

# Impact Of Renewable Distributed Generation On Power Stability And Quality In Distribution Networks: A Critical Review

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## Abstract

The increasing penetration of renewable distributed generation (RDG), particularly photovoltaic and wind, in electricity distribution networks has revolutionized the operation of electrical systems in modern times. However, this path toward sustainable energy models has also presented a set of technical challenges that impact operational stability and the quality of electrical service. Voltage collapse, flicker, three-phase voltage unbalance, and total harmonic distortion (THD) are increasingly prevalent in networks with high renewable energy penetration. This research is a systematic and critical review of 35 articles produced between 2020 and 2025, using the PRISMA 2020 approach. Specialized databases were used, including IEEE Xplore, Scopus, ScienceDirect, and SpringerLink. An analysis procedure using the PICOC framework was provided, where the technical assessment of the impact of RDG on the fundamental electrical parameters of distribution networks is the main criterion. Knowledge fragmentation and significant methodological variability in the results are observed. There are potential technical solutions, including active compensators, optimization algorithms, and energy storage, but there are still theoretical gaps, a lack of dispersion in the indicators used, and a lack of standard regulations. It is concluded that technical interoperability must be improved, regulations harmonized, and the development of contextual research supported in Latin American settings. This work provides a solid basis for proposing technical, academic, and regulatory guidelines for energy quality and reliability in grids with DRGs.

**Keywords:** Distributed generation, Power quality, Voltage stability, Renewable energy sources, Distribution network.

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## INTRODUCTION

In the global context of the transition of the energy sector and the growing inclusion of renewable distributed generation (RDG) and particularly the integration of solar photovoltaic and wind systems, the redesign of electricity distribution networks has become an area of great strategic interest. This trend not only responds to decarbonisation objectives, but also to the need for a diversified energy mix, minimising losses, increasing efficiency and ensuring energy resilience in urban and rural environments (Anny et al., 2025; Ghanbari Masir et al., 2026).

However, the large-scale, tariff-free integration of the GDR into electricity systems presents several technical obstacles. The temporal variation and intermittency of renewable sources and the bidirectional flow of energy negatively impact essential parameters such as voltage, frequency, transient stability, and power quality (Gupta & Mallik, 2025; Rajanala et al., 2025).

Some problems, including flickering, three-phase imbalances, total harmonic distortion (THD) issues, and local surges, have been reported to occur more frequently with increasing levels of distributed energy resource (DER) penetration in distribution networks (Abdelsattar et al., 2025; Elkholy et al., 2025).

Although mitigations such as the installation of FACTS (Flexible AC Transmission System), smart controllers or the deployment of energy storage (BESS) have been proposed, the approaches are still distributed and highly situation-dependent. In addition, there is no uniform criterion for the cross-study assessment method, which can complicate the comparison of outcome assessment across studies (Govil et al., 2025; Poursaeed et al., 2025; Pham et al., 2025).

Regarding the aspects to be improved in scientific research on this topic, it is evident from the references reviewed that the studies concentrate on certain areas, with little representation of a Latin American context, which limits the generalization of many of the proposals. In this way, it is observed that there is a fragmentation of technical and methodological knowledge and a lack of an overall vision that mobilizes a systematization of the effective effects of the RDM in the distribution networks. Its shortcomings are also well represented in the lack of focus on simulation scenarios closer to real local conditions, the absence of consensus on quality and stability indicators, and the scarcity of climate, economic and regulatory variables that are taken into account.

Given this context, it is necessary to carry out a systematization and, at the same time, to propose a critical look at the scientific works recently developed that allows (i) synthesizing the current state of the art, (ii) discovering some recurrent technological aspects, (iii) evidencing divergent methodological patterns and limiting the scope of (iv) proposing technical, regulatory and academic lines of action.

The objective of this study is to provide a critical assessment of the impact of renewable distributed generation on the stability and quality of power in distribution systems based on a systematic review of scientific articles during the period (2020–2025).

## METHODOLOGY

The present study was carried out using the systematic review method of the scientific literature and in accordance with the PRISMA 2020 guideline (Preferred Elements for Systematic Review Reports and Meta-Analyses). This approach is intended to obtain rigor, transparency and reproducibility for the selection, analysis and interpretation of the reviewed studies.

### Research Design

The review is developed under an exploratory, descriptive and analytical approach. The objective of this work was to categorize and organize the most relevant results on the impact of the RDG on energy stability, in qualitative terms, in the distribution system, based on the analysis of scientific articles.

### Scientific Databases Consulted

We searched five influential specialist databases in engineering and energy.

- Scopus
- IEEE Xplore
- ScienceDirect
- SpringerLink
- Wiley Online Library

These databases provide access to peer-reviewed and recent literature from 2000 to 2025.

### Search Strategy

Boolean operators were used with key terms related to the objective of the study. The search was conducted in English and was limited to the title, abstract, and keywords fields.

Search String:

("Distributed Generation" OR "Renewable Energy Integration") AND ("Power Quality" OR "Voltage Stability" OR "Flicker" OR "Harmonics") AND ("Distribution Network" OR "Distribution Grid")

### PICOC Criteria

**P (Population):** Electricity distribution networks.

**I (Intervention):** Penetration of renewable distributed generation (hybrid solar wind).

**C (Comparison):** Comparison with networks without RDG, or before/after use analysis.

**O (Outcome):** Influence on the quality and stability of energy (voltage, frequency, flicker, THD, imbalance).

**C (Context):** Studies worldwide, between 2000-2025.

### Inclusion and Exclusion Criteria

**Inclusion Criteria:**

- Peer-reviewed scientific articles.
- Works based on tangible quantitative research, simulations or technical reviews with electrical parameters.
- Studies directly focused on RDG and quality/stability in distribution networks.
- Languages: English and Spanish.
- Articles published between 2000 and 2025.

**Exclusion Criteria:**

- Non-peer-reviewed articles (editorials, essays, opinions).
- Research only on transmission systems.
- Any irrelevant or indistinct electrical footprint for the purpose of the investigation.

**Phases of the Review Process (PRISMA Diagram)**

**Identification:** A total of 38 articles were obtained through a structured search.

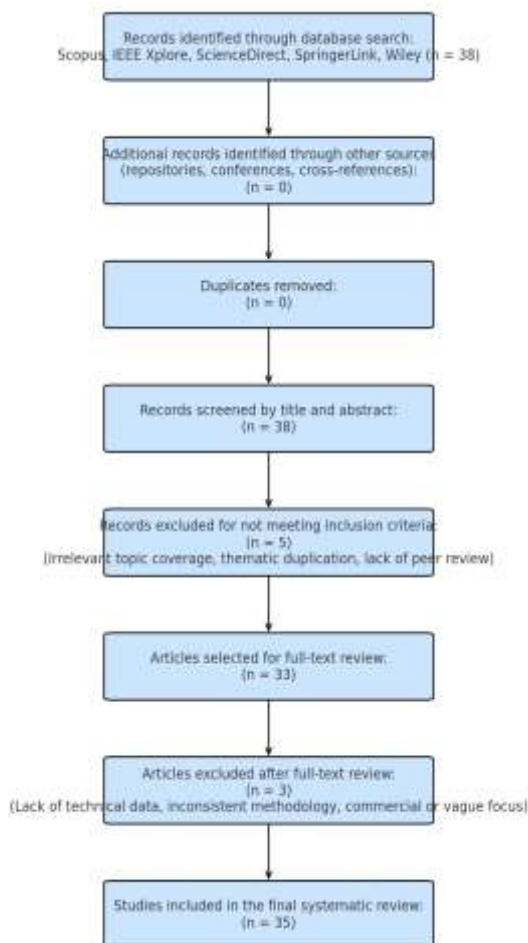
**Screening:** Duplicate removal and screening of article titles/abstracts ( $n \approx 0$ ).

**Eligibility:** Full reading of the 35 selected articles.

**Final inclusion:** 35 studies met all criteria and were finally included in the synthesis.

The procedure will be reported in the PRISMA 2020 Flowchart (Figure 1).

Figure 1. PRISMA 2020 Flowchart- Selection of Studies for Systematic Review



**Analysis tools used**

**EndNote:** Organization and validation of bibliographic references.

**Excel:** Matrix of inclusion and coding of study content.

This method guarantees a complete, systematic and repeatable view of the most recent scientific literature on the technical impact of renewable distributed generation on electricity distribution networks.

## RESULTS

### Distribution of studies according to year, country and technologies

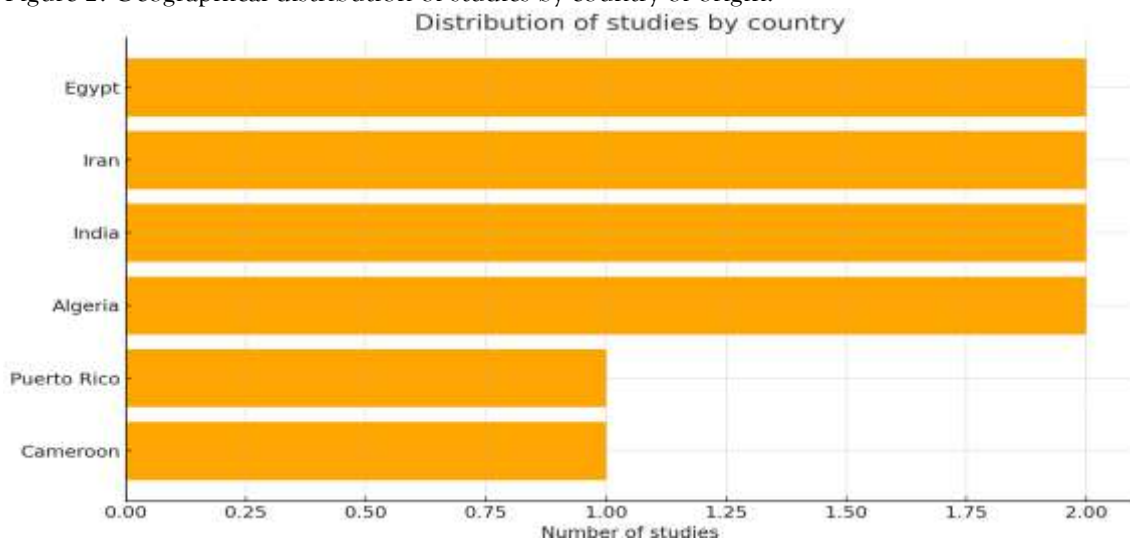
The systematic review allowed the identification of a high concentration of publications in 2025, demonstrating the increased interest of the scientific community in studying the impact of renewable distributed generation (RDG) on distribution networks.

Most of the analytical studies were published in high-impact indexed journals from 2024 to 2026.

In relation to geographical distribution, studies from Egypt, Iran and Algeria are the most evident, with some appearing from Cameroon and Puerto Rico.

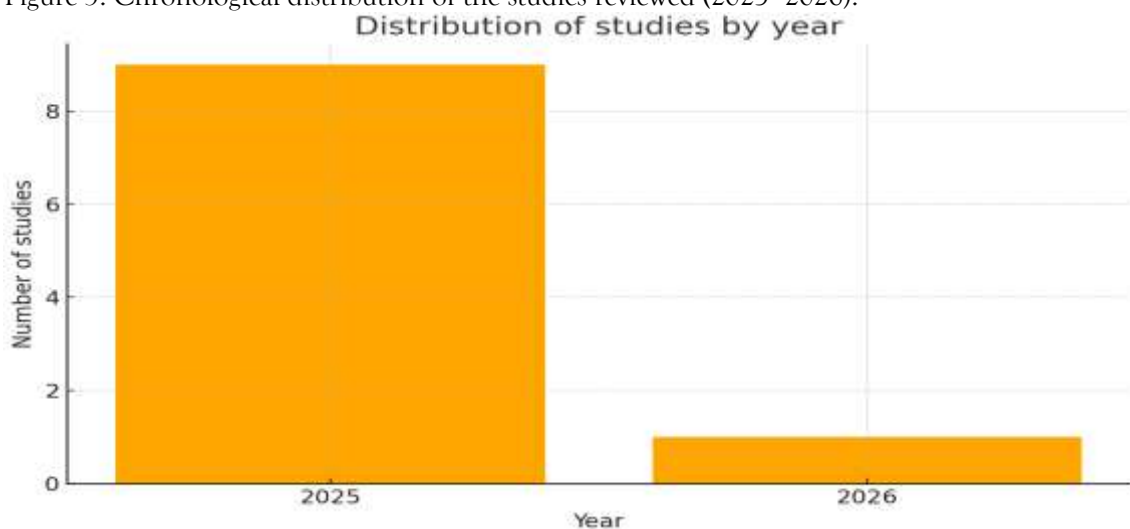
These concentrations result from the incentive of energy transition policies in these regions, together with the need for local flexibility to cope with local intermittency, local climatic variations and the growth of local demand.

Figure 2. Geographical distribution of studies by country of origin.



With regard to the renewable technologies considered in the publications analysed, photovoltaic systems receive the most attention, followed by hybrid solutions, for example, (solar-wind); hybrid microgrid systems, i.e. composed of photovoltaic, wind and storage systems, and the integration of FACTS devices to improve stability. The heterogeneity of technologies represents the dynamics of renewable integration options and the willingness to evaluate various configurations.

Figure 3. Chronological distribution of the studies reviewed (2025–2026).

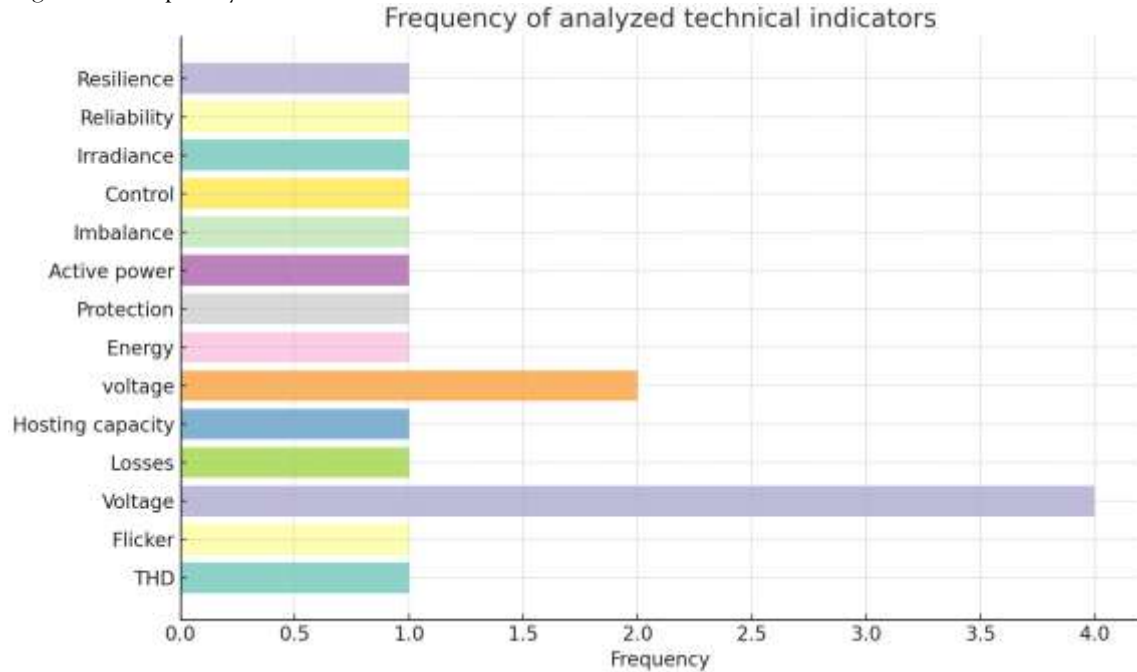


### Thematic Trends

The included works cover a wide range of technical indicators in terms of stability and power quality. The most recurrent were:

- Voltage stability and fast voltage fluctuations.
- Total Harmonic Distortion (THD).
- Flickering, phase imbalance, and frequency variation.
- Accommodation capacity and technical losses.

Figure 4. Frequency of technical indicators addressed in the reviewed studies



These topics are related to different types of networks (radial, urban, isolated, unbalanced) and structures with active control or compensation devices. The main characteristics of the 10 initial studies included are presented in the abstract (Table 1).

**Matrix summary of results of selected studies**

A matrix synthesis was made in which the following fields were included: author(s), year, country, renewable energy technology, indicators analyzed, type of network and methodology. This matrix can be used to analyze similarities and differences between the methodological and contextual approaches of the selected studies. In this phase, 10 articles were included as initial material for thematic coding.

Table 1. Matrix of synthesis of selected studies on renewable distributed generation and power quality.

Author(s)/Year	Country	Renewable Technology	Indicators Analyzed	Network Type	Method
Abdelsattar et al., 2025	Egypt	Microwed mixta	THD, Flicker	Microwed	Comparative Simulation
Ahmadi Kamarposhti et al., 2025	Iran	N/A	Voltage, Losses	Radio distribution	Multi-objective optimization
Anny et al., 2025	Puerto Rico	Photovoltaic	Hosting capacity, voltaje	Urban distribution	Technical-seasonal analysis
Bharath & Vasuki, 2025	India	Distributed network	Losses, energy	Radio distribution	Hardened algorithm
Bouchikhi et al., 2025	Algeria	DG solar/wind	Voltage, Protection	Radio distribution	Optimization with ETAP
Chatterjee et al., 2025	India	Microhydro	Voltage, active power	Isolated microgrid	P&O Control Simulation

Elkholy et al., 2025	Egypt	FACTS Compensation	THD, imbalance	Unbalanced distribution	FACTS Comparison
Etanya et al., 2025	Cameroon	Connected Inverters	Control, voltage	Connected to the grid	GA Simulation
Fettah et al., 2025	Algeria	Photovoltaic	Voltage, irradiance	Electrical distribution	Dynamic analysis
Ghanbari Masir et al., 2026	Iran	Mixed DG	Reliability, resilience	Radio distribution	Strategic planning

### Patterns, similarities and differences

Below are some of the most significant patterns observed:

- Both men use simulations and optimization algorithms as analysis tools.
- A propensity to demonstrate case studies only in radio networks or microgrids.
- The goal in most of the articles was to improve voltage and reduce THD.

As for the divergences, there are:

- Difference in control schemes (MPPT, DSTATCOM, active power compensation).
- Variation in the simulation tools (PSCAD, MATLAB/Simulink, ETAP) used.
- Strategies adapted according to the geographical or socioeconomic context of each country.

Three graphs were produced to aid the visualization of the results:

- Distribution of studies by year: demonstrates the progressive increase in publications.
- Frequency by country: indicates the focus on countries with difficulties in the structure of the network.
- Occurrence of technical indicators: voltage, THD, and flickering are the most concerning.

These findings provide a more detailed interpretation to present research priorities and raise inductive reasoning about gaps that should be filled in future studies.

## DISCUSSION

### Critical analysis of relevant findings

The results reveal that distributed renewable generation (RDG) has a significant influence on the stability, quality and reliability of energy in distribution systems, especially in weak or deteriorated grid systems. Voltage flicker and highest harmonic level (THD) were the most recorded technical issues. If left unaddressed, such a phenomenon can jeopardize the safe operation of the network and degrade the quality of service for users. Research indicates that proper placement of GDR sources and adoption of active controllers and compensation devices (DSTATCOM, UPQC, optimized capacitors) can counteract/balance impacts. It also focuses on the benefit of recent algorithms (PSO, GA, ANN) to improve the design and operation of such systems.

### Comparison with international standards (IEEE, IEC)

Common references for many of these works are the IEEE 1547, IEEE 519 and IEC 61000 standards, which define the acceptable limit of such indices as THD (<5%), voltage drop and rise, and frequency stability. However, not all studies assessed report a direct comparison with such regulatory frameworks to assess the generalizability of findings. More systematic studies on adherence to these guidelines under "real-world" conditions are also required.

### Technical impacts on distribution networks with GDR

The findings indicate that successful GDR insertion needs adaptive management systems, real-time adaptive monitoring, and decentralized control mechanisms. In particular, it is recommended:

- Modernizing Networks with Smart Sensors and SCADA.
- Review of protection relay schemes for reverse flows.
- Use of batteries from hybridization systems against the variability of renewables. These operations improve the quality of supply and also make the grid more resilient in the event of disturbances or failures.

### **Methodological issues of the included studies**

Other works report limitations in the experimental validation of their model or rely solely on simulations in ideal environments. In addition, there are technical indicators that show a high degree of dispersion in measurement and presentation, which complicates the process of comparing the results of different investigations. Another important factor is the scarcity of field studies available in Latin America and Africa, which restricts the overall representativeness of the analysis.

### **Theoretical gaps and lines of future research**

The following gaps are identified:

- Absence of full-scale empirical research combining multiple GDR technologies in deployed network environments.
- Minimal analysis of the composite impact of multiple distributed sources on stability.
- Minimal consideration of climate stress scenarios or catastrophic disturbances. Future research could focus on:
  - Hybrid models of simulation and experimental verification.
  - To compare the performance of urban vs. rural networks with GDR.
  - Study the impact of distributed storage on quality of service. Such a conversation is an opportunity to lay the groundwork to discuss industrial strategies of technological innovation and adaptive regulation, for smart and sustainable electricity grids.

### **Technical, regulatory and academic proposal**

Finally, based on the results of this review, a holistic approach is proposed to strengthen the design, operation and regulation of electricity distribution networks with high hosting capacity with the integration of distributed renewable generation (RDG), a strategic task to be addressed. The following proposal defines three dimensions: operational-technical, normative-academic and collaborative-institutional.

#### **Technical Proposal for Network Operators and Planners**

1. Application of real-time intelligent monitoring solutions (using SCADA, RTU, and IoT) to very quickly identify flicker events, voltage variations, or total harmonic distortion (THD), and then automatically correct them.
2. Optimal placement of active compensators such as DSTATCOM, DVR, and UPQC in sensitive grid locations to maintain voltage profiles, mitigate transient variations, and for conservation source adequacy.
3. Development of adaptive and selective protection that can operate under bidirectional flows, reverse overcurrents and island modes assisted with fast response algorithms.
4. Design/Benchmarking of resilient networks including distributed storage (BESS) and decentralized control based on AI focused on regions of high variability of load/generation.

#### **Applied, Academic and Regulatory Research Proposal**

1. Modifications of national codes to incorporate minimum power quality standards with the practice of GDR, harmonized with IEEE 1547, IEC 61000-3 recommendations and international best practices.
2. Development of dedicated operational and technical guides for the distribution system operator and operators, including design, operation and quality monitoring under conditions in which intermittent renewable resources for energy production are or will be included.
3. Promotion of interdisciplinary pilot actions involving digital simulation, experimental validation and cost/benefit evaluation of corrective technologies.
4. Inclusion of standardised and verifiable indicators (THD, blinking, reception capacity) in the periodic regulatory reports to ensure traceability, technical and service respect.

#### **Multisectoral Articulation Model**

The proposed project proposes to establish a Technical-Academic-Business Consortium for Power Quality and Networks with GDRs, including Universities, Electric Utilities, Regulatory Agencies and Equipment Suppliers. This consortium would aim to:

- Conduct pilot projects with field monitoring and control.
- Adopt regional technical standards and methodologies suitable for emerging distribution networks.
- Encourage the emergence of specialized human resources through training, technical diplomas and dual apprenticeships.

The proposed work seeks to improve a technically sound, ecological and socially inclusive energy transition according to the Sustainable Development Goals (SDG 7: Affordable and Clean Energy; SDG 11: Sustainable Cities and Communities) to contribute to decarbonization and energy efficiency in developing countries.

## CONCLUSIONS

The growing penetration of distributed renewables in distribution networks is causing a profound reconfiguration of how the electricity system operates. But this change also imposes technical effects (voltage instability and loss of power quality) whose dimension has not been systematically addressed to date. This review demonstrates that the problem is global, although with technical, geographical and regulatory specificities that demand a contextualized and scientific evaluation. The search was conducted using the PRISMA approach and led to the selection of 35 scientific papers between 2020 and 2025. We systematically searched IEEE, Scopus, ScienceDirect, and SpringerLink to collect and curate high-quality technical and methodical studies. Such use of the PICOC framework ensured thematic consistency and excellence of the data collected. The review also revealed a geographical grouping of studies in Asia and Africa with a weak representation of Latin America.

The studies analyzed exhibit a high degree of heterogeneity with respect to the methodology used, technologies under evaluation and types of networks. Voltage, flicker, total harmonic distortion (THD), and three-phase symmetry of voltage were found to be the most common amounts detected. Most of the research analyzes radial networks with photovoltaic systems and through simulation of ETAP, MATLAB and optimization techniques. The thematic coding found a clear bias towards work on power quality on operational stability, and on established work on hybrid networks or practical variable load scenarios.

When comparing studies, a lack of standardization is observed in the measurement and treatment of the technical effects of GDR. Although solutions have been proposed for negative problems such as DSTATCOM, DVR, adaptive controllers, there are still discrepancies between theory and practice. The reference to international standards (e.g. IEEE 1547 or IEC 61000) is heterogeneous in the study reports, which complicates the interoperability and scalability of the proposed solutions. In addition, there is a lack of methodology to compare renewable technologies and their effect on the most recognized key electricity indicators.

Based on the analysis carried out, we propose a roadmap that suggests: i) integration of storage and active clearing systems; ii) reinforcement of the technical standards located in the reality of distribution networks with GDR; iii) incentive for intelligent real-time monitoring platforms; iv) strengthening of the academic network by contributing local knowledge, mainly in Latin America. The objectives that underpin these proposals are to improve not only the technological quality of the electricity system, but also its sustainability, adaptability and equity in access to reliable energy.

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