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Evaluation of Power Quality in a Residential Photovoltaic System: Case Study

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ABSTRACT

This paper evaluates the power quality in a residential photovoltaic system in Colombia. Power quality parameters were monitored in a residence in Barranquilla with a 4.44 kW system connected to the grid, analyzing its behavior over time and comparing it with regulatory limits. Graphical and statistical analysis tools were used to identify deviations and problems in the network based on current regulations. The results show a voltage unbalance reaching 9.84% and a current unbalance of up to 147.7%, with a total demand distortion of up to 17.1% and a k-factor >70%. These results show high unbalance and harmonics in the supply source, affecting network stability, efficiency, and equipment life. The research confirms that the injection of energy from photovoltaic systems can affect power quality in low-voltage networks, highlighting the need for mitigation strategies. The implementation of advanced controls in inverters, active filters, and FACTS devices is proposed, along with strengthening the regulation of harmonic distortion and load balancing in residential networks. Given the accelerated growth of photovoltaic generation in Colombia, it is essential to evaluate its long-term impact to ensure the stability of the electrical system and maximize the benefits of distributed generation in the country.

Keywords: Distribution System, Harmonic, Power Quality, Photovoltaic System, Residential Customer, Voltage Unbalance
JEL Classifications: L8, Q2, Q4

1. INTRODUCTION

Solar photovoltaic energy generation has achieved unprecedented growth worldwide, consolidating itself as one of the fundamental technologies in the transition towards sustainable energy systems. In 2022, the production of this renewable source grew by 270 TWh, reaching almost 1,300 TWh and surpassing wind energy for the 1st time in absolute terms (International Energy Agency [IEA], 2023). A combination of factors, such as the decrease in technological costs, the massive development of the supply chain, and the implementation of support policies in leading economies such as China, the United States, the European Union, and India, has driven this advance (International Energy Agency, 2024). In addition, the strengthening of decentralized technologies, such as off-grid systems and mini-grids, has expanded the possibilities of access to electricity in remote and urban regions with unreliable infrastructures.

In Colombia, photovoltaic generation showed remarkable cumulative growth, going from 6 GWh in 2000 to 964 GWh in 2023, representing an increase of more than 160 times. The turning point occurred in 2017 when generation doubled between 2016 and 2017, and in 2019, there was a sixfold increase compared to the previous year (International Energy Agency, 2025). This behavior was driven by a favorable regulatory framework, including Law 1715 of 2014 (Congreso de Colombia, 2014), Law 2099 of 2021 (LEY 2099 DE 2021-Ley de Transición Energética., 2021) and CREG Resolution 174 of 2021 (Comisión de Regulación de

Energía y Gas [CREG], 2021), which facilitated investment in renewable energy projects. In addition, Decree 2236 of 2023 (Carvajal-Romo et al., 2019a) established specific guidelines for the financing and development of solar systems. On the other hand, the country has a high potential for solar radiation, with daily values varying between 5.01 and 6 kWh/m^2/day, with an estimated annual generation potential of 93,778 GWh per year (Carvajal-Romo et al., 2019b), highlighting regions such as La Guajira, which have become a benchmark for large-scale solar projects.

The residential sector, which represents 26% of Colombia's total final energy consumption, represents a strategic opportunity for the implementation of photovoltaic systems (International Energy Agency (IEA), 2023a). Their adoption could contribute to reducing greenhouse gas emissions, strengthening energy security, reducing billing costs, and improving the quality of life, particularly in rural communities and developing urban areas. However, it is essential to consider the negative impact that photovoltaic systems can have on the power quality (PQ) in distribution systems. This impact may be due to the use of low-quality inverters, such as six-pulse inverters, or to the inherent intermittency of solar radiation, which could compromise the performance and stability of the electrical grid (Gandoman et al., 2018). PQ problems have become more relevant due to the increase in non-linear loads and the integration of distributed generation sources. These sources, by using equipment with non-linear behavior, introduce distortions in the voltage and current waveforms, which can affect the operation of electrical systems, reduce energy efficiency, and shorten the useful life of the equipment (Angarita et al., 2024; Angarita et al., 2024).

Various scientific studies address PQ in photovoltaic (PV) systems from multiple perspectives, but they do not focus specifically on the connection point of a residential PV system. In (Adric et al., 2024), harmonic distortion caused by PV and EV charging stations in low voltage networks is analyzed. Although the total harmonic distortion (THDv) index on a 0.4 kV bus is studied, the work focuses on distribution networks, not residential systems. On the other hand, (Mahmoodi and Tarimoradi, 2024) introduces a partitioning approach to mitigate voltage sags in active distribution networks with PV generation. Despite the advances in network stability and PQ, it does not address PQ at the connection point of a residential system.

In (Sarkar et al., 2024), a fuzzy logic controlled cascaded multilevel inverter is presented to reduce THD in a distribution system. However, the impact on residential systems or specific connection points is not analyzed. The study in (Majeed et al., 2024) optimizes the location of PV distributed generation in urban distribution networks, improving losses and voltage profiles. This work also does not focus on residential systems.

In (Cebrian et al., 2024), the financial impacts of integrating PVS in distribution networks are evaluated, considering energy losses and voltage sags. Although it highlights the economic relevance of these systems, it does not address PQ at the connection point of a residential system. Paper such as (Dyussembekova et al., 2024) and (Zhang et al., 2024) analyze power transfer devices and hybrid transformers to improve voltage quality in distribution networks, highlighting technological solutions applied to industrial or urban scenarios but not residential ones.

In (Shakeri et al., 2024), a method is proposed to monitor harmonic resonances in electrical networks. While it optimizes the distribution of PQ monitors, it does not analyze PQ at residential connection points. On the other hand, (Benavides et al., 2024) develops a multimode management model for photovoltaic systems with storage. Although it improves PQ in microgrids, it does not explicitly address residential systems.

Studies such as (Alqattan et al., 2024) and (Aslan and Farsadi, 2024) propose advanced controllers for D-FACTS devices and their application in hybrid systems, showing improvements in stability and THD, but without focusing on residential connection points. In (Alharbi et al., 2024) and (Li et al., 2024) improvements in controllers and energy storage to mitigate PQ problems are proposed, but they do not analyze their impact on residential systems or connection points.

In (Boulahchiche et al., 2024) and (Hachemi et al., 2024) the impact of ramp events and the dynamic operation of networks with PV are studied, demonstrating benefits in PQ, but without considering the connection point in residential environments. Finally, (Castro Charris et al., 2024; Charris et al., 2023; Luna Alvarino et al., 2024, 2024; Naick et al., 2024; Tadjeddine et al., 2025; Wang et al., 2025) present strategies to integrate PV in industrial systems and evaluate the efficiency of PV-powered motors but do not analyze PQ in residential systems.

The recent literature highlights the relevance of PQ problems generated by photovoltaic systems, especially in distribution networks and industrial environments. However, no study addresses the PQ at the connection point of a residential photovoltaic system.

This paper aims to evaluate the PQ in a residential photovoltaic system, focusing on the system's connection point. To do so, a case study is developed in a residence in Barranquilla, Colombia, where PQ parameters are analyzed per international and national regulations.

This study's main contribution is evaluating the PQ at the connection point of a residential photovoltaic system, which has little been addressed in the scientific literature. By measuring harmonic distortion, voltage and current imbalance, and voltage variation, this study provides relevant information on the impact of distributed generation on residential networks.

2. MATERIALS AND METHODS

In this study, the implementation of the methodology represented in Figure 1 was carried out.

The study is carried out in a residence located in the city of Barranquilla, Colombia, with a nominal voltage of 120 V to which eight Znshine brand solar panels were installed, with the data shown in Table 1 (Solar, 2022).

Figure 1: Methodology for evaluating the power quality in a residential photovoltaic system

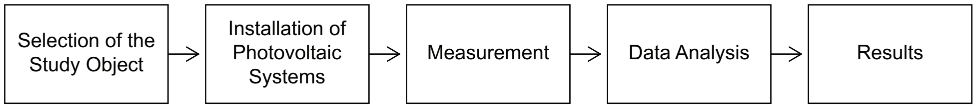


Table 1: Solar panel data

Parameter	Value
Model	ZXM7-SHLDD144
Type	Monocrystalline bifacial
Power range (W)	530-555
Maximum efficiency (%)	21.48
Voltage at maximum power (V)	41.1-42.1
Open circuit voltage (V)	49.4-50.4

The panels are connected by two groups of four in series with a generation capacity between 4,240 W and 4,440 W. The solar panels are connected to a Growatt MIN 4200TL-X2 inverter for grid-connected photovoltaic systems, with the data in Table 2 (Growatt New Energy Technology Co., 2025).

Table 2: Inverter data

Parameter	Value
Input voltage range (V DC)	40-550
Maximum input current per MPPT (A)	16
Maximum short-circuit current (A)	24
Continuous output power (W)	4,200
Nominal grid voltage (V AC)	240 (Split-phase)
Grid voltage range (V AC)	211-264
Nominal frequency (Hz)	60
Operating frequency range (Hz)	59.5-60.5
Maximum continuous output current (A)	19
Power factor	>0.99
Standards	UL 1741, IEEE 1547

Considering that the inverter is reigned by the IEEE 1547 standard (Generation et al., 2023). The total demand distortion (TDD) must not exceed 5% of the inverter's nominal current.

For the study, a Dranetz Power Visa network analyzer (Dranetz, 2020) was connected to the inverter output at the connection point with the residence circuit. The Dranetz PowerVisa network analyzer is designed to monitor and analyze PQ using the data in Table 3.

Table 3: Network analyzer data

Magnitude	Measurement range	Accuracy (%)
Voltage (RMS)	1 V to 600 V phase to neutral	±0.1 of nominal voltage
Current (RMS)	0.1 A to 3000 A	±0.1
Frequency	45 Hz to 65 Hz	±0.01 Hz
Power factor	0 to 1	±0.1
Power	According to the clamp meter scale	±1
Energy	According to the clamp meter scale	±1

The Dranetz power analyzer can record voltage dips, swells, and interruptions and capture low and medium-frequency transients with a resolution of up to 32 µs. It also performs harmonic and inter-harmonics analysis by IEC 61000-4-7 (Dranetz, 2020).

Measurements were carried out over 1 week, with parameters recorded every minute, by the established limits and regulations presented in Table 4.

Table 4: PQ parameters, limits, and standards

PQ parameters	Limit	Data within limits (%)	Standard
ΔV (p.u.)	0.92-1.05	100	NTC 1340-2013 (ICONTEC, 2013)
VU (%)	2	99	NTC 5001-2008 (ICONTEC, 2008)
CU (%)	20	95	NTC 5001-2008 (ICONTEC, 2008)
CF-V (p.u.)	1.41	100	IEEE Std 1159 (IEEE Std 1159, 2019)
Flicker (%)	1	95	NTC 5001-2008 (ICONTEC, 2008)
THDV (%)	8	95	IEEE Std 519-2022 (IEEE, 2022)
TDD (%)	5	95	IEEE Std 519-2022 (IEEE, 2022) Manufacturer (Growatt New Energy Technology Co., 2025)
IVD (3-13) (%)	5	95	IEEE Std 519-2022 (IEEE, 2022)
ICD (3-13) (%)	4	95	IEEE Std 519-2022 (IEEE, 2022) Manufacturer (Growatt New Energy Technology Co., 2025)
k-factor (%)	1	100	IEEE Std 519-2022 (IEEE, 2022)

Where ΔV is the voltage variation, VU is the voltage unbalance, CU is the current unbalance, FC-V is the voltage crest factor, IVD is the individual voltage harmonics, and ICD is the individual harmonics of current.

For the calculation of the voltage and current unbalance, the definition established in the standard (American National Standard Motors and Generator, 2011) will be used and adapted to the analysis of only two phases. In this study, the voltage unbalance is not calculated considering the three phases since the power comes from one or two phases in a typical residential circuit. Specifically, in this case, the residence under study is supplied by a two-phase system, with each phase supplying 110 V concerning the neutral and 220 V between phases.

Although evaluating the voltage unbalance in two phases does not allow us to characterize the asymmetry of the three-phase system entirely, it does provide relevant information about the discrepancy between the phases present in the installation (Abasi et al., 2025). This partial analysis is helpful since an unbalance between two phases can generate adverse effects on the distribution system, such as overloads in transformers, voltage fluctuations in the connected loads, and reduced energy efficiency in electric motors (Quispe et al., 2018). In addition, the two-phase analysis allows the detection of variations in the magnitude and angle of voltage between phases, which facilitates the identification of unfavorable operating conditions in the electric power distribution system.

In the case of current harmonics, although the IEEE Std 519-2022 (IEEE, 2022) standard establishes different limits depending on the harmonic order and the ratio between the short-circuit current (ISC) and the maximum load current (IL); in this study, it was decided to work with the limit specified by the inverter manufacturer, which is 5% for the TDD and 4% for the individual current harmonics (Growatt New Energy Technology Co., 2025). These values coincide with the limits established in the IEEE Std 519-2022 (IEEE, 2022) standard for the case where the ISC/IL ratio is <20.

For the analysis of the PQ, a typical day was selected, with 1440 data recorded at a 1-min interval, and the following tools were used:

2.1. Graph of the Behavior of the Parameters over Time Next to the Limits Established by the Standards

This graph visualizes the evolution of the parameters over time in comparison with the limits established by the standards. Its analysis facilitates the identification of deviations and the detection of possible problems with the PQ.

2.2. Statistical Analysis of the Parameters beyond the Established Limits

The maximum, minimum, average, and standard deviation values and the percentage of data that exceeded the normative limits or those specified by the manufacturer were determined. This analysis allows the characterization of the distribution of the data and the evaluation of its variability, considering that some normative limits depend on the percentage of data that exceed them (Viego Felipe et al., 2011).

The results of these analyses were represented graphically using a box-and-whisker diagram, which shows the minimum, maximum, and average values; a scatter graph, which illustrates the standard deviation of each parameter; and a bar graph, which indicates the percentage of data that exceeds the limits established by the standard.

3. RESULTS AND DISCUSSION

The results of the behavior over time of the PQ parameters during a typical day are presented and analyzed below. In addition, the parameters outside the limits established by the PQ standards are statistically analyzed.

3.1. The Behavior of PQ Parameters over Time

Figure 2 shows the graph of the behavior over time of the voltage variation on a typical day compared to the limits of 0.92 and 1.05 established by the NTC 1340-2013 standard (ICONTEC, 2013).

Figure 2 shows that the voltage remains within the allowed range (0.92-1.05 p.u.), with a slight decrease in the morning and evening, possibly due to the variation in load demand and solar generation. During midday, a slight voltage recovery is recorded, coinciding with the period of maximum photovoltaic generation.

Figure 3 shows the behavior graph of the voltage unbalance over time during a typical day compared to the 2% limit established by the NTC 5001-2008 standard (ICONTEC, 2008).

Figure 3 shows that the voltage unbalance is high in the early hours of the day, reaching values above 5%, progressively decreasing until it remains mainly below the regulatory limit between 06:00 and 17:00 h. However, unbalances peaks are recorded around 09:30 and 12:00 h, possibly due to changes in photovoltaic generation and variations in the load. From 18:00 h onwards, the voltage unbalance increases again, exceeding the regulatory limit on several occasions and reaching values close to 8%, suggesting a more significant asymmetry in the load distribution at night. These fluctuations can affect the stability of the system and the efficiency of the connected equipment, so it is recommended that load distribution and the influence of distributed generation on the network be analyzed to mitigate the effects of the unbalance.

Figure 4 shows the behavior of the current unbalance during a typical day compared to the 20% limit established by the NTC 5001-2008 standard (ICONTEC, 2008).

Figure 4 shows the behavior of the current unbalance throughout a typical day, compared to the regulatory limit of 20%. On several occasions, the current unbalance significantly exceeds this

Figure 2: Voltage variation behavior

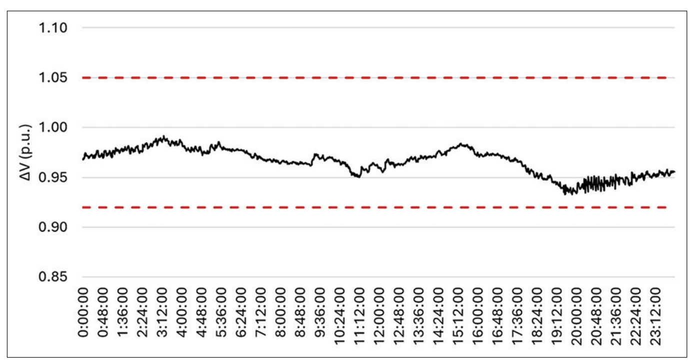


Figure 3: Voltage unbalance behavior

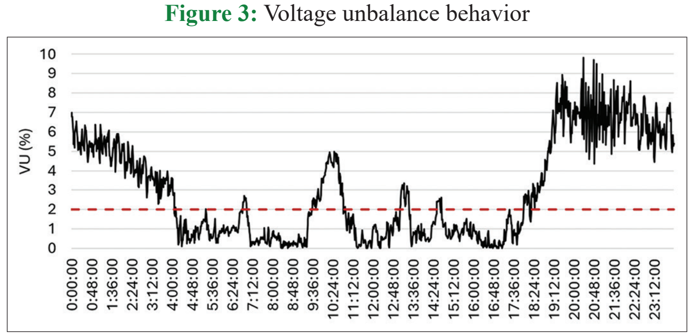


Figure 4: Current unbalance behavior

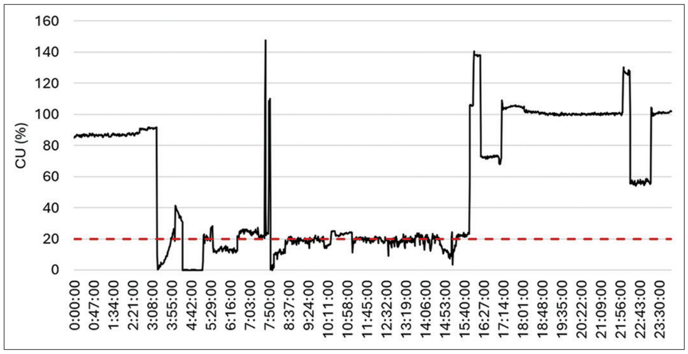
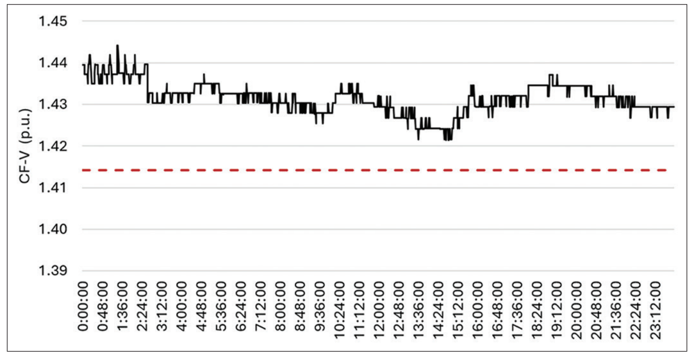


Figure 5: Crest factor behavior



threshold, reaching values close to 100%, especially in the early hours of the day and in the afternoon, suggesting an asymmetric load distribution and variations in the energy injection of the photovoltaic system. Between 07:00 and 15:30, the unbalance remains within the regulatory limits, indicating better stability in the current distribution. However, in the afternoon and at night, there are abrupt fluctuations and high peaks, possibly associated with changes in load demand and the reduction of photovoltaic generation.

Figure 5 represents the voltage crest factor compared to the 1.41% limit established by IEEE Std 1159 (IEEE Std 1159, 2019).

Figure 5 shows that the crest factor remains above the normative value throughout the measurement period, with variations between 1.42 and 1.44 p.u., indicating the presence of voltage peaks higher than the expected value in the waveform. In the early hours of the day, the crest factor presents a more excellent dispersion, possibly due to transient events or fluctuations in the load, stabilizing slightly during the morning and afternoon. However, slight variations that may be related to the photovoltaic system's operation and the electrical grid's interaction are recorded throughout the day.

Figure 6 shows the behavior of the Flicker over time compared to the one p.u limit established by the NTC 5001-2008 standard (ICONTEC, 2008).

According to Figure 6, for most of the day, the flicker remains below the threshold, with values between 0.4% and 0.8%, indicating moderate variability in voltage. However, at night, especially after 8:00 p.m., an increase in flickers is observed, reaching and at times exceeding the regulatory limit, which may be associated with changes in load demand or the transition between photovoltaic generation and grid supply. These high values can cause flickering in lighting and affect sensitive electronic equipment, so it is recommended to monitor their evolution and evaluate mitigation strategies, such as optimizing inverter control or regulating reactive power in the installation.

Figure 7 represents the behavior of THDV over time compared to the 8% limit established by IEEE Std 519-2022 (IEEE, 2022).

Figure 7 shows that the THDV remains stable at low values, oscillating around 1%, well below the allowed threshold. The absence of significant variations indicates that the injection of energy from the photovoltaic system does not generate relevant distortions in the voltage waveform. This result suggests an adequate quality of the electrical supply regarding voltage harmonic distortion.

Figure 6: Flicker behavior

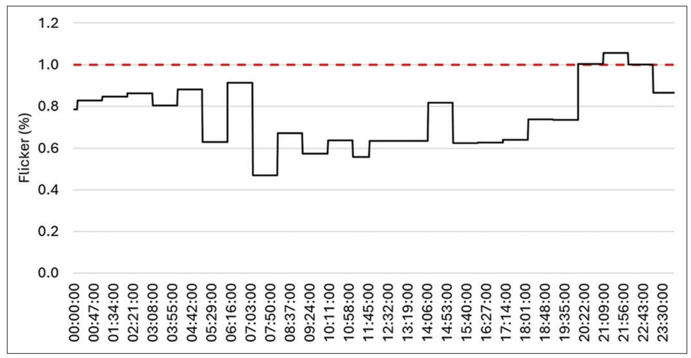


Figure 7: Total harmonic distortion behavior

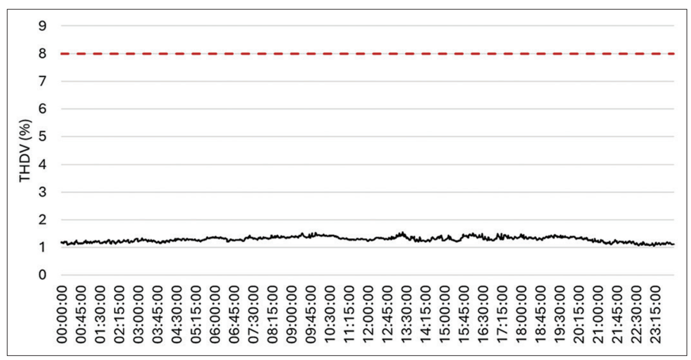
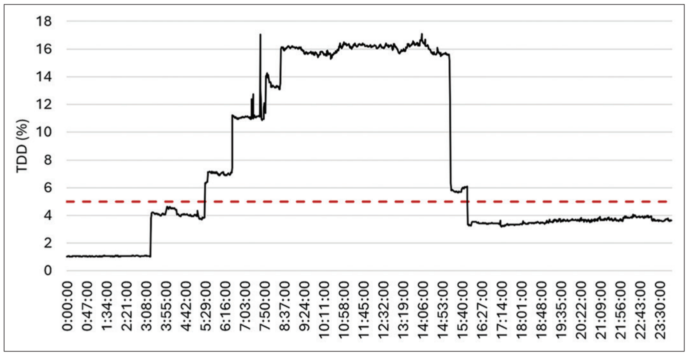


Figure 8 shows the behavior of the TDD over time compared to the 5% limit established by the IEEE Std 519-2022 standard (IEEE, 2022).

Figure 8 shows the TDD behavior throughout a typical day, compared to the 5% limit established by the inverter manufacturer. It can be observed that, during the early morning, the TDD remains below this threshold; however, from 06:00 h, it begins to increase, reaching values close to 16% between 07:30 and 15:30 h, coinciding with the period of maximum photovoltaic generation. Subsequently, the TDD decreases abruptly and remains stable at around 5% during the rest of the day. This behavior indicates that,

Figure 8: Total demand distortion behavior



during the hours of highest solar production, the current harmonic distortion exceeds the limit recommended by the manufacturer, suggesting the need to evaluate the operation of the inverter and consider mitigation strategies to reduce the injection of harmonics into the grid.

Figure 9 shows the behavior of individual voltage harmonics over time compared to the 5% limit set by the inverter manufacturer and IEEE Std 519-2022 (IEEE, 2022).

Figure 9 shows that the values of individual harmonics of orders 2 to 13 remain constantly below the allowed limit throughout the measurement period, oscillating around 1%. No significant peaks or fluctuations are identified in any harmonic component, indicating adequate voltage quality in harmonic content.

Figure 10 shows the behavior of individual current harmonics over time compared to the 4% limit set by the inverter manufacturer (Growatt New Energy Technology Co., 2025) and IEEE Std 519-2022 (IEEE, 2022).

Figure 10 shows that the order harmonics (2, 3, 4, 5, 7, 9, 11, and 13) exceed the 4% threshold at various times of the day, especially between 06:00 and 15:30, coinciding with the period of maximum photovoltaic generation. Among these, the order harmonics 3, 5, and 7 present the highest and most sustained values, reaching peaks above 30% in some periods. This suggests that the current injection from the inverter introduces a significant distortion in the network, with a predominance of low-frequency harmonics, which could generate overheating in the conductors, interference in electronic equipment, and affect the efficiency of the electrical system.

Figure 11 shows the behavior of the k-factor over time compared to the 1% limit established for standard transformers in IEEE Std 519-2022 (IEEE, 2022).

According to Figure 11, throughout the measurement period, the k-factor dramatically exceeds the 1% limit, reaching values above 10% at multiple times of the day and registering a peak close to 70% around 07:30 h. These high values indicate a high presence of harmonic currents, which can generate overheating in the transformers, reduce their useful life, and increase electrical losses in the system. The variability of the k-factor suggests a strong influence on photovoltaic generation and load demand on the grid.

Figure 9: The behavior of individual voltage harmonics

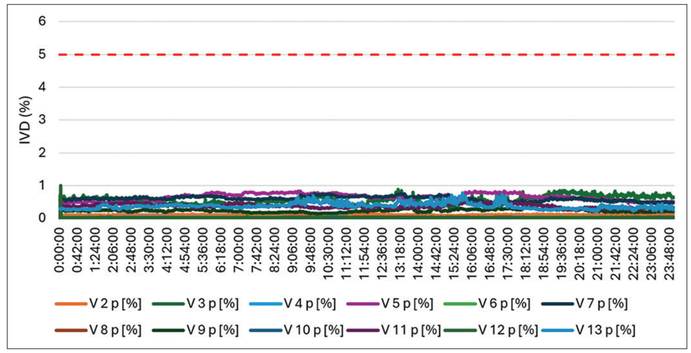


Figure 10: The behavior of individual current harmonics

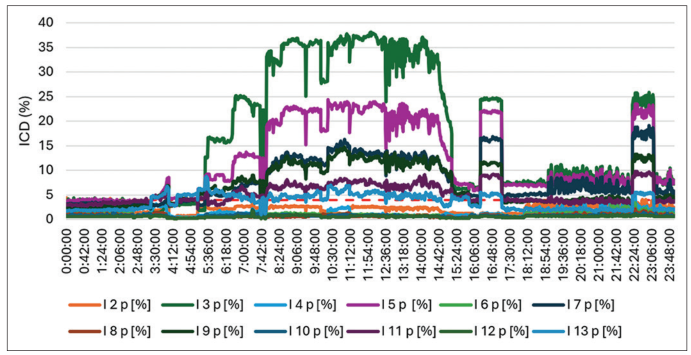
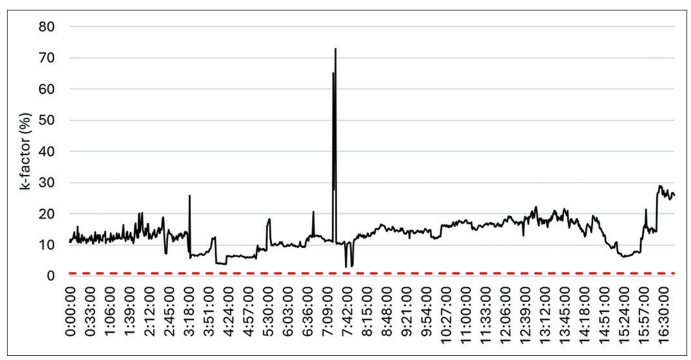


Figure 11: k-factor behavior



Analyzing the PQ parameters on a typical day revealed several problems. The voltage unbalance exceeded 2% at certain times, and the current unbalance reached values close to 100%, evidencing a strong asymmetry in the current injection. The voltage crest factor remained above the limit of 1.41, and the flicker exceeded 1% at night, which could affect sensitive equipment. Although the THDV remained within the normative values, the TDD exceeded the inverter's 5% limit, reaching up to 16% during hours of maximum solar generation. In addition, individual current harmonics of order 2, 3, 4, 5, 7, 9, 11, and 13 exceeded 4%, with harmonics 3, 5, and 7 reaching peaks above 30%. Likewise, the k-factor presented high values throughout the measurement period, with peaks close to 70%, indicating a high presence of harmonic currents that can generate overheating in the transformers and affect their useful life.

3.2. Statistical Analysis of Parameters outside the Established Limits

Figure 12 presents a box-and-whisker plot representing each parameter's maximum, minimum, and average values. Figure 13 shows a scatter graph, while Figure 14 presents a bar graph with the percentage of data exceeding the limits established by the standard.

As shown in Figures 12-14, the voltage unbalance, with an average of 2.94% and a maximum of 9.84%, exceeds the 2% limit established by the standard on several occasions, with 50% of the data out of range. This behavior is reflected in Figure 3, where it is observed that, in the early hours of the day, the unbalance exceeds 5%, decreasing during the day but increasing again at night, reaching values close to 8%.

The current unbalance, with an average of 54.1% and a maximum of 147.7%, presents the most significant deviation from the normative values, with 69.6% of the data outside the 20% limit. Figure 4 shows these fluctuations, highlighting that extreme values are recorded in the early hours of the day and the afternoon, suggesting a strong asymmetry in the injection of current by the photovoltaic system.

Figure 12: Box-and-whisker plot of each parameter

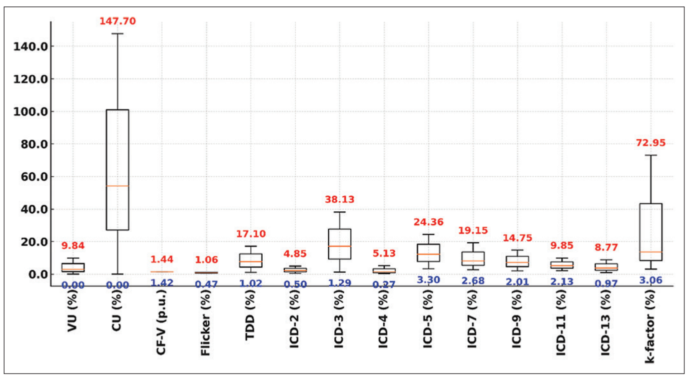


Figure 13: Scatter plot of the standard deviation of each parameter

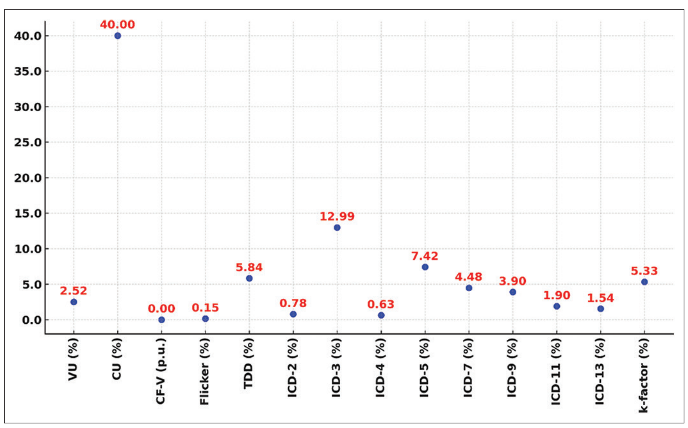
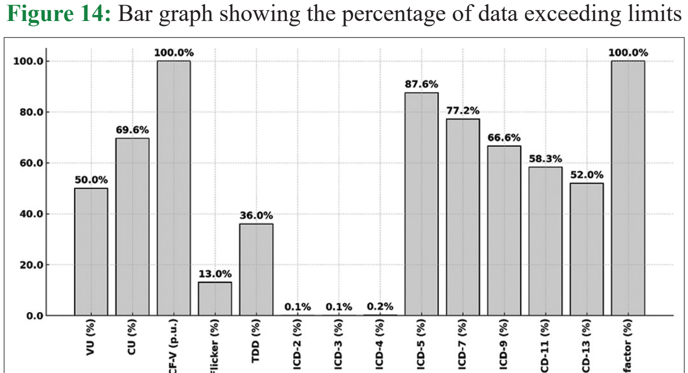


Figure 14: Bar graph showing the percentage of data exceeding limits



The voltage crest factor, with an average of 1.43 p.u. and a maximum of 1.44 p.u., remains constantly above the regulatory limit of 1.41 p.u., with 100% of the data outside the permitted threshold. This is confirmed in Figure 5, where stability is observed in the presence of voltage peaks, which could affect the useful life of the connected equipment.

The Flicker, with an average of 0.75% and a maximum of 1.06%, exceeds the 1% limit in 13% of the data. Figure 6 shows how this parameter increases during night hours, suggesting that the voltage fluctuation could be related to changes in load demand and the interaction between the photovoltaic system and the grid.

The THDV remains stable and at low levels, with an average of 1%, without exceeding the limit of 8%. Figure 7 supports these results, indicating that the injection of the photovoltaic system does not introduce significant distortions in the voltage.

However, the TDD presents an average of 7.65% and a maximum of 17.10%, with 36% of the data outside the 5% limit established by the inverter manufacturer. In Figure 8, it can be observed that the TDD increases progressively from 06:00 h, reaching values close to 16% in the period of maximum solar generation and decreasing after 15:30 h, which suggests that the harmonic distortion increases with the injection of photovoltaic energy.

The ICD reflects high values, mainly in the 3rd, 5th, and 7th orders, with averages of 17.09%, 12.20%, and 8.08%, respectively. Figure 10 shows that these harmonics exceed the 4% limit at various times of the day, with peaks above 30% in the 3rd, 5th, and 7th order harmonics. This indicates a strong distortion in the current injected by the inverter, which can affect the system's stability and increase losses in the network.

Finally, with an average of 13.53% and a maximum of 72.95%, the k-factor remains constantly above the 1% limit, with 100% of the data out of the norm. Figure 11 shows a significant increase in the k-factor in the morning, with a peak close to 70% around 07:30, indicating a high presence of harmonic currents that can generate overheating in the transformers and reduce their useful life.

The results of this study confirm that, although photovoltaic generation is key in the transition towards sustainable energy systems, its integration into residential networks can significantly affect the quality of electrical power. Problems such as current unbalance, harmonic distortion, and k-factor show the need to implement mitigation strategies to minimize their impact on system stability. Unlike previous studies (Adric et al., 2024), (Majeed et al., 2024) and (Benavides et al., 2024), which have analyzed PQ in distribution networks and industrial environments; this work focuses on the connection point of a residential photovoltaic system, a perspective explored little in the literature.

The results of this study highlight the importance of active filters, advanced controllers in inverters, and load balancing to improve the operation of these systems in low-voltage residential networks.

4. CONCLUSION

In the study carried out on a residential photovoltaic system in Colombia, voltage unbalances of up to 9.84% (average of 2.94%), current unbalances of up to 147.7% (average of 54.1%), TDD of up to 17.1% (average of 7.65%) and a k-factor more significant than 70% were identified. These results show a high presence of harmonics that can compromise the stability of the network and reduce the useful life of transformers. These effects suggest implementing mitigation strategies to minimize the impact on residential networks and ensure compliance with current regulations, especially in a country where the residential sector represents 26% of energy consumption.

To improve the integration of these systems in Colombia, the development of advanced controls in inverters, the implementation of active filters and FACTS devices to mitigate harmonics, and the optimization of load and storage management algorithms are proposed. Furthermore, considering the growth of solar energy in regions such as La Guajira and the challenges associated with solar intermittency, it is essential to analyze the long-term impact of its penetration in low-voltage networks. Likewise, a strengthening of the regulation on harmonic distortion and load balancing in residential networks is required to guarantee the stability of the electrical system and maximize the benefits of photovoltaic generation in the country.

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