Harmonic Spectrum Analysis at Interconnection Points between Electrical Power Networks and Photovoltaic Systems via Numerical Simulation

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ABSTRACT

The growing use of photovoltaic systems (PVs) as renewable energy sources has driven their interconnection with conventional electrical grids. However, this integration can lead to power quality issues, including harmonic distortion. Understanding the harmonic spectrum at interconnection points is vital to ensure network reliability. This study investigated four photovoltaic generation sites, each with distinct characteristics. The analysis revealed more pronounced harmonic distortions where the capacity of PVs was significant compared to the load. The predominant harmonic frequencies indicated possible sources of distortion. Understanding this spectrum is crucial to prevent transformer damage and maintain electrical system stability. This study contributes to a holistic approach that considers photovoltaic generation and interconnection elements.

Keywords: Harmonics; Transformers; Mathematical models.

Introduction

The increasing adoption of photovoltaic systems (PVs) as renewable energy sources has led to greater interconnection between these systems and conventional electrical power grids. However, the interaction between PVs and power grids can result in power quality issues, such as harmonic distortion. Understanding the harmonic spectrum at interconnection points becomes crucial to ensure the stability and reliability of electrical grids.

Despite their promising success, PV penetration poses several issues, and its impact on the distribution system needs to be addressed for seamless integration into the power system. Harmonic distortion of current and voltage waveforms is becoming a significant concern. This is due to the conversion of DC current to synchronize with the AC mains using inverters. According to current practices and techniques, the inherent nonlinearity of inverters in harmonics can be injected into the AC mains. Knowing that photovoltaic inverters are the main source of current harmonics injected into the distribution system, and current harmonics can also cause voltage harmonics and Total Harmonic Distortion (THD) in the system, contributing to increased distribution losses through heating[1].

In Brazil, distributed generation takes a significant step in its development when mentioned in Law No. 10.848/04 (Electricity Commercialization Law)[2] as one of the possible sources of energy generation. The details presented in Decree No. 5.163, dated July 30, 2004 [3], provide characteristics that will help distribution companies, which until then opposed this form of generation, see distributed generation as a way to mitigate planning risks.

Article 14 of Decree No. 5.163/04 [4] explicitly defines distributed generation as the production of electrical energy from permit holders, concessionaire agents, or authorized agents, directly connected to the buyer's electrical distribution system. The exception is for hydroelectric plants with installed capacity greater than 30 MW and thermal power plants, including cogeneration, with energy efficiency less than 75%.

Only biomass or waste-fired thermal power plants are not limited by this percentage. This restriction placed on thermal power plants was revised by Regulatory Resolution No. 228, dated July 25, 2006, since current thermal power plants with pure electricity generation (without cogeneration) do not achieve energy efficiency greater than 75%. Therefore, this regulatory resolution aims to establish more elaborate and consistent requirements for meeting energy efficiency criteria, in order to certify these thermal power plants as Distributed Generators.

For the International Council on Large Electric Systems (CIGRÉ), distributed generation has powers less than 50 MW and is usually connected to the distribution network. It is a form of generation planned and dispatched in a decentralized manner, without a governing body to command its actions. According to the Institute of Electrical and Electronics Engineers (IEEE), distributed generation is defined as a form of energy generation that occurs from small-scale generation units connected to the distribution system and close to consumption. In turn, the National Institute of Energy Efficiency (INEE) understands that when generation is carried out close to the consumer, it is considered distributed generation, regardless of its power, technology, or energy resource used[5].

It can also be noted that Brazil, compared to the European continent, has nearly twice the average annual insolation, based on information published in the Brazilian Solar Energy Atlas. This demonstrates the country's great capacity to generate electrical energy through solar radiation capture, and even with high implementation costs, photovoltaic energy is beginning to be introduced into the energy matrix as an alternative to existing sources of electrical energy connected to the national electrical system[6].

Methodology

The methodology of this study involved data collection at different points of interconnection between photovoltaic systems and electrical power grids[7]. Representative simulated locations were selected, considering different types of PVs and grid characteristics. Measurements were made based on the simulation of a set of values that belong to a real range of values, allowing for detailed capture of harmonic components present in the systems.

The methodology proposed in this Electrical Engineering article combines numerical and graphical simulations to support the sizing of specific photovoltaic systems. Initially, data on consumption and power quality are collected, and a mathematical model is developed using the Python language. Subsequently, simulations estimate solar irradiance and photovoltaic generation throughout the year, while total harmonic distortion (THD) is quantified at various points in the electrical installation. Based on this information, the photovoltaic system is sized numerically, and the results are graphically visualized, enabling scenario comparisons and adjustments to optimize both efficiency and the quality of the electrical energy supplied to the residence. Experimental validation complements the methodology, ensuring the accuracy of the simulations and contributing to a sustainable and efficient transition in the locality's energy supply.

To perform an analysis of the harmonic spectrum at interconnection points between PVs and electrical grids, a series of procedures is required. These procedures aim to identify and quantify the harmonic distortions present, allowing for measures to ensure the quality and stability of electrical energy. Here are the steps to be followed:

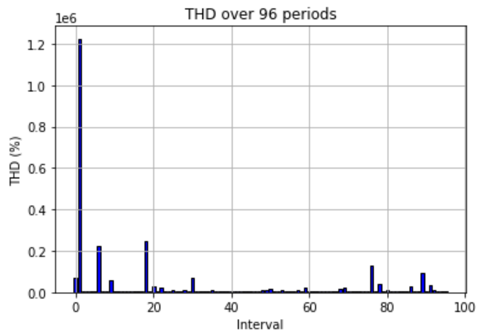


Figure 1: THD at the Installation Point

These methodological procedures are essential for conducting the experiment and analyzing data related to THD over multiple time periods in a low-voltage electrical grid system. The use of the Python programming language and the Matplotlib library facilitated the visualization and interpretation of the results.

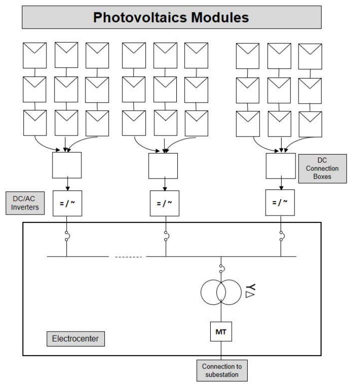
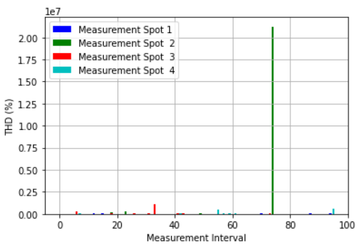
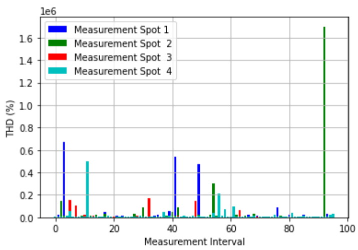


Figure 2: Representative diagram of the photovoltaic system.



(a)



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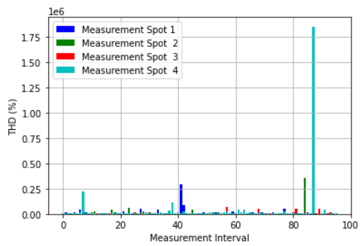

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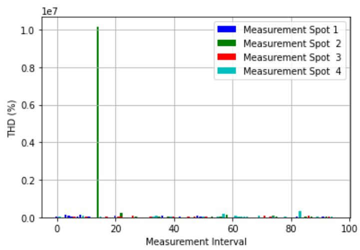

(d)

Figure 3: Comparison of measurements taken at different locations

Experiments

Simulated experiments were conducted considering four different locations, each with a distinct profile of photovoltaic generation and grid conditions[8]. The systems were monitored by identifying 96 measurements (over one month) to capture seasonal and demand variations. Power quality measurements included spectral analysis, identification of dominant harmonic components, and assessment of total harmonic distortion.

This scientific article describes the methodological procedures used to conduct an experiment involving random power and current data in a low-voltage electrical grid system. The aim of the experiment is to analyze the total harmonic distortion (THD) over 96 periods. The methodological procedures can be represented by the following diagram:

For different locations, a standard graph was established, and comparisons were made with the simulation of a specific set of measurements taken at a given moment.

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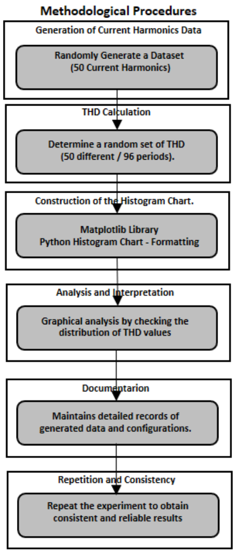

Figure 4: Procedures adopted in the simulation

Results

The results of the harmonic spectrum analysis revealed interesting patterns at different interconnections between PVs and electrical grids[9]. It was observed that harmonic distortions were more pronounced at interconnection points where the capacity of PVs was significant compared to the demanded load. Additionally, certain harmonic frequencies prevailed at each interconnection point, indicating possible sources of distortion. Based on these characteristics, a second phase will be to assess potential behaviors in the operation of the system by varying the surroundings of these points through statistical approaches and numerical optimization.

Conclusions

Based on the results obtained, it is clear that understanding the harmonic spectrum is essential to mitigate power quality issues at the interconnection points between electrical power grids and photovoltaic systems, especially concerning transformers. Neglecting harmonics during installation can result in transformer damage, leading to failures in the electrical system. Identifying the main harmonic frequencies allows for the development of appropriate control strategies to reduce harmonic distortions and maintain system stability, while regular inspection of transformers ensures their integrity over time. Therefore, a holistic approach that considers both photovoltaic generation and interconnection elements is fundamental.

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