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# Comparative analysis between provided values and measured values on photovoltaic modules

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**Abstract:** This article aims to address a fundamental topic regarding photovoltaic modules, their respective performance. In the planning of a photovoltaic system, the power delivered by the module is the basis for project calculations, and it is investigated whether this value reflects reality. At Institute of Energy and Environment (IEE/USP), the I-V characteristic curve is plotted in a solar simulator to obtain the maximum values for two modules of different cell technologies compared to the values in the manufacturer's datasheet. Additionally, electroluminescent images are also taken to corroborate possible distinctions between the measured values, as well as probable drops in their performance for photovoltaic systems. Thus, the analysis shifts from theoretical to practical with real numbers and curves that highlight any discrepancies that may exist in the stated description, as well as the accepted percentage with the respective tolerances.

**Keywords:** Photovoltaic Module, I-V Characteristic Curve, Electroluminescence, Maximum Power Point.

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# Análise comparativa entre valores fornecidos e valores medidos em módulos fotovoltaicos

**Resumo:** Este artigo busca tratar de um tema primordial no que se refere a módulos fotovoltaicos, seu respectivo rendimento. No planejamento de um sistema fotovoltaico a potência que a módulo entrega é a base de cálculo para o projeto, com isso é investigado se este valor reflete a realidade. No IEE é realizado a plotagem da curva característica I-V em simulador solar para obtenção dos valores máximos que dois módulos de diferentes tecnologias celulares em comparação com valores do datasheet do fabricante. Em adição, é realizado também imagens eletroluminescentes que buscam corroborar com possíveis distinções entre os valores medidos, assim como prováveis quedas em seu rendimento para sistemas fotovoltaicos. Desta forma a análise passa de teórica para prática com números e curvas reais que venham evidenciar a discrepância que podem conter na descrição anunciada, tal como o percentual aceito com as respectivas tolerâncias.

**Palavras-chave:** Módulo fotovoltaico, Curva Característica I-V, Eletroluminescência, Ponto de Máxima Potência.

## 1. INTRODUCTION

At a global level, technology is developing faster and faster, in recent years a series of new technologies have been introduced aimed at the use of renewable energy, such as solar energy and wind energy. [1] Going deeper into solar energy, we find the photovoltaic effect that is the basis of this system, which consists of converting the Sun's electromagnetic radiation into electrical energy through potential difference. Photovoltaic modules are responsible for generating of energy, its function is to collect photons from sunlight.

The photovoltaic effect occurs when these photons collide with the atoms and semiconductors of the modules, the electrons are displaced, thus generating the current. [2] The material of its constitution determines the mode of energy generation, with the main types of modules being Monocrystalline Silicon and Polycrystalline Silicon.

Photovoltaic modules are made from encapsulated and electrically connected solar cells, whose resistance and durability can exceed 25 years under certain conditions. However, these cells can wear out due to the effects of solar radiation, particularly ultraviolet radiation, which can damage materials and equipment, as well as manufacturing defects, installation, and even transportation. [3]

Among other means of assessing degradation in modules, imaging examinations such as electroluminescence and thermography are used. The main challenge is evaluating the captured results; for this, the IEC TS 60904-13 standard serves as a foundation for guidance and qualitative interpretation of electroluminescent images, as well as a normative method for conducting the tests.

In addition to the material constitution of the module, another point to be highlighted is the power of these modules, thus determining the energy capacity of the system. However, the calculation basis is linked to the nominal demand made available by the manufacturer, but the main issue is to consider whether the module delivers what is assured, thus questioning all previously established predictions.

It is increasingly necessary to pay attention to financial matters since photovoltaic technology is involved with opportunity creation, market injection, and high-level investment.

> For photovoltaic energy generation, an important factor is that for each megawatt installed, between 25 to 30 direct jobs are created, distributed among panel installers, designers, manufacturers, and system assemblers. The recent reductions in the costs of photovoltaic solar energy systems have driven the implementation of this technology both in power plants and in distributed generation. This represents a boost in job creation, as globally, in 2015, photovoltaic solar installations were 20% higher than the previous year, with China, Japan, and the United States leading the way. [4]

This demonstrates that the added value of the entire photovoltaic system directly depends on what the module can deliver. For this reason, it is extremely important that the modules can provide the power specified in the manufacturer's manual.

## 2. MATERIALS AND METHODS

The method used in the present study is based on the analysis of the power of the modules, where a curve of their current is established as a function of the applied voltage, thus it is possible to measure the analysis parameters through the I-V characteristic curve, a curve which provides detailed data on the electrical factors of a photovoltaic system. [5] In the proposal in question, the I-V characteristic curve is carried out using a Solar Simulator from the company Pasan installed at Institute of Energy and Environment (IEE/USP). Two modules with different cellular compositions were used for the case study, they are: Polycrystalline Module from Resun, model RSM-100P; and the Resun Monocrystalline Module, model RS6E-155M.

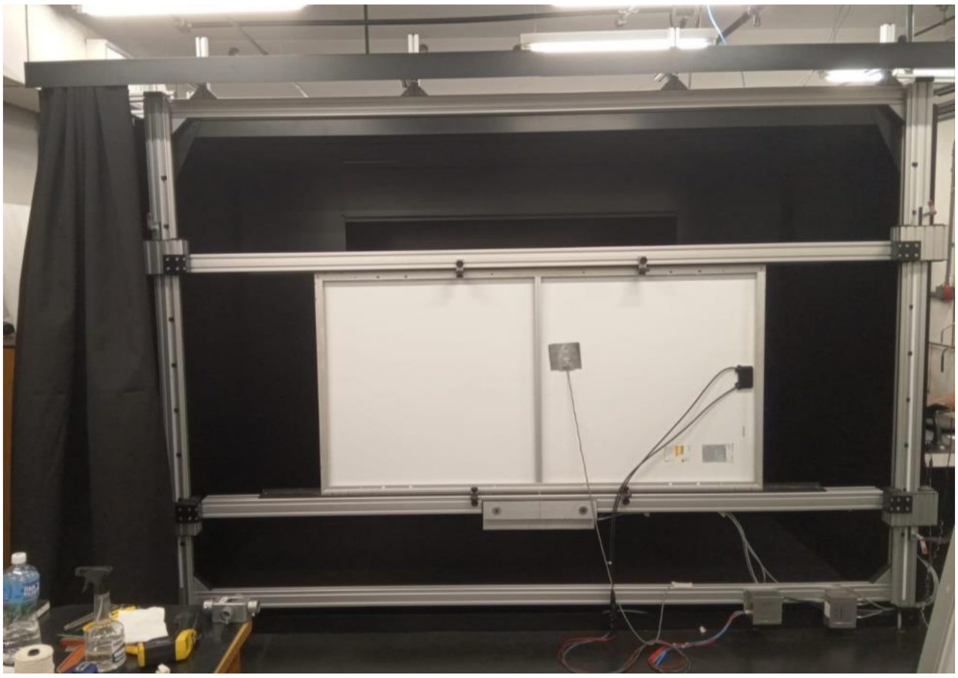
In order to compare the power values, which are the basis of the study, the curve is simulated with the module still unused so that there is no interference in the initial value due to degradation or something similar. The reference value used is that which appears in the datasheet provided by the manufacturer, thus starting from this premise to maintain parity between the described value and the real value.

For the purpose of to approve the real values of the polycrystalline modules (model RSM-100P) and the monocrystalline module (model RS6E-155M), the flash test on the Solar Simulator HighLIGHT from Pasan Measurement Systems, version R2.4.0, is carried out at IEE - Institute of Energy and Environment, located in São Paulo, set in an air-conditioned laboratory at 25ºC.

This simulator includes an electronic load and the flash test with the purpose of measuring the electrical performance of a given module, obtaining the I-V Characteristic Curve and parameters such as Open Circuit Voltage (Voc), Short-Circuit Current (Isc), Maximum Power Voltage (Vmp), Maximum Power Current (Imp), and Maximum Power Point (Pmp).

Tests are carried out individually, where the module is sanitized in order to eliminate impurities and particles that could affect the incident irradiance. The module is then attached to the support inside the simulator, in order to isolate it against the passage of light through a black cotton curtain. After these procedures, the operator starts the simulation, where a flash of light is emitted generated from a Xenon gas lamp, in a short duration that varies from 1 to 30 milliseconds. This action is performed in duplicate, as the measurement occurs directly and reversely in order to attest to the values produced, ensuring the reliability of the measurement. Figure 1 shows the environment where the simulator performs measurements in the IEE building in São Paulo.

**Figure 1:** Pasan simulator installed at IEE/SP



Source : Author, 2023.

The I-V Characteristic Curve is generated automatically using the Simulator's own software, Pasan software version 2.3. A file is provided containing information relating to the measurement that contains data from the module in simulation, as well as its various measured parameters, including cell temperature, incident irradiance, cell efficiency, fill factor, etc. In addition to electrical parameters such as Open Circuit Voltage (Voc), Short-Circuit Current (Isc), Maximum Power Voltage (Vmp), Maximum Power Current (Imp) and Maximum Power Point (Pmp).

Another method used to assess possible degradations in modules is electroluminescent imaging. This is a non-invasive technique for detecting defects in photovoltaic cells and modules. This method is obtained through photons emitted in the radiative recombination of charge carriers excited under forward bias, where an external power source is used to electrically stimulate the module for the emission of electroluminescent radiation. [5]

The examination is conducted at the IEE in a chamber used for electromagnetic compatibility testing, making it a light-proof environment. In addition to allowing complete absence of light, the room is equipped with a DC power source, a support for fixing the module, a tripod, and the camera itself. The DC power source is used to excite the current in order to obtain the transcendent image of the cells, allowing for the adjustment of voltage and current according to the module in question.

Along with its polarization, the module is placed on the mounting support, then the tripod is positioned at a distance that can frame the entire module in the camera. Once everything is positioned, the camera that will capture the image is connected to a computer that triggers it within 30 seconds, the time needed to turn off the lights in the chamber to obtain the image. The environment used for capturing the image can be seen in Figure 2.

**Figure 2:** Chamber of electromagnetic compatibility at IEE/SP

Source : Author, 2023.

The image is obtained using a Canon digital camera, model EOS Rebel T6. This device is equipped with compact DSLR (Digital Single Lens Reflex) technology, featuring an 18MP APS-C sensor and a DIGIC 4+ image processor. The lens used is an EF-S 18-55mm f/3.5-5.6 IS II, which provides a focal length range equivalent to 28.8-88mm, covering perspectives from wide-angle to short telephoto.

To capture the image of the module, it is necessary to remove the infrared filter from the camera, replacing it with a full-spectrum window of equal optical path length. This allows the observation of the infrared wavelength range, which is naturally invisible to the naked eye.

## 3. RESULTS AND DISCUSSIONS

According to the data provided by the module manufacturer, the following values are found in accordance with Table 1:

**Table 1 :** Measurements provided in the modules datasheet.

| | POLYCRYSTALLINE MODULE | MONOCRYSTALLINE MODULE |
|---|---|---|
| Power | 100 W | 155 W |
| Open circuit voltage | 21,58 V | 24,46 V |
| Short-circuit current | 6,04 A | 8,31 A |
| Maximum Power Voltage | 17,40 V | 20,64 V |
| Maximum Power Current | 5,75 A | 7,51 A |
| Module efficiency | 15,44% | 18,05% |

Source : Author, 2024.

To obtain the simulation values of the I-V Characteristic Curve, its measurement are carried out three times in each method (direct and reverse), in order to ensure the values found through an uncertainty of 2.2% of the simulator's percentage error. In this way, the average values of each parameter are used to manipulate the data. In this way, the next step presents the real values that the modules can reach, based on the simulation carried out, it is possible to obtain the following values presented in Table 2 below.

**Table 2 :** Measurement carried out on the Pasan Simulator.

| | POLYCRYSTALLINE MODULE | MONOCRYSTALLINE MODULE |
|---|---|---|
| Power | 95,83 W | 111,61 W |
| Open circuit voltage | 23,77 V | 22,96 V |
| Short-circuit current | 5,15 A | 5,98 A |
| Maximum Power Voltage | 19,59 V | 19,30 V |
| Maximum Power Current | 4,89 A | 5,77 A |
| Module efficiency | 16,82% | 13,00% |

Source : Author, 2024.

According to Table 3 below, it is possible to analyze the difference between both modules comparatively based on the percentage values.

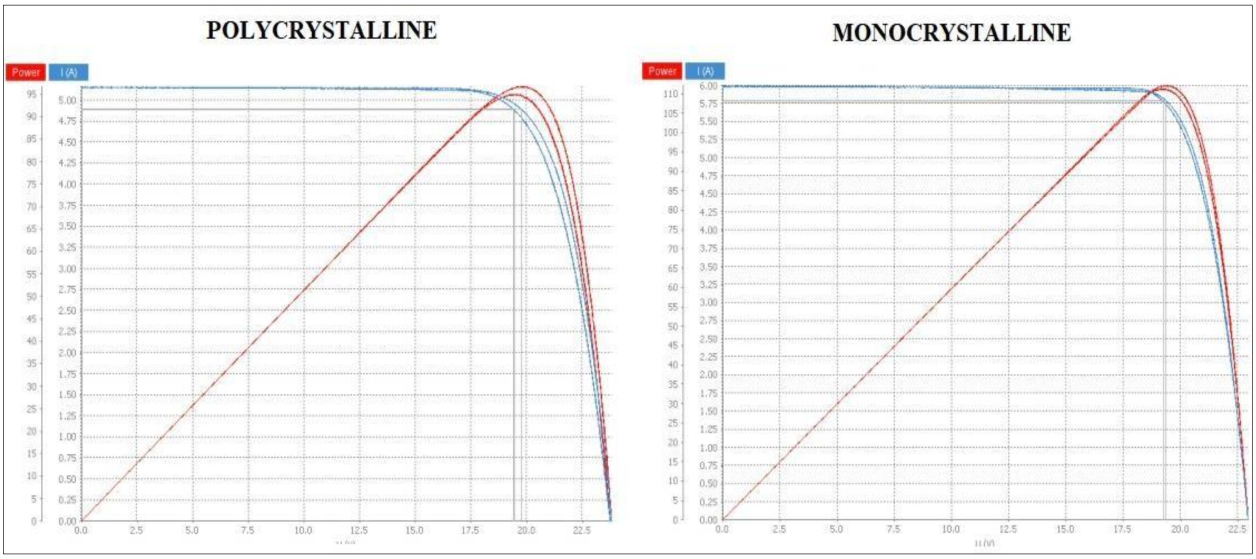
**Table 3 :** Difference between described and measured values.

| | POLYCRYSTALLINE MODULE | MONOCRYSTALLINE MODULE |
|---|---|---|
| Power | -4,17 | -43,39 |
| Open circuit voltage | 2,19 | -1,5 |
| Short-circuit current | -0,89 | -2,33 |
| Maximum Power Voltage | 2,19 | -1,34 |
| Maximum Power Current | -0,86 | -1,74 |
| Module efficiency | 1,38 | -5,05 |

Source : Author, 2024.

It is possible to observe a considerable divergence in the values found, mainly in the Monocrystalline module, which exceeds the specified tolerance, reaching around 28% below what was reported, while the Polycrystalline module presents around 4% below. According to the datasheet, it is mentioned in both modules that the tolerance is from -0 to +5W. In addition to the values, the I-V Characteristic Curve is also simulated, which presents these values graphically as shown in Figure 3.

**Figure 3:** I-V characteristic curve of both modules




Source : Author, 2024.

In the figures above, the values on the abscissas (X-axis) correspond to the module voltage, and the values on the ordinates (Y-axis) correspond to the current. Alongside the current, it is possible to visualize the power values, which are the result of the product of the current and voltage parameters.

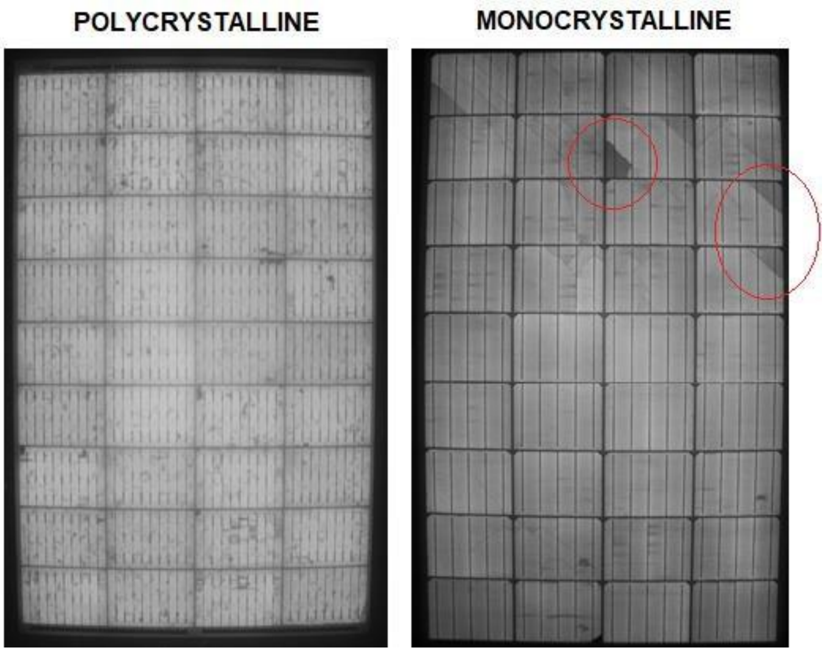
In the described configuration, the graph displays lines of three different curves. The red curve represents the power parameter, where its maximum point is exactly the maximum power point of the module. On the abscissa, it is possible to know the module's voltage value when it reaches maximum power, while on the ordinate, the module's current at its maximum power is found.

The blue curve represents the short-circuit current point, that is, when the module does not operate under real conditions, simulating the current flow when the module's output (both poles) are connected to each other. This is followed by the gray lines that form a right angle pointing to the intersection between the maximum voltage and current values.

It is also possible to notice the existence of double lines, which in this case refer to direct and reverse measurements. Another point to highlight is that the open-circuit and short-circuit values do not represent the maximum power value because the module is not in an appropriate condition for use under these circumstances.

An electroluminescent image of each module was recorded to assess any internal structural damage, in order to corroborate the values found in the simulations. The Figure 4 presents the results found in the images.

**Figure 4:** Electroluminescent images of both modules.




Source: Author, 2024.

Based on the literature and the respective IEC TS 60904-13 standard, an analysis is made of the images reflecting the condition of the modules before exposure to irradiation. The polycrystalline module showed a slight change compared to the initial description, directly reflected in its electroluminescent image with minimal defects, cracks, and fissures, thus confirming an acceptable value of its performance.

The monocrystalline module showed a percentage well below that reported in the manufacturer's manual. Consequently, some defects were found in the cells, such as cracks and fissures highlighted by the red circle in Figure 4. It is possible to state that the identified faults do not justify such a significant disparity in the reduction of energy efficiency.

## 4. CONCLUSIONS

According to the results above, it is clear that the relationship between manufacturer and consumer needs to have greater transparency. The simulation carried out by IEE had no costs as it was an academic study, however for a regular consumer this simulation has a high cost, in addition to being limited to individual modules and not the entire batch. As a result, many modules may not meet the stipulated minimum tolerance, causing problems in system sizing, as well as a significant financial impact, as in the case study in question, where some of the modules affect 28% below the nominal measurement.

Associated with the I-V Characteristic Curve simulations, the imaging examinations conducted provide evidence that the observed degradation was related to possible cracks, fractures, hot spots, or even broken cells. In any case, a greater vulnerability is observed in the Monocrystalline module, both with small cracks and fractures. Despite this, it cannot be directly linked to the significant energy loss.

INMETRO (National Institute of Metrology, Quality and Technology) is the body responsible for regulating these values for manufacturers of photovoltaic modules, however, as mentioned above, the conformity test is carried out in batches, that is, the measurement is carried out in a module that serves to regularize all modules that have passed the same manufacturing process over a given period of time. This causes some modules to be validated without being within the desired tolerance.

It is therefore necessary to provide details to determine the best means of studying this validation, as well as an analysis to establish whether this failure is restricted to some manufacturers or whether it is applied generally. A flaw in sample testing for INMETRO approval can be identified.

In any case, the study presents a specific approach focused solely on a single commercialized model. Based on the data obtained, it is not possible to assert this trend for photovoltaic modules in general. This study is highly valuable as it highlights the methodology employed in the tests conducted, thereby establishing a normative testing standard that can more clearly inform consumers about the actual efficiency the module can deliver.

Future research provides a range of potential avenues. Exploring cell technology could offer deeper insights into the trends observed in this study, as well as clarify the impact of the module manufacturer on this behavior. Moreover, increasing the sample size of modules, including diverse models and brands, would enable a more comprehensive and robust analysis, ultimately leading to more conclusive findings.

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## CONFLICT OF INTEREST

The authors Vinicius Puglia and Thadeu Conti declare that there are no conflicts of interest in the research in question.

The Institute of Energy and Environment declares that there is no conflict of interest in the simulation of the module data as it is an academic research.

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