The influence of the energy quality parameters of an electrical installation on the electrical network

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Abstract. The increasing penetration of residential photovoltaic (PV) systems introduces new challenges regarding power quality in low-voltage distribution networks. Although PV generation contributes to sustainable energy production, the power injected by prosumers may introduce disturbances such as voltage fluctuations, harmonic distortion, and phase unbalance. This paper investigates the influence of photovoltaic energy injection on key power quality parameters in a residential electrical installation. Experimental measurements were carried out using a Fluke 435 power quality analyzer, focusing on voltage, current, frequency, waveform distortion, and phase unbalance. The obtained results are evaluated in relation to the limits imposed by EN 50160, demonstrating that, under the analyzed operating conditions, the measured parameters remain within acceptable limits. The study highlights the importance of continuous monitoring of power quality in residential networks with increasing PV integration.

1 Introduction

The rapid expansion of distributed generation, particularly residential photovoltaic systems, has significantly altered the operating conditions of low-voltage electrical networks. While PV systems offer clear environmental and economic benefits, their integration introduces challenges related to power quality, especially in networks originally designed for unidirectional power flow [1-3].

Variations in generation and consumption, inverter-based interfaces, and uneven phase loading can lead to voltage deviations, harmonic distortion, flicker, and phase unbalance. These phenomena may negatively affect both the distribution network and end-user equipment [4-5].

This paper analyses the impact of photovoltaic energy injection on power quality parameters in a residential electrical installation. Measurements were performed using a Fluke 435 power quality analyzer, and the results obtained were evaluated in accordance with the EN 50160 standard.

2 Power quality parameters

Power quality is influenced by both the operation of the electrical supply system and the behavior of connected consumers. Numerous industrial consumers and, more recently, certain segments of electricity generators such as wind farms and solar photovoltaic systems may result in significant disruptions to the power supply network in the shape of voltage fluctuations, harmonics, interharmonics, dips and swells, asymmetries, which can cause a reduction in the level of quality of electricity delivered to consumers connected to the network. For consumers' technological processes to run smoothly, the power system must possess the capability to maintain sufficient electrical quality, manage disruptions introduced by consumers' facilities into the electrical supply network, and accommodate potential fluctuations in power demand and consumption [6-8].

The monitoring of electricity quality indicators and the adoption of measures to maintain them within acceptable limits, as an obligation of the electricity supplier, can only be done in correlation with the monitoring of disturbances introduced into the electrical supply network by certain consumers [9].

The primary electricity quality indicators referring directly to the electricity as a product are [7]:

- frequency;
- supply voltage amplitude;
- temporary and transient overvoltage;
- voltage gaps.

The secondary indicators refer in particular to disturbances determined by the operation of consumers [7]:

- harmonics and interharmonics;
- voltage fluctuations;
- flicker effect.

While the primary indicators are the result of the planning, design and organization of the operation of the installations, the secondary indicators of the quality of electricity are mainly determined by the type of load of the consumer. We are going to present the secondary indicators in the next paragraphs.

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2.1 Harmonics and interharmonics

In an electric power system, the following can be found: harmonics, interharmonics, switching impulses, and noise. In an ideal electrical system, the shapes of the voltage and current curves are perfectly sinusoidal.

When dealing with a circuit comprising purely resistive, inductive, or capacitive linear loads, a sinusoidal current will be observed when the applied voltage follows a sinusoidal pattern, given the direct proportionality between current and voltage. In electrical power systems, non-sinusoidal currents develop when the loads present a non-linear response to the applied voltage. Modern industrial technologies, but also most receivers in office buildings, as well as those in the commercial and residential sectors (air conditioning systems, computers, audio and video systems, etc.) represent non-linear systems that generate distortions of electric current curves [10-12].

Interharmonics are signals whose frequency is not a multiple of the fundamental frequency. Some of them are caused by nonlinear loads, while others are directly injected by the distributor. Interharmonics can be generated at any voltage level and transferred to another voltage level, for example, interharmonics generated in high and medium-voltage networks can be injected into low-voltage networks and vice versa. Interharmonics can also be generated by the oscillations that appear, for example, in systems containing capacitors mounted in series or in parallel or in the case of transformers operating in saturation mode and during switching processes [11].

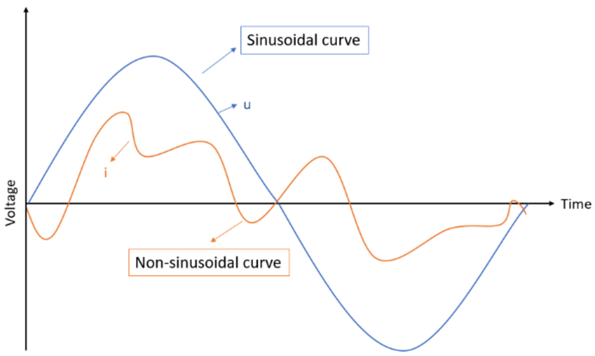

Fig. 1. Sinusoidal curve of the voltage and non-sinusoidal curve of the associated electric current

2.2 Dips and swells

The effective voltage amplitude in electrical networks can experience slow variations primarily caused by voltage drops across lines and transformers, resulting from the slow changes in the electrical load of consumers. Effective voltage variations can also be determined by changes in the regime of the reactive power sources, as well as by changes in the configuration of the electrical scheme of the electrical network or as a result of the production of defects in these networks [13-14].

However, in the normal operation of electrical networks, the amplitude of the effective voltage must fall within the allowed voltage band specific to each electrical network. From a production point of view, voltage variations are often classified into slow voltage variations due to variations in electrical loads, voltage fluctuations, voltage swells and dips [13].

According to the European standard EN 50160:2010 [15], voltage variation is defined as the fluctuation of the effective voltage, typically resulting from changes in electrical loads.

According to the standard mentioned above [15]:
- a temporary decrease in the effective voltage, lasting up to 1 minute, below the lower threshold of the acceptable voltage range is referred to as a voltage dip;

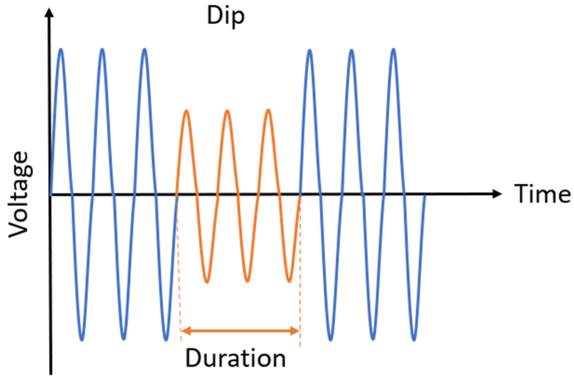

Fig. 2. Voltage dip

- the transient rise in the effective voltage, lasting up to 1 minute, beyond the upper threshold of the permissible voltage range is known as "temporary overvoltage of industrial frequency" or commonly referred to as voltage swell.

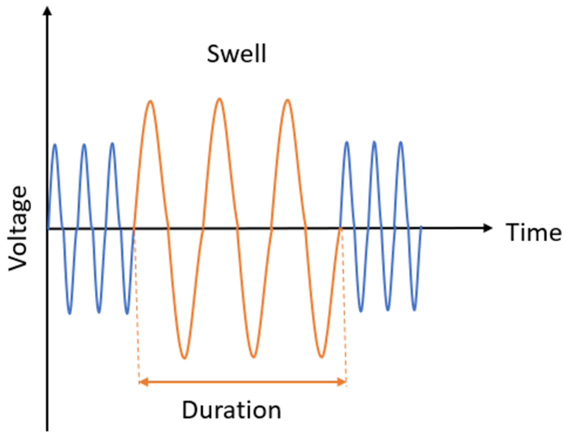

Fig. 3. Voltage swell

Based on the aforementioned provisions, it can be concluded that if the amplitude of the effective voltage in an electrical network, for a time duration greater than 1 minute, from the admissible voltage band specific to the respective network, from the point of view of energy quality, it is considered that a voltage variation has occurred with a voltage deviation that exceeds the admissible voltage band [13].

According to the EN 50160:2010 standard [15]:

- a voltage dip refers to a momentary decrease in voltage below a predefined threshold within the power supply network. According to this standard, the initial threshold for recognizing a voltage dip is set at 90% of the reference voltage. The duration of a voltage dip can vary, occurring within a timeframe spanning from 10 milliseconds to 1 minute.

- voltage interruption occurs when the voltage at the supply point drops below 5% of the reference voltage.

2.3 Flicker

The voltages in the electrical networks vary over time due to the disturbances that occur in the process of generating, transporting and distributing electricity. The interaction between the electrical loads and the electrical networks to which they are connected often causes fluctuations in the voltage of the electrical networks [2].

Voltage fluctuations are due to rapid variations in the active and reactive power of some loads such as refrigerators, elevators, welding machines, pumps, etc. Voltage fluctuations in electrical networks can also be generated by wind power plants [2].

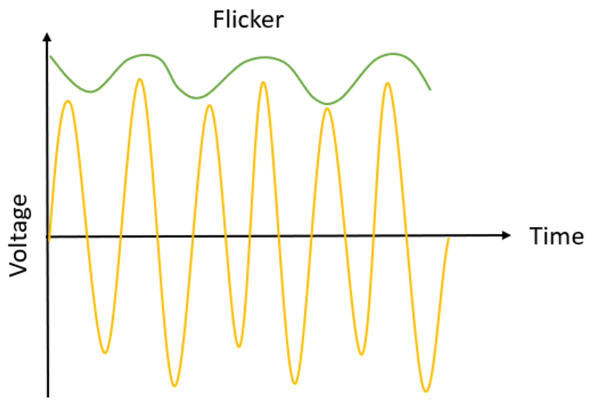

Fig. 4. Flicker

3 Power quality analysis

The assessment of power quality was carried out in a residential electrical installation equipped with a photovoltaic (PV) system. Measurements were performed at the terminals of the main electrical distribution panel using a Fluke 435 power quality analyzer, which allows the monitoring and recording of key electrical parameters in accordance with international standards [9].

The analyzed parameters included voltage magnitude, frequency, waveform shape, and phase unbalance. These indicators are particularly relevant in installations with distributed generation, where inverter-based PV systems may influence the quality of the electricity supplied to and injected into the distribution network.

Figure 5 presents a snapshot of the measurement results obtained during the monitoring period. The recorded system frequency was 49.998 Hz, while the phase voltages were approximately 238 V. These values fall within the admissible limits specified by the EN 50160 standard, indicating stable operating conditions of the electrical network despite the presence of photovoltaic generation.

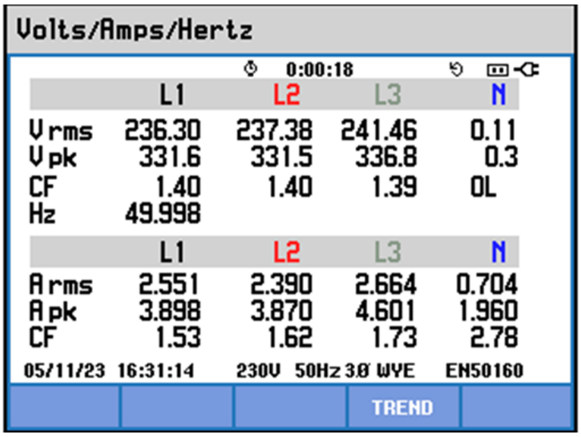

Fig. 5. Meter screen

Table 3. Summary of measured power quality parameters.

Parameter	Min	Mean	Max	EN 50160 limit
Frequency (Hz)	49.97	49.998	50.02	50 ±1%
Phase voltage (V)	236	238	240	230 ±10%
Voltage unbalance (%)	0.8	1.1	1.4	≤2%
THD voltage (%)	1.9	2.3	2.8	≤8%

Table 3 summarizes the statistical indicators of the measured parameters (minimum, mean and maximum values), allowing a clearer evaluation of compliance with the EN 50160 limits.

Beyond confirming compliance with EN 50160, the measured voltage and frequency stability indicate that the photovoltaic system operates without inducing noticeable disturbances at the point of common coupling. This behavior suggests effective synchronization between the inverter and the public distribution network, even under local generation conditions [5].

Voltage unbalance represents one of the most common issues in low-voltage electrical installations and can occur due to unequal phase loading, supply system impedance, or the operating conditions of connected generators. In residential networks, phase unbalance is often amplified by single-phase loads and uneven distribution of prosumers across phases. The phasor diagram shown in Figure 6 highlights the phase relationships between voltages, revealing a balanced system with no significant deviations that could negatively affect connected equipment.

A high-quality power supply is characterized by constant availability, voltage and frequency values within permissible limits, and voltage waveforms that closely resemble an ideal sinusoidal shape. Deviations from sinusoidal waveforms are typically caused by non-linear loads and power electronic converters, such as PV inverters, and may lead to additional losses, overheating of electrical equipment, and malfunction of protection devices.

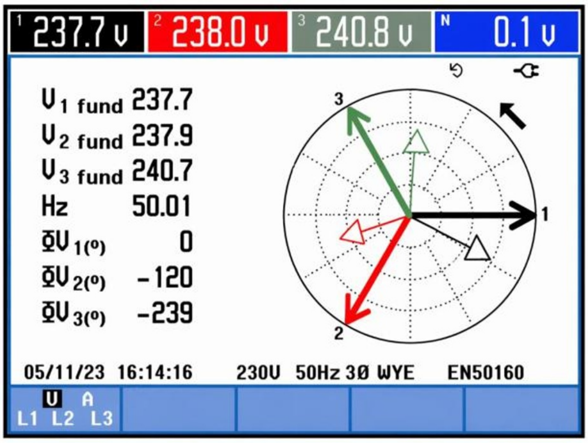

Fig. 6. Phasor screen

The phasor representation further confirms the absence of significant voltage asymmetry, which is essential for limiting additional losses and thermal stress in transformers and conductors. In residential networks with photovoltaic generation, improper phase allocation of single-phase inverters may amplify unbalance effects; however, the analyzed installation does not exhibit such behavior.

Figure 7 illustrates the voltage waveform measured at the connection point. The waveform exhibits minimal distortion and remains close to the ideal sinusoidal form, indicating a low level of harmonic distortion in the analyzed installation. This suggests that the photovoltaic system and associated inverter do not introduce significant harmonic disturbances into the electrical network under the examined operating conditions.

The near-sinusoidal voltage waveform indicates that the harmonic emission of the photovoltaic inverter is effectively limited by its internal control and filtering mechanisms. Maintaining low distortion levels is crucial for preventing additional losses in magnetic components and avoiding malfunction of sensitive electronic equipment connected to the low-voltage network [3,12].

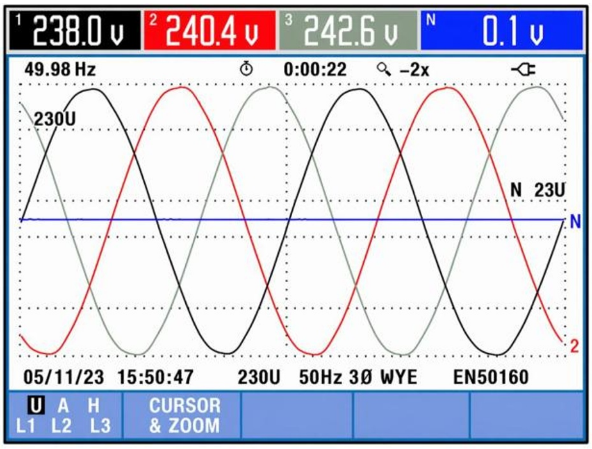

Fig. 7. Waveform screen

The total harmonic distortion (THD) of the voltage remained below 3% during the monitoring period, which is significantly lower than the limit of 8% specified by EN 50160 for low-voltage networks. No significant voltage dips or swells were recorded during the analyzed interval, and the measured voltage unbalance remained below 2%, indicating a well-balanced three-phase system.

Overall, the conducted measurements demonstrate that the analyzed residential photovoltaic installation operates within acceptable power quality limits. The results emphasize the importance of continuous monitoring, especially as the number of prosumers connected to low-voltage networks continues to increase.

In addition to the instantaneous graphical representations, the analyzed parameters provide insight into the overall operating behavior of the installation under steady-state conditions. The stability of voltage magnitude and frequency suggests that the interaction between local generation and consumption is well balanced, reducing the likelihood of voltage rise phenomena commonly associated with high photovoltaic penetration in low-voltage networks. This aspect is particularly relevant in residential areas, where network impedance and short-circuit power are typically low.

Furthermore, the absence of significant voltage imbalance and waveform distortion indicates that the photovoltaic inverter operates within its designed performance limits and complies with grid code requirements. Proper inverter control strategies, combined with adequate filtering, play a crucial role in limiting the propagation of disturbances toward the public distribution network. These aspects contribute to maintaining acceptable power quality levels not only at the point of common coupling but also for neighboring consumers connected to the same feeder.

It should be noted that power quality parameters in photovoltaic installations are influenced by multiple factors, including solar irradiance variability, load dynamics, and network configuration. Although the presented results correspond to a specific operating scenario, they underline the importance of systematic monitoring and periodic assessment of power quality in residential networks with distributed generation. Such analyses support network operators and prosumers alike in ensuring compliance with applicable standards and in preventing potential long-term degradation of network performance.

4 Conclusions

This paper analyzed key power quality parameters in a residential electrical installation with photovoltaic energy injection. Measurements performed using a Fluke 435 power quality analyzer showed that voltage levels, frequency, waveform distortion, and phase balance remained within the limits imposed by EN 50160.

The measurements presented correspond to a specific operating scenario in which the photovoltaic installation was connected to the grid. Future work will include comparative measurements under different operating conditions (PV generation active/inactive and varying load levels) in order to isolate the influence of photovoltaic generation on power quality indicators.

The results indicate that, for the analyzed case study, the integration of a residential PV system does not significantly degrade power quality. However, as the number of prosumers increases, continuous monitoring and proper network management become essential to prevent cumulative effects such as voltage rise and harmonic distortion.

Future work will focus on extended monitoring periods and comparative analyses under varying generation and load conditions.

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