Ref	555,00	Ref.	41,90	Ref.	13,25	Ref.	49,80	Ref.	14,05	Ref.
M1	550,27	-0,85%	42,22	0,77%	13,03	-1,66%	50,17	0,75%	13,60	-3,20%
M2	549,88	-0,92%	42,20	0,72%	13,03	-1,66%	50,20	0,80%	13,59	-3,27%
M3	549,16	-1,05%	42,17	0,64%	13,02	-1,74%	50,15	0,70%	13,60	-3,18%
M4	548,80	-1,12%	42,11	0,50%	13,03	-1,64%	50,06	0,53%	13,61	-3,11%
M5	547,50	-1,35%	42,08	0,42%	13,01	-1,81%	50,07	0,54%	13,59	-3,27%
M6	548,03	-1,26%	42,08	0,42%	13,02	-1,71%	50,10	0,60%	13,60	-3,20%
M7	547,87	-1,28%	42,07	0,41%	13,02	-1,74%	50,03	0,47%	13,61	-3,16%
M8	547,95	-1,28%	42,02	0,28%	13,04	-1,58%	50,01	0,42%	13,63	-3,02%
M9	548,37	-1,19%	42,06	0,37%	13,04	-1,58%	50,06	0,52%	13,62	-3,06%
M10	547,93	-1,27%	42,08	0,43%	13,02	-1,74%	50,02	0,44%	13,60	-3,20%
M11	548,58	-1,16%	42,14	0,58%	13,02	-1,76%	50,12	0,64%	13,60	-3,20%
M12	550,02	-0,90%	42,12	0,53%	13,06	-1,43%	50,14	0,68%	13,66	-2,80%
M13	549,57	-0,98%	42,11	0,49%	13,05	-1,51%	50,09	0,58%	13,65	-2,85%
M14	549,44	-1,00%	42,13	0,55%	13,04	-1,58%	50,10	0,60%	13,61	-3,13%
M15	548,99	-1,08%	42,15	0,59%	13,03	-1,69%	50,13	0,67%	13,60	-3,18%
M16	549,47	-1,00%	42,14	0,56%	13,04	-1,58%	50,10	0,60%	13,61	-3,13%
M17	550,14	-0,88%	42,12	0,52%	13,05	-1,53%	50,08	0,57%	13,63	-2,97%
M18	548,52	-1,17%	42,13	0,54%	13,02	-1,74%	50,07	0,54%	13,59	-3,27%
M19	548,43	-1,18%	42,10	0,49%	13,02	-1,71%	50,10	0,60%	13,62	-3,08%
M20	548,57	-1,16%	42,083	0,44%	13,03	-1,64%	50,07	0,54%	13,59	-3,25%

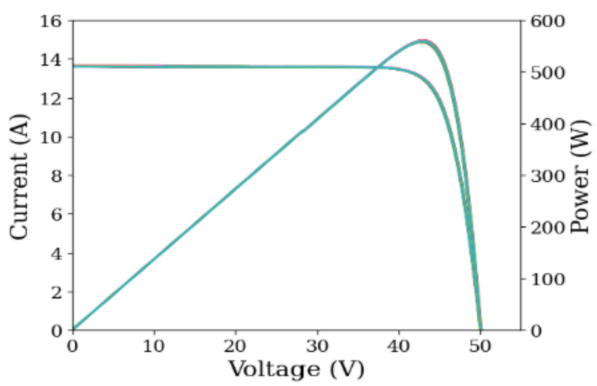


Figure: IxV and PxV curves of the modules.

The fact that photovoltaic modules provide less power than claimed by manufacturers was studied by TÜV Rheinland, which states that in 2015 and 2016, the percentage of equipment that exceeded the specified value was 71.7%, while in 2024, this percentage fell to 34.3%. The study notes that conventional modules performed worse when compared to emerging and more expensive technologies. Thus, the conventional silicon modules that were used to perform this test and in most residential and commercial applications are, for the most part, in the category below the specified value. This behavior may be indicative of the low performance complaints observed in some photovoltaic plants in northeastern Brazil.

For the insulation test under standard conditions, the results obtained are shown in Figure 6. The requirements for this test are defined in the ordinance, which stipulates a value greater than 40 MΩ.m² for modules with an area greater than 0.1 m². For the modules evaluated, there were no inconsistencies resulting from the insulation test, with the lowest measured resistance value being 28.3 GΩ, which more than exceeds the value established by the standard considering the area of the module. With the results of the insulation test, it is possible to compare the insulation results obtained for module 5, which had the lowest power, but its insulation performance was satisfactory, causing the module to pass this test.

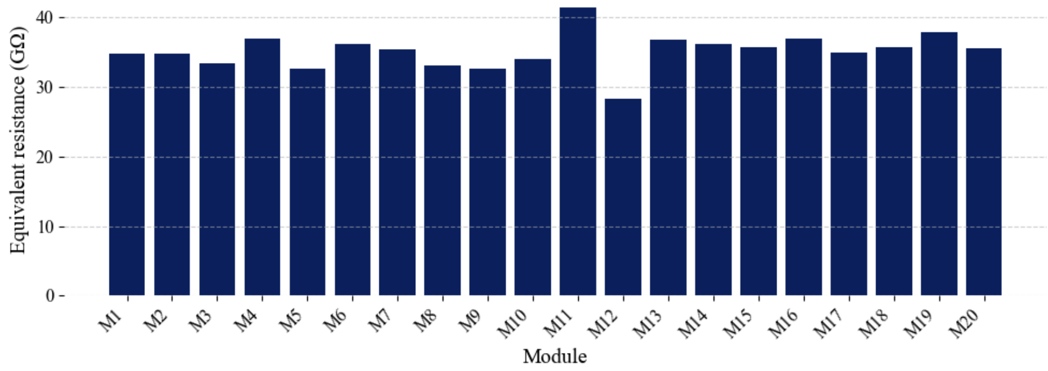


Figure 6: Equipment insulation resistance test.

To assess the condition of the cells, it was necessary to perform an electroluminescence test. The results of this test do not follow a standard established by the ordinance precisely because, to date, it is not part of the tests that comprise the approval requirements. In the results obtained, three defects were observed: spots, microcracks, and dark spots, which are shown in Figure 7. Spots are very common in photovoltaic modules, with a discrepancy of 168 occurrences in 20 modules analyzed.

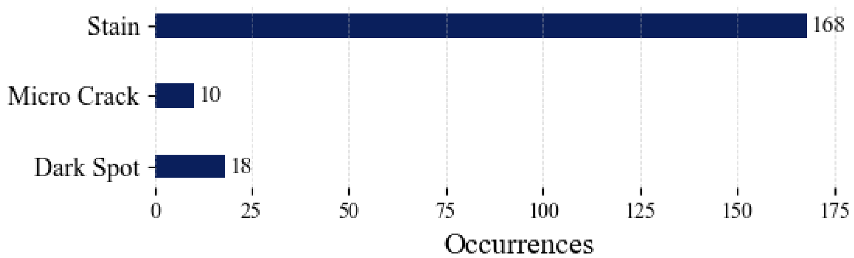


Figure 7: Defects recorded in the electroluminescence test.

When analyzing the results of module 1, shown in Figure 8, it can be seen that even with the presence of stains and welding flaws visible in the electroluminescence, there are no major impacts on the power output and are, in fact, inconsistencies that exist and, despite them, the power predicted by the manufacturer is guaranteed. In any case, this is a point to consider when analyzing the results, since spots and flaws in the welding can contribute to factors that degrade the photovoltaic module when exposed to operating conditions in the field.

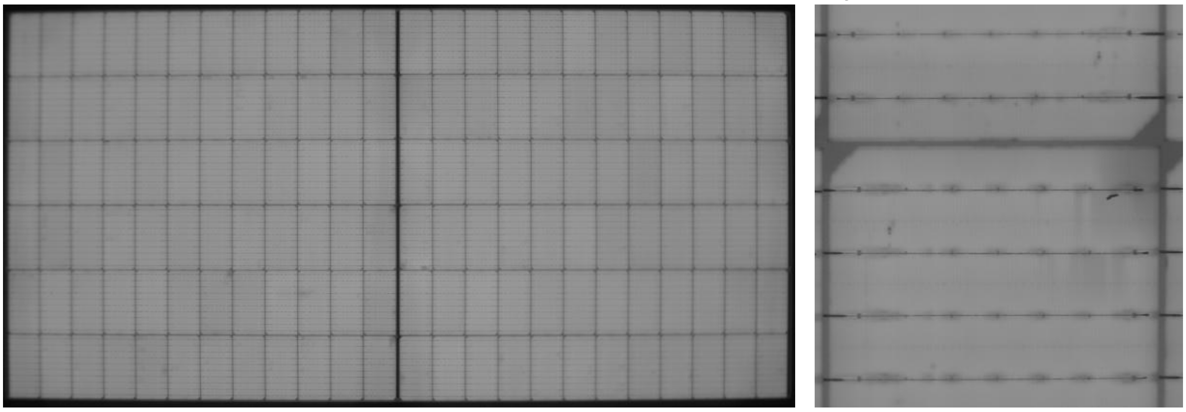


Figure 8: Electroluminescence of the highest power module.

In module 5, shown in Figure 9, there are a considerable number of spots more than in the other equipment presented, as expected, in addition to having a dark spot in one of its cells. The presence of these types of defects in equipment that has never been exposed to operating conditions compromises the estimated useful life of the module, making it essential for the manufacturer to identify this type of defect that compromises its optimal operation.

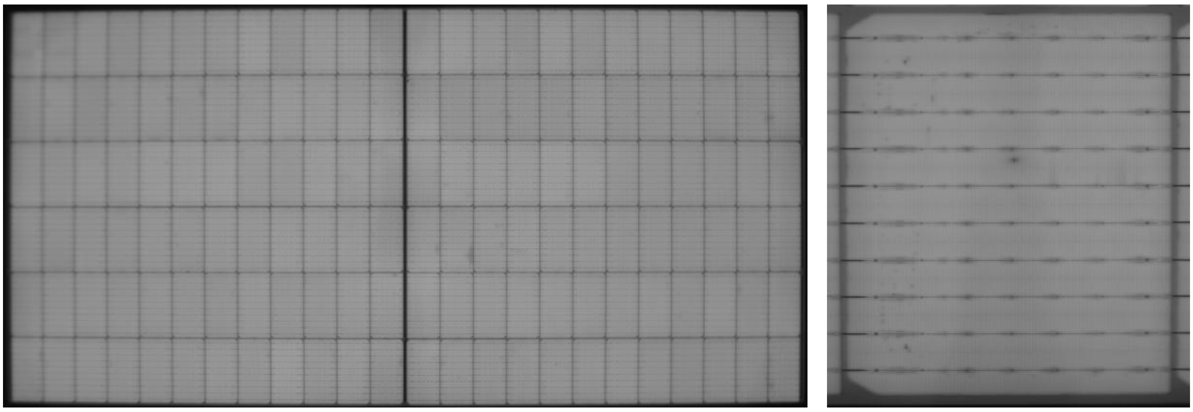


Figure 9: Electroluminescence of the lower power module.

By comparing Figures 8 and 9 with the maximum power test results for the respective modules, it is possible to understand their poor performance in relation to the required standard. Even with the different tests being carried out in accordance with the ordinance, the difference between the powers would not have been diagnosed if the test had not been performed, making its importance paramount for the actual verification of the conditions for approval of a module for operation. In fact, the tests fulfill their role and identify which modules are or are not capable of being marketed, but it is important to carry out a thorough inspection of the cells, which is only possible with electroluminescence.

4. Conclusion

The analysis of the results highlights the importance of standardized procedures for evaluating the performance and compliance of photovoltaic modules. The tests carried out in accordance with INMETRO Ordinance 140, visual inspection, maximum power measurement, and electrical insulation verification proved to be effective in characterizing the equipment and identifying physical and electrical non-conformities.

It was found that, although 65% of the modules had minor visual irregularities, all fully met the electrical insulation criteria, ensuring the dielectric integrity of the devices. However, analysis of the IxV curve revealed that only 15% of the modules achieved the nominal power declared by the manufacturer, which corroborates recent trends in the sector regarding the reduction in the actual performance of conventional silicon modules compared to the specified values. This problem is emerging mainly due to the mass use of silicon modules in residential and power generation applications.

The inclusion of electroluminescence testing has proven essential for detecting internal anomalies that cannot be identified by traditional tests, such as spots, microcracks, and hot spots. These defects, even in new modules that have not been exposed in the field, may indicate weaknesses in the manufacturing process and emphasize the need for a more comprehensive approach to qualification protocols. Therefore, it is important to consider the recent standard that defines the technical criteria for the inspection of photovoltaic modules by electroluminescence, the ABNT NBR 17258:2025 standard.

Therefore, the integration of electroluminescence testing into national and international regulatory procedures represents a strategic measure to improve the diagnosis of photovoltaic module quality, contributing to the mitigation of premature failures, the improvement of operational reliability, and the consolidation of more rigorous performance standards in the photovoltaic sector.

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