COMPARATIVE ANALYSIS OF THE DYNAMIC EFFICIENCY OF COMMERCIAL PHOTOVOLTAIC INVERTERS UNDER STANDARDIZED IRRADIANCE PROFILES

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Abstract

The assessment of the dynamic performance of photovoltaic inverters has largely been based on the tracking efficiency of the maximum power point, as defined by IEC 62891:2020. Although this assessment provides important information, it does not take into account losses in the conversion stage, which leads to an underestimation of performance under dynamic conditions. Given this scenario, this work proposes the evaluation of total dynamic efficiency, which includes, in addition to MPPT tracking, conversion efficiency. The combination of these two parameters makes it possible to characterize the behavior of inverters under variations in irradiance. Experimental tests were carried out with trapezoidal irradiance profiles on ten commercial inverters, five of which were microinverters and five were string inverters. The results indicate that the microinverters showed lower total dynamic efficiency values, with an average of 79.32% for the five devices evaluated, especially in low irradiance conditions. In contrast, string inverters maintained a high and stable performance, with an average of 95.78%. These results reinforce the importance of considering the conversion stage in the normative assessment.

Keywords: commercial photovoltaic inverters; maximum power point tracking; dynamic efficiency; irradiance profile; standard procedure.

1. Introduction

The inverters used to connect photovoltaic (PV) systems to the utility grid convert direct current (DC) into alternating current (AC), control power injection, and continuously track the point of maximum power of the modules (Villalva, 2012; Prieb, 2014). Efficiency is one of the main criteria for evaluating this equipment (Bletterie, 2011; Lima, 2023), and can be categorized into two kinds: static efficiency and dynamic efficiency. Static efficiency reflects performance under stationary conditions, while dynamic efficiency considers fast variations in irradiance to represent real operating conditions (Bortolini, 2018; Rodrigues, 2023).

Initially, efficiency studies focused predominantly on measuring static efficiency, disregarding the effects of rapid and frequent variations in real operating conditions. Recent studies have emphasized the practical importance of dynamic efficiency, showing that the inverter's ability to respond quickly to changes in irradiance influences the actual performance of grid-connected PV systems (Rodrigues, 2023). The first initiative aimed at dynamic evaluation came from the California Energy Commission (CEC) (Bower, 2004), which proposed experimental methods using irradiance ramps. In the 2000s, Haeberlin consolidated these concepts, introducing formal procedures for quantifying dynamic efficiency (Haeberlin, 2006; 2009). These advances resulted in the publication of EN 50530 (European Committee for Electrotechnical Standardization, 2010), which standardized dynamic maximum power point tracking (MPPT) tests, later internationalized by IEC 62891 (International Electrotechnical Commission, 2020), the current reference for assessing the tracking capacity of inverters under dynamic conditions.

In 2021, IEC TS 63156 (International Electrotechnical Commission, 2021) extended this approach by proposing the use of weighted real irradiance profiles to estimate overall efficiency. However, this standard has important limitations: it requires high temporal data resolution (granularity of less than 1 second), uses short test periods, and can compromise the representativeness of the results for real operating conditions. These restrictions open up space for complementary assessment methods. In Brazil, INMETRO Ordinance 140 still only covers static efficiency criteria.

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Against this backdrop, this work evaluates the total dynamic efficiency of photovoltaic inverters, including the IEC 62891 standard, which focuses only on evaluating the MPPT's tracking capacity. This study also includes the simultaneous analysis of conversion efficiency. Combining these two parameters makes it possible to determine the total dynamic efficiency, which better reflects the actual performance of the inverters under varying conditions.

For this analysis, ten commercial inverters were selected, classified according to their construction technologies, power ratings, and kind of MPPT approach, as reported on each one's datasheet, making it possible to assess the influence of these characteristics on the dynamic performance of the PV inverter.

2. Dynamic efficiency of PV inverters

The dynamic efficiency of PV inverters refers to the ability of the MPPT algorithm to quickly keep up with the Maximum Power Point (MPP) during variable environmental conditions. This measure is obtained by the ratio between the power actually extracted by the inverter and the maximum theoretical power available (Ishaque, 2014), called dynamic MPPT efficiency by IEC 62681:2020.

IEC 62891:2020 establishes that dynamic efficiency tests must be conducted with variations in irradiance, using a crystalline silicon (c-Si) photovoltaic model at an ambient temperature of 25°C ± 5°C. For each test condition, a photovoltaic source must emulate the respective I/V characteristic curve, considering that an irradiance of 1000W/m² corresponds to the nominal power of the inverter tested.

The standard also defines a minimum stabilization period of 5 minutes for the inverter. It should be noted that due to the complexity of MPPT algorithms, this time may vary between devices. In addition, three main test conditions are established: low and medium irradiance (100 to 500 W/m² with eleven sequences - Test I), medium and high irradiance (300 to 1000 W/m² with six sequences - Test II), and start-up and shut-down (10 to 100 W/m² with a single sequence - Test III). In each test, both the irradiance and its rate of change over time are adjusted, generating a trapezoidal profile. Each test consists of a set number of sequences in which various parameters are adjusted. The irradiance ranges tested vary from 10% to 100%, with 100% being equivalent to 1000 W/m² at 25°C (under STC conditions).

Once the three tests have been completed, IEC 62891:2020 suggests adopting a calculation procedure. The first step is to determine the MPPT efficiency of each sequence, according to Eq.1.

$$\eta_{MPPT_{dyn}} = \frac{1}{\sum_j (P_{MPP,SPV,J} \cdot \Delta T_j)} \sum_i (V_{DC,i} \cdot I_{DC,i} \cdot \Delta T_i) \qquad \text{(eq. 1)}$$

Where $\eta_{MPPT_{dyn}}$ is the dynamic MPPT efficiency of the sequence, $P_{MPP,SPV,J}$ is the power of the maximum power point provided by the PV emulator, $V_{DC,i}$ is the DC input voltage of the inverter, $I_{DC,i}$ is the DC input current of the inverter, ΔT_j is the period in which $P_{MPP,SPV,J}$ is measured, and ΔT_i is the period in which $V_{DC,i}$ e $I_{DC,i}$ are sampled.

Based on the MPPT efficiencies calculated for each sequence, the equipment's dynamic MPPT efficiency must be determined, given by Eq. 2.

$$\eta_{MPPT_{dyn,t}} = \frac{1}{N} \sum_{i=1}^{N} (a_i \cdot \eta_{MPPT_{dyn,i}}) \qquad \text{(eq. 2)}$$

Where $\eta_{MPPT_{dyn,t}}$ is the dynamic MPPT efficiency of the equipment, N is the number of test sequences, a_i is the weighting factor, $\eta_{MPPT_{dyn,i}}$ is the dynamic MPPT efficiency of each sequence. The standard also includes a note indicating that, unless other time values are defined for each test sequence, the weighting factor is assumed to be $a_i = 1$.

2.1. Dynamic total efficiency proposal

No standard currently covers the concept of total dynamic efficiency. The publication that comes closest is IEC TS 63156:2021, which deals with efficiency under dynamic conditions in a weighted manner. However, the standard imposes a limitation by requiring high granularity in the acquisition of irradiance data. The main difficulty arising from this requirement is that not all monitoring equipment or meteorological databases offer this temporal resolution, making it difficult to apply in practice.

A recent example along these lines is the work by Figueira et al. (2023), which proposes a methodology for defining the overall efficiency of photovoltaic inverters, serving as a single evaluation index by considering both static and dynamic tests. This global efficiency is achieved through a weighted sum of efficiency results measured under various conditions, overcoming previous methods that resulted in "multiple numbers" without clear weighting criteria. Although this approach represents an important advance in the attempt to unify results, evaluating the dynamic efficiency of the inverter remains a challenge.

Existing standards, such as IEC 62891:2020, are important for standardizing dynamic testing, as they establish procedures for verifying the equipment's response to rapid variations in irradiance. However, these guidelines mainly focus on the inverter's ability to track the MPP, through the so-called dynamic MPPT efficiency $\eta_{MPPT_{dyn}}$. This assessment, although useful for evaluating tracking, does not adequately represent the inverter's behavior in the field, as it disregards conversion efficiency ($\eta_{conv_{dyn}}$). This efficiency can vary under dynamic conditions, even when MPP tracking is satisfactory, directly influencing the energy delivered to the grid. In this context, this paper proposes dynamic total efficiency, which combines both tracking and conversion efficiency in a single measure. This also includes the dynamic component of global efficiency methodologies, such as Figueira et al. (2023), which are based on standards whose tests do not adequately consider conversion efficiency. Thus, the dynamic MPPT efficiency is calculated according to Eq. 1 defined by the standard. The dynamic conversion efficiency is given by Eq. 3.

$$\eta_{conv_{dyn}} = \frac{1}{\sum_j (P_{DC,j} \cdot \Delta T_j)} \sum_i (P_{AC,i} \cdot \Delta T_i) \qquad \text{(eq. 3)}$$

Where $\eta_{conv_{dyn}}$ is the dynamic conversion efficiency of the sequence, $P_{DC,j}$ is the input power of the inverter, $P_{AC,j}$ is the input power of the inverter, ΔT_j is the period in which $P_{DC,j}$ is measured, and ΔT_i is the period in which $P_{AC,i}$ is sampled.

It should be noted that the values obtained using Eqs. 1 and 3 correspond to the efficiencies calculated for each sequence individually. To determine the inverter's dynamic conversion efficiency, considering all the sequences together, Eq. 4 must be used in a similar way to the procedure adopted to calculate the dynamic MPPT efficiency in Eq. 2.

$$\eta_{conv_{dyn,t}} = \frac{1}{N} \sum_{i=1}^{N} (a_i \cdot \eta_{conv_{dyn,i}}) \qquad \text{(eq. 4)}$$

Thus, from Eqs. 2 and 4, the expression for total dynamic efficiency is obtained ($\eta_{total_{dyn}}$), shown in Eq. 5.

$$\eta_{total_{dyn}} = \eta_{MPPT_{dyn,t}} \cdot \eta_{conv_{dyn,t}} = \eta_{conv_{dyn}} = \frac{1}{\sum_j (P_{MPP,j} \cdot \Delta T_j)} \sum_i (P_{AC,i} \cdot \Delta T_i) \qquad \text{(eq. 5)}$$

Figure 1 provides a schematic summary of the main equations discussed, highlighting the normative basis and the additional elements proposed.

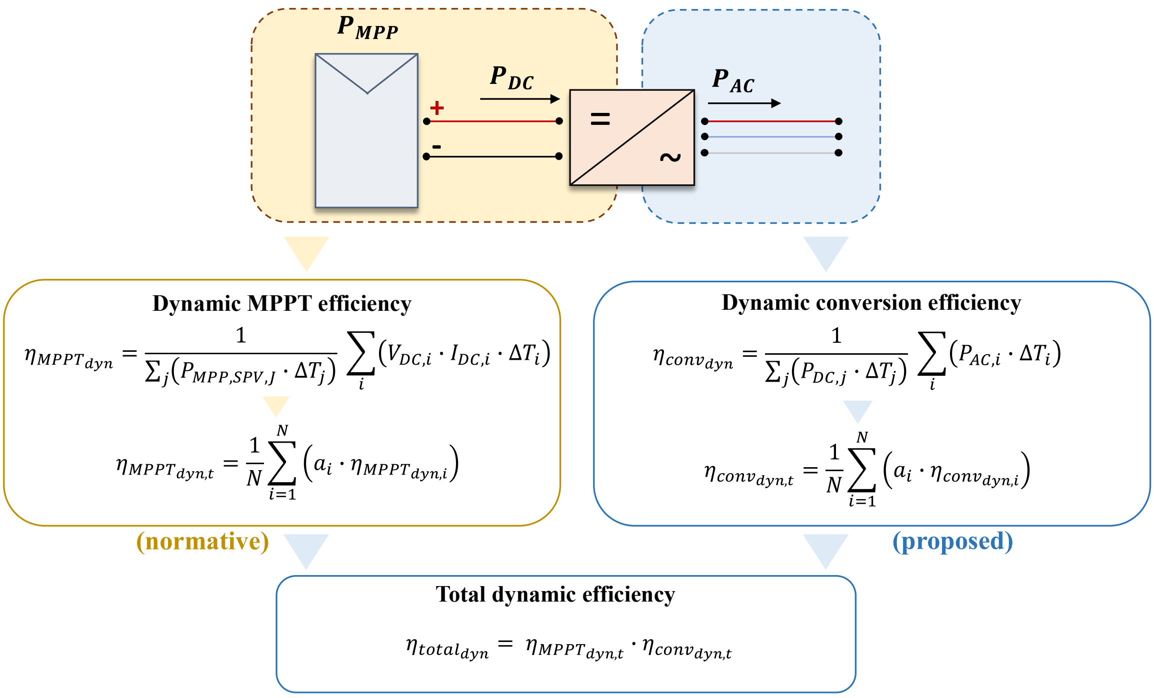


Figure 1: Dynamic total efficiency proposal.

3. Methodology

This paper evaluates different categories of commercial inverters. Tests were carried out on ten devices, five microinverters and five string inverters, of different power ratings and brands. The input configuration of each device under test (EUT) defines the number of photovoltaic simulators required. In the tests, up to three PV emulators were used for the string inverters and up to four for the microinverters. This information can be checked on each device's datasheet, according to the number of inputs per MPPT.

The stages planned for carrying out this research were structured according to the flowchart in Figure 2, which illustrates the process from setting up the test bench to comparative analysis of the results obtained.

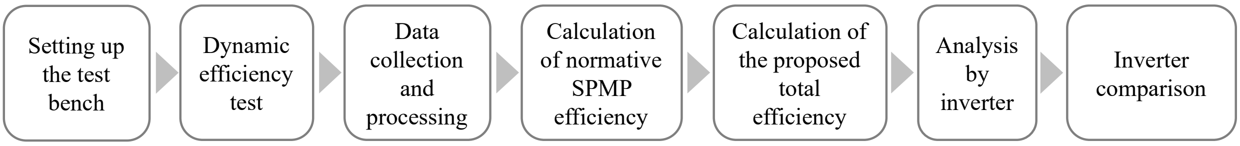
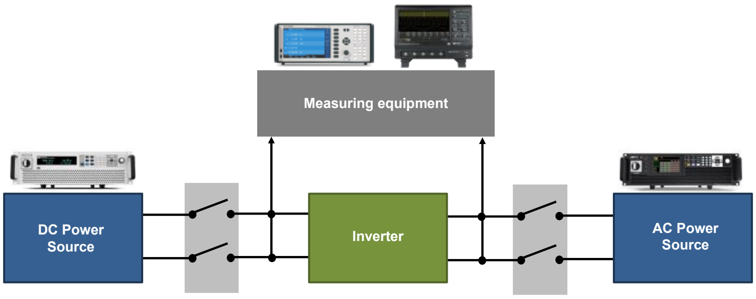


Figure 2: Research flowchart.

3.1. Test setup

The test procedure adopted follows the guidelines established by Bortolini (2018), ensuring compliance with all regulatory specifications. For this, an experimental setup was set up that allows for the controlled simulation of irradiance profiles, as illustrated in Figure 3.



(a)

(b)

Figure 3: Test setup: (a) schematic diagram proposed for dynamic efficiency tests and (b) photograph of the experimental setup.

The test bench assembled, shown in Figure 3, has ITECH DC power supplies, model IT6018C-1500-40 (item 3), used for similar photovoltaic modules, as well as an ITECH AC power supply, model IT7930 (item 2), which represents the electricity grid. The main measuring equipment used was a Zimmer power analyser, model LMG67 (item 4), responsible for monitoring electrical quantities such as voltage, current and input and output power of the inverters. To connect the equipment to the mains, the power switchboard was used (item 5). Finally, the EUT is fixed to the support.

3.2. Tested inverters

Inverters A to E correspond to microinverters, with nominal power between 330W and 2000W, while inverters F to J are of the string type, ranging from 1500W to 8200W of nominal power. One of the inverters evaluated has a datasheet stating that it uses a global tracking algorithm, capable of avoiding local maximums and achieving the maximum global power. For the other inverters, as there is no mention of this feature in their datasheets, they were considered to operate with conventional tracking algorithms. The inverters tested are listed in Table 1, along with some important information on each model.

Table 1: Information on tested inverters.

Identification	Model	Rated power (kW)	Type of MPPT	Efficiency datasheet
A	Microinverter	0,3	Conventional	96,5% (CEC)
B	Microinverter	0,8	Conventional	>99,9% (MPPT)
C	Microinverter	1,6	Conventional	95,0% (CEC)
D	Microinverter	2,0	Conventional	>99,9% (MPPT)
E	Microinverter	2,0	Conventional	96,5% (CEC)
F	Inverter string	1,5	Conventional	97,3% (EURO)
G	Inverter string	3,0	Conventional	97,0% (EURO)
H	Inverter string	3,3	Conventional	97,2% (EURO)
I	Inverter string	8,0	Conventional	97,3% (EURO)
J	Inverter string	8,2	Global	97,5% (EURO)

4. Results and discussion

This paper evaluates the dynamic performance of ten commercial photovoltaic inverters with different characteristics. The results show clear differences between the behavior of string inverters and microinverters in dynamic efficiency tests. To make the presentation of the results more objective, the main power and efficiency graphs for inverter A will be highlighted and analyzed in greater detail. This approach allows us to illustrate the procedure adopted for evaluating the other inverters. The complete results for the other equipment will be presented in comparative tables and graphs.

4.1. Inverter A results

Inverter A is a microinverter with a nominal power of 330W and with only one MPPT, only one DC power supply was used for the test. In all sequences, P_{DC} should accompany P_{MPP}, but a large gap was observed. In the first few sequences, even with slower incline ramps, the inverter showed low tracking capacity, maintaining P_{DC} considerably lower than P_{MPP}. As the rate of inclination of the ramps increased, this difference was gradually reduced. Figure 4 shows the relationship between P_{DC} and P_{MPP} during the sequences with the worst and best performance.

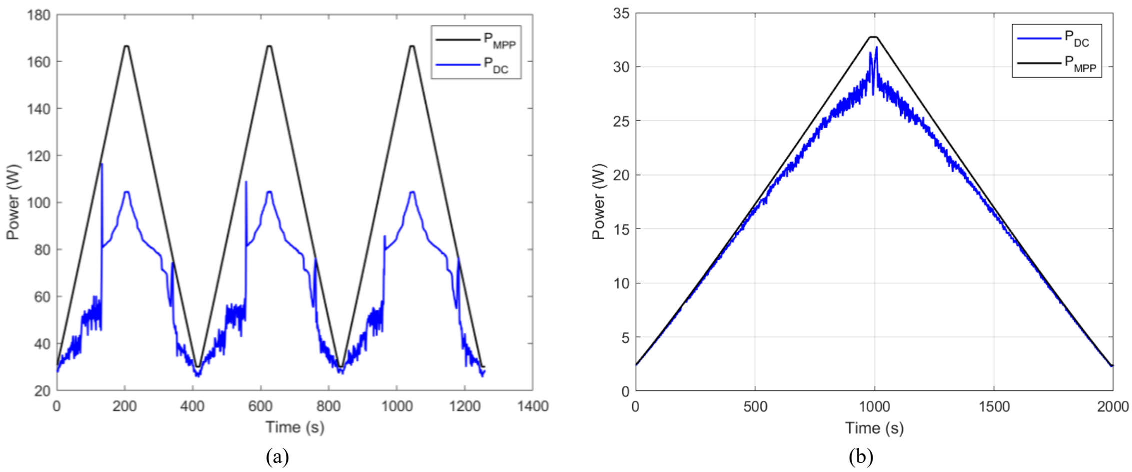
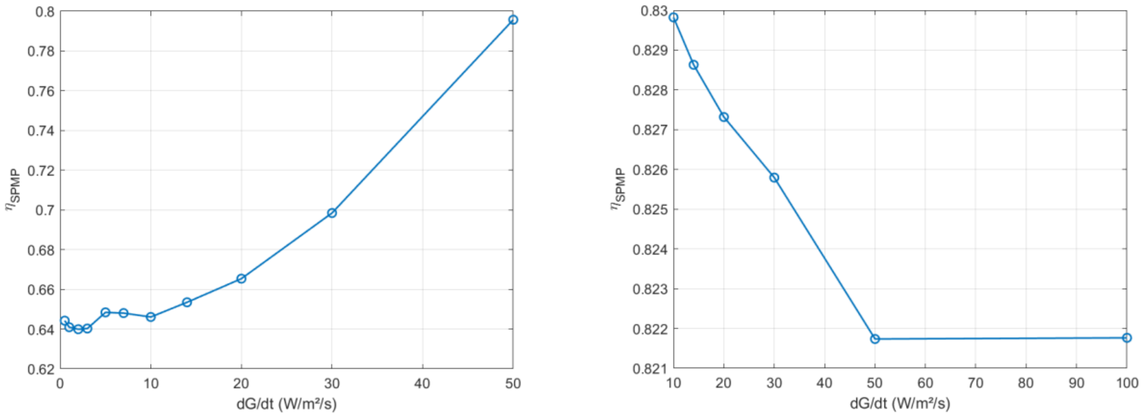


Figure 4: Relationship between P_{DC} and P_{MPP} throughout the rehearsal: (a) worst performance (2,0 W/m²/s - Test I) and (b) better performance (0,1 W/m²/s - Test III).

Figure 1(a) shows the worst tracking performance throughout the test, with an MPPT efficiency of 63.99%. Figure 1(b) shows the best result, achieving an MPPT efficiency of 94.10 %. Figure 5(a) shows the variation in dynamic

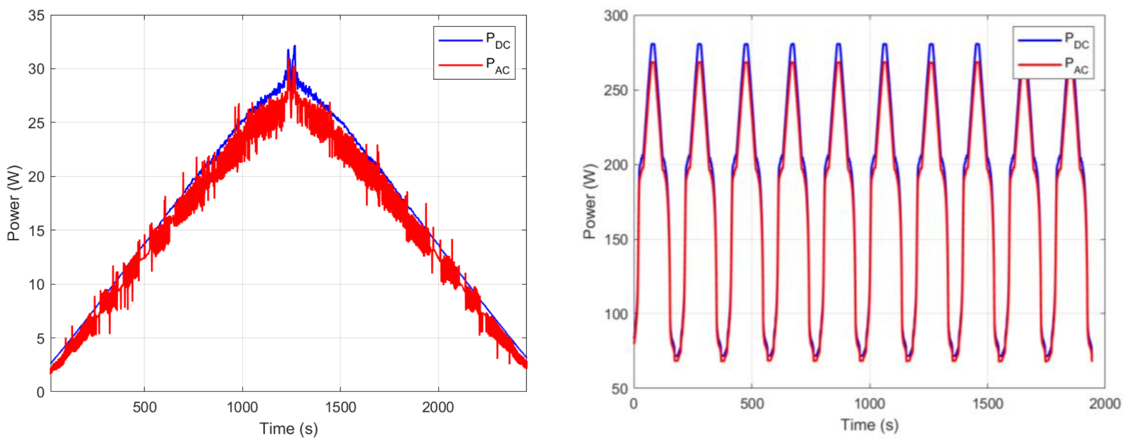
MPPT efficiency throughout each sequence of Test I, showing an increase in performance on ramps with higher irradiance inclination rates (faster variations). This same behavior is not repeated in Test II (Figure 5(b)), which has a wider irradiance range and higher inclination rates.



(a) MPPT efficiency for test I (low-medium). (b) MPPT efficiency for test II (medium-high).

Figure 5: Dynamic MPPT efficiencies obtained during tests I and II.

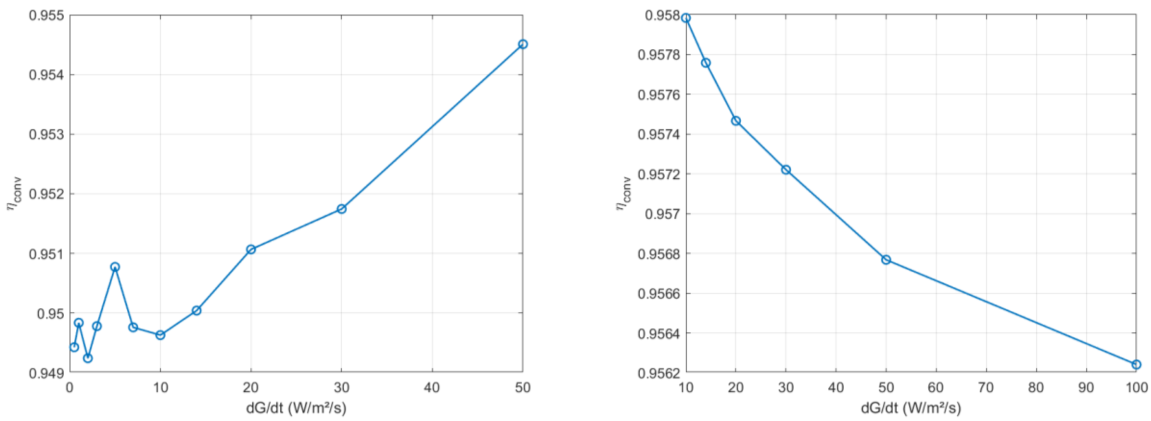
Following the same principle, Figure 6 shows the relationship between P_{AC} and P_{DC} in the sequences that recorded the worst and best performance. The worst result was obtained in the sequence with a gradient rate of 0.1 W/m²/s in Test III, with a dynamic conversion efficiency of 92.1%, as shown in Figure 6(a). The best performance occurred in the 10 W/m²/s sequence in Test II, achieving an efficiency of 95.80%, as shown in Figure 6(b).



(a) Worst performance (0,1 W/m²/s - Test III). (b) Better performance (10 W/m²/s - Test II).

Figure 6: Relationship between P_{AC} and P_{DC} throughout the rehearsal.

Figure 7 shows the inverter's performance in the conversion stage during Tests I and II. In Figure 7(a), there is a tendency for the conversion efficiency to increase as the inclination rate increases. On the other hand, Figure 7(b) shows the opposite behavior, in which the conversion efficiency decreases as the tilt rate increases, which is similar to that observed for the dynamic MPPT efficiency.



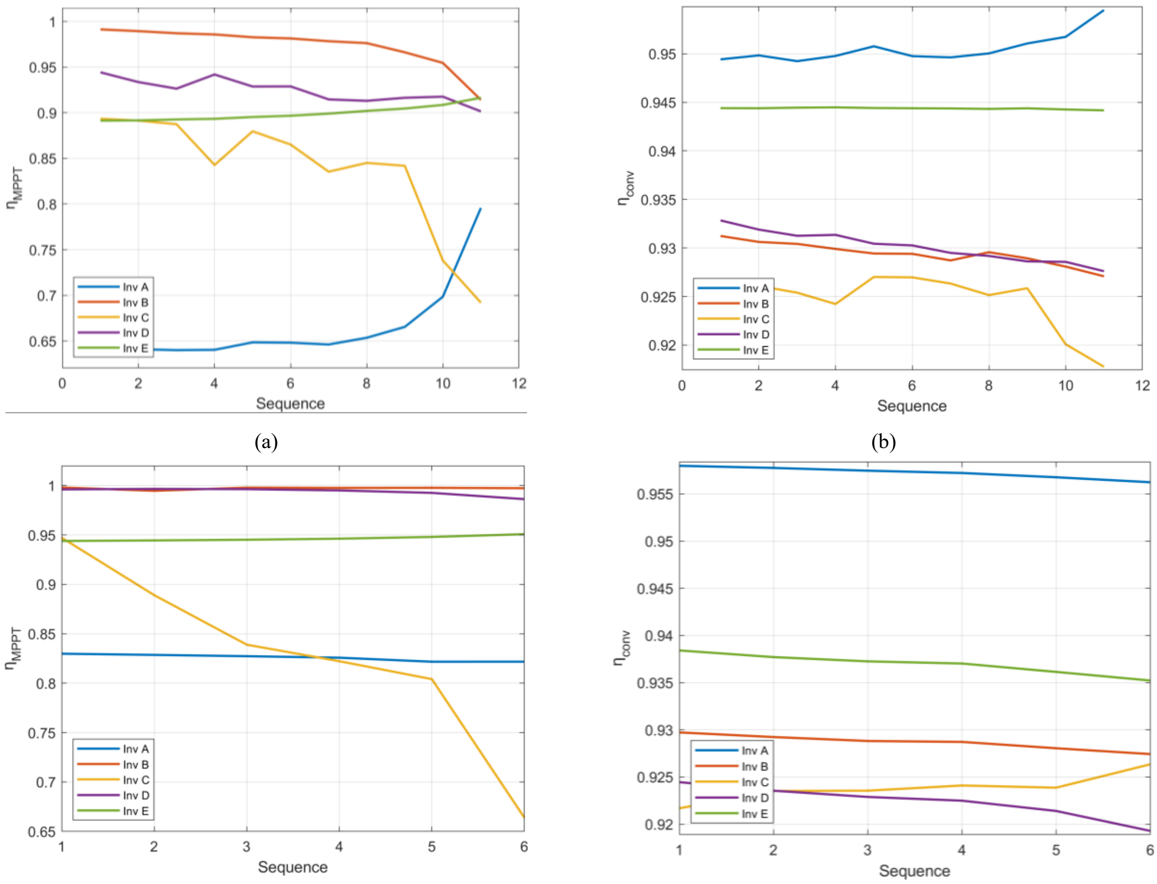
(a) (b)

Figure 7: Dynamic conversion efficiencies: (a) conversion for test I (low-medium) and (b) conversion for test II (medium-high).

Inverter A had a total dynamic efficiency of 69.84%. This result stems from an average dynamic MPPT efficiency of 73.43% and an average dynamic conversion efficiency of 95.11%, indicating that overall performance was mainly dependent on tracking. The eleven sequences in test I concentrated the lowest MPPT values and, because they were more numerous within the set, had a decisive influence on the final average. The six sequences in test II raised the MPPT, but not enough to compensate for the previous block. The only sequence in test III showed high MPPT and conversion at low irradiance, but its relative weight is small within the total of eighteen sequences.

4.2. Inverters comparison

Firstly, evaluating the five microinverters tested, in the test I profiles shown in Figure 8(a), inverter B remains very close to 100% in the initial sequences and only loses efficiency as the slope increases. In contrast, inverter D starts at over 94% and drops smoothly to around 90%. Inverter E starts at around 89% and gradually improves, an atypical behavior among microinverters and indicative of an algorithm that benefits from faster ramps. In contrast, inverters A and C operate at lower levels throughout the test. A increases towards the end, but remains well below the others, and C suffers a sharp drop in the last sequences. Figure 8(b) confirms that the conversion is much less sensitive to irradiance variation. A leads the way with values in the 95% to 96% range and a slight upward trend, inverter E maintains a practically constant 94.4%, B and D are close to 93% with minimal variation and C is just over 92%. Thus, in test I, the differences between microinverters are mainly due to the MPPT and not the conversion.



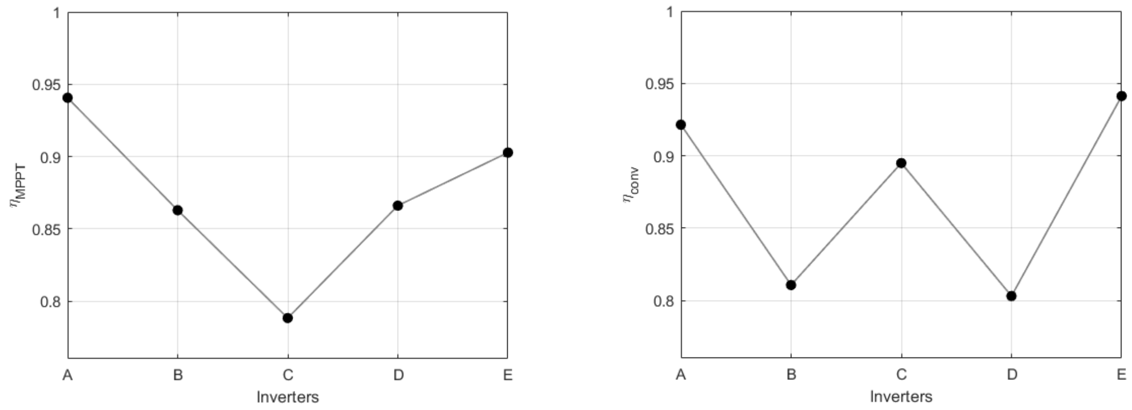
(a) (b)

(c) (d)

Figure 8: Efficiencies for microinverters: (a) dynamic MPPT for test I (low-medium), (b) conversion for test I (low-medium), (c) Dynamic MPPT for test II (medium-high) and (d) Conversion for test II (medium-high).

In test II, the pattern continues. Figure 8(c) shows B and D again at the top with efficiencies above 99%, E at around 94.6% with a slight improvement when accelerating up the ramps, A stabilized at around 82.6% and C falling to below 70%. Figure 8(d) shows that all of them preserve the conversion with small inclinations. A remains around 95.7%, E around 93.7% and B, C, and D between 92% and 92.5%.

In test III, the dynamic MPPT efficiency (Figure 9(a)) of inverter A rises to around 94% and E is around 90%, while B and D drop to the 86% range, and C remains below 80%. In conversion (Figure 9(b)), E stands out at around 94%, A falls back to around 92% and B and D suffer the greatest losses at just over 80%, which explains the drop in total efficiency of these two in very unfavorable conditions.



(a) (b)

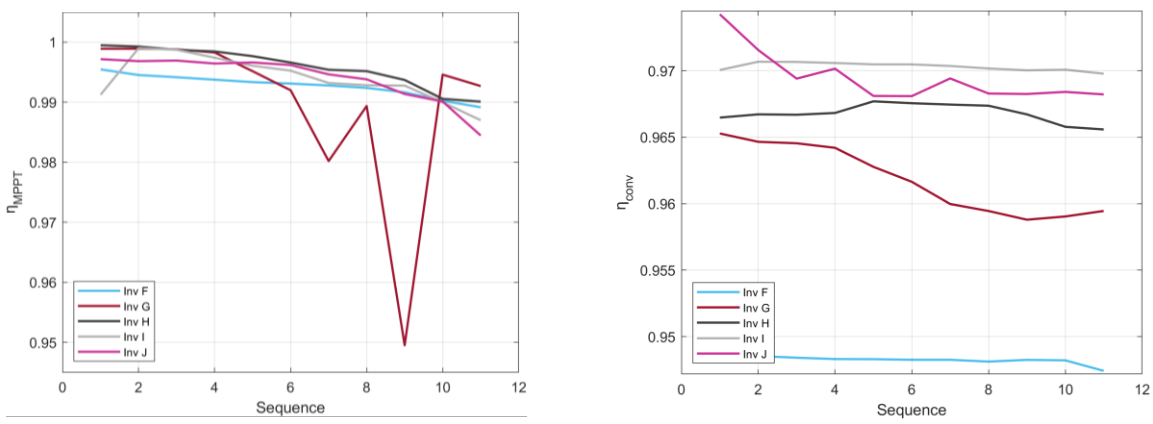
Figure 9: Efficiencies for microinverters during test III (start-up and shut-down): (a) dynamic MPPT and (b) dynamic conversion.

Grouping the three tests, E delivers the best balance between tracking and conversion and results in the highest total efficiency of the group, followed by D, which tracks very well at medium and high irradiance, although it loses out on conversion at low power. Next up is the B, which also tracks very well on gentle and moderate ramps, but yields performance at the low irradiance limit and always has a conversion of around 93%. The C lags due to its consistently lower MPPT despite stable conversion of around 92%. The A closes the list with lower MPPT, even though it maintains high conversion, as shown in Table 2.

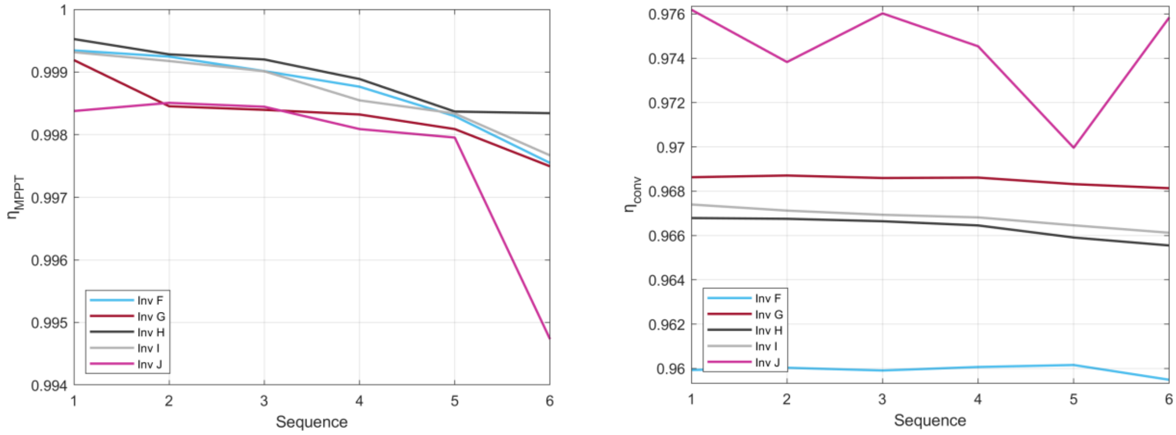
Table 2: Results obtained for microinverters.

Inverter	$\eta_{total,dyn}$	Efficiency datasheet
A	69,84%	96,5% (CEC)
B	81,37%	>99,9% (MPPT)
C	76,72%	95,0% (CEC)
D	82,49%	>99,9% (MPPT)
E	86,18%	96,5% (CEC)

A comparative analysis of the string inverters shows that all of them had high MPPT efficiencies, above 96% in most of the sequences, especially inverters F, G, H, and I, which maintained values above 98%, as shown in Figure 10(a). Inverter J, although still efficient, showed greater variation and occasional drops. In the conversion stage (Figure 10(b)), all the devices remained close to 97%, with little variation between the models. The performance of the J inverter once again stood out negatively, with values below 96% in several sequences, which reinforces the tendency for this model to be more sensitive in dynamic conditions.



(a) (b)

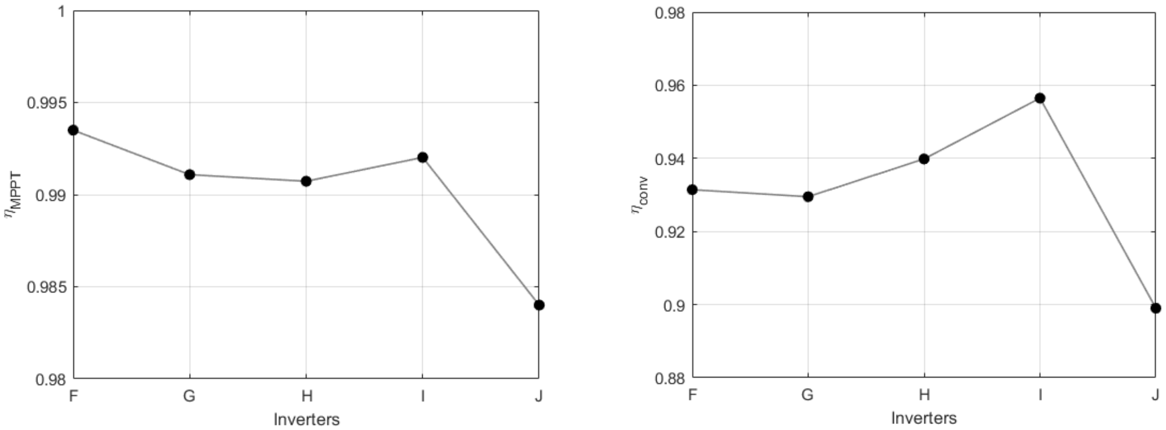


(c) (d)

Figure 10: Efficiencies for string inverters: (a) dynamic MPPT for test I (low-medium), (b) conversion for test I (low-medium), (c) Dynamic MPPT for test II (medium-high), and (d) Conversion for test II (medium-high).

In test 2 (Figure 10), which applies ramps up to 1000 W/m2, the general trend was maintained, with all the inverters preserving high MPPT efficiency, with averages close to or above 99.7%, indicating that even in rapid irradiance variations, tracking was good. The curves in Figure 10(c) are practically superimposed for F, G, H, and I. Conversion (Figure 10(d)), on the other hand, showed greater variation between the models, with inverter J again having values below the others, at around 97.4%.

In test 3 (Figure 11), the differences between the models become more evident. The MPPT efficiency of all the string inverters remained high, above 98.4%, with inverter J once again showing the lowest value. However, in conversion, while the H and I inverters preserved values close to 96% and 97%, the F and G inverters were around 93% and the J inverter fell below 90%.



(a) (b)

Figure 11: Efficiencies for string inverters during test III (start-up and shut-down): (a) dynamic MPPT and (b) dynamic conversion.

Table 3 shows the total dynamic efficiency values of the string inverters. Inverter F had the lowest total dynamic efficiency with 94.15%, inverter I had the highest value with 96.48%, closely followed by H (96.34%) and J (96.21%). Inverter G also performed well, reaching 95.73%, above the average for the microinverters analyzed previously.

Table 3: Results obtained for microinverters.

Inverter	$\eta_{total,dyn}$	Efficiency datasheet
F	94,15%	97,3% (EURO)
G	95,73%	97,0% (EURO)
H	96,34%	97,2% (EURO)
I	96,48%	97,3% (EURO)
J	96,21%	97,5% (EURO)

When analyzing all the inverters tested, it can be seen that between microinverters and string inverters, there are important differences related to the dynamic tracking behavior and, above all, the conversion stage. In microinverters, it was observed that the dynamic efficiency of the MPPT was the most limiting factor, resulting in lower total efficiency values, with an average of 79.32% considering the five pieces of equipment. Although some models maintained reasonable conversion performance, the low tracking efficiency compromised the overall result. This shows that simply analyzing MPPT efficiency, as required by current standards, is not enough to characterize the real performance of this equipment under dynamic conditions, since it does not take into account losses in the conversion stage.

On the other hand, the string inverters showed far superior overall performance, with total dynamic efficiency, with an average of 95.78%. In these devices, the tracking stage remained high in practically all the tests, while the conversion contributed to sustaining the consistency of the final result. It can be seen that even though there were small differences between the models, the string inverter set maintained close and high values.

5. Conclusions

The results showed that analyzing MPPT efficiency alone is not enough to characterize inverter performance. In real situations, the power delivered depends not only on the quality of the tracking, but also on how the conversion from direct current to alternating current takes place at different power levels and variation conditions. The inclusion of conversion efficiency has shown that in various devices, mainly microinverters, losses appear at reduced irradiances, influencing the final value of the total dynamic efficiency. In the case of microinverters (A to E), it was found that performance varied the most between the different test conditions.

Inverter A showed STC efficiency values below 70%, resulting in a low overall dynamic efficiency. Inverter B maintained acceptable results at medium and high irradiances but experienced a drop under low irradiance conditions, reducing its final value to just above 80%. Inverter C exhibited similar behavior, with reduced efficiency during faster ramps, achieving an overall dynamic efficiency close to 77%. Inverter D maintained consistent performance at medium and high irradiances but recorded losses at low power, resulting in a final value around 82%. Inverter E achieved the best results, with stable STC efficiency values, conversion efficiency close to 94%, and overall dynamic efficiency of 86%.

For string inverters (F to J), the results were superior in all cases, with total dynamic efficiency ranging between 94% and 96.5%. Inverter F showed the lowest value within the group, but still above 94%. Inverters G, H, I, and J achieved similar results, all above 95%. Inverter I, with the highest nominal power, recorded the highest value at 96.48%, while inverter J, equipped with a global tracking algorithm, showed similar performance.

In general, string inverters showed more stable behavior in both tracking and conversion. In this way, it can be seen that the microinverters showed greater variation in performance and lower values of total dynamic efficiency, influenced mainly by the tracking stage, but in some cases also by low-power conversion. In contrast, string inverters showed high results in all conditions, with total dynamic efficiency very close to MPPT efficiency, since conversion remained above 93% in practically all tests.

The results obtained confirm that considering only the MPPT efficiency, as required by the standard, does not describe the dynamic performance of the inverters. Including the conversion efficiency in the calculation showed that it directly influences the final value of the total dynamic efficiency. In microinverters, for example, the MPPT efficiency can indicate values close to 90%, but when combined with low-power conversion, the final result drops to values close to 80%. In string inverters, the proximity between MPPT values and total dynamic efficiency indicates that tracking dominates behavior, but conversion still contributes to the final result. This difference between the two categories shows that evaluating MPPT alone can lead to incorrect interpretations, especially for microinverters.

6. Acknowledgments

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7. References

Bletterie, B., Bründlinger, R., Lauss, G., 2011. On the characterisation of PV inverters' efficiency: introduction to the concept of achievable efficiency. Progress in Photovoltaics: Research and Applications,

Bortolini, R.J.F., et al., 2018. Ensaio automatizado de medição da eficiência energética de inversores fotovoltaicos conectados à rede.

Bower, W., Whitaker, C., Erdman, W., Behnke, M., Fitzgerald, M., 2004. Performance test protocol for evaluating inverters used in grid-connected photovoltaic systems.

Brasil, Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO), 2024. Programa brasileiro de avaliação da conformidade - PBAC. Disponível em: http://www.inmetro.gov.br/index-pbac.asp. Acesso em: 10 mar. 2025.

European Committee for Electrotechnical Standardization, 2010. Overall efficiency of grid connected photovoltaic inverters.

Haeberlin, H., Borgna, L., Kaempfer, M., Zwahlen, U., 2006. Measurement of dynamic MPP-tracking efficiency at grid-connected PV inverters. In: 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, September 2006.

Haeberlin, H., Schaerf, P., 2009. New procedure for measuring dynamic MPP-tracking efficiency at grid-connected PV inverters. In: 24th European Photovoltaic Solar Energy Conference, Hamburg, Germany, September 2009.

International Electrotechnical Commission, 2020. Maximum power point tracking efficiency of grid connected photovoltaic inverters. International Standard, IEC, Geneva, Switzerland, July 2020.

International Electrotechnical Commission, 2021. Photovoltaic systems – power conversion equipment performance – energy evaluation method. Technical Specification IEC TS 63156:2021, Edition 1.0, IEC, Geneva, February 2021.

Ishaque, K., Salam, Z., Lauss, G., 2014. The performance of perturb and observe and incremental conductance maximum power point tracking method under dynamic weather conditions.

Lima, G.P. de, 2023. Classificação, desenvolvimento e validação de ensaios para inversores fotovoltaicos comerciais. Dissertação de Mestrado. Universidade Estadual de Campinas, Faculdade de Engenharia Elétrica e de Computação.

Portaria 140, de 21 de março de 2022. Instituto Nacional de Metrologia, Qualidade e Tecnologia – INMETRO, março 2022.

Prieb, C.W.M., Krenzinger, A., 2014. Determinação da eficiência dinâmica de seguimento do ponto de máxima potência de inversores para SFCR. In: V Congresso Brasileiro de Energia Solar, Recife, Brasil.

Rodrigues, H.R., Rüther, R., Zilles, R., 2023. Experimentation in exploring photovoltaic inverter dynamics under different irradiance levels through a data-driven approach. Solar Energy, 259, 170–180.

Villalva, M.G., Gazoli, J.R., 2012. Energia solar fotovoltaica: conceitos e aplicações. 2ª ed. Érica, São Paulo.