

# Comprehensive Power Quality Assessment in Radial Distribution Systems: A Harmonic-Aware NCPI Collapse Prediction Index-Based Harmonic Impact Analysis

Sofyan Sofyan<sup>1,a</sup>, Andarini Asri<sup>2,b</sup>, Alamsyah Achmad<sup>3,c</sup>

<sup>1,2,3</sup> Department of Electrical Engineering, State Polytechnic of Ujung Pandang, Makassar, 90234, Indonesia.

<sup>1</sup> Faculty of Electrical Engineering Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

<sup>a</sup> [sofyansofyan@graduate.utm.my](mailto:sofyansofyan@graduate.utm.my), <sup>b</sup> [andariniasri@poliupg.ac.id](mailto:andariniasri@poliupg.ac.id), <sup>c</sup> [alamsyahachmad@poliupg.ac.id](mailto:alamsyahachmad@poliupg.ac.id)



**Abstract**—The proliferation of non-linear loads in modern distribution systems has necessitated a comprehensive understanding of harmonic distortion effects on system stability and collapse prediction metrics. This study presents a novel analytical framework employing the Novel Collapse Prediction Index (NCPI) to quantify harmonic impacts on voltage stability in radial distribution networks. Utilizing the IEEE 33-bus test system as a benchmark, we developed an integrated methodology that incorporates Total Harmonic Distortion in voltage (THD<sub>v</sub>) and current (THD<sub>i</sub>) into the classical NCPI formulation. The proposed approach extends the conventional collapse prediction analysis by introducing harmonic correction factors that explicitly account for voltage and current distortions in stability assessment. Our analysis reveals that harmonic distortion can increase NCPI values by 0.5-1.8%, indicating reduced stability margins, with more pronounced effects in heavily loaded branches distant from the source. The study establishes critical thresholds for harmonic-induced stability degradation, providing quantitative evidence that THD<sub>i</sub> > 15% and THD<sub>v</sub> > 3% significantly compromise voltage stability margins. Through comprehensive correlation analysis, we demonstrate strong interdependencies between harmonic content, voltage regulation, and collapse prediction indices, with harmonic distortion contributing to measurable reduction in system stability margins. The findings offer practical insights for power system engineers and regulators, facilitating evidence-based decision-making for harmonic mitigation strategies focused on preserving voltage stability in contemporary distribution networks.

**Keywords**—Power quality, Novel Collapse Prediction Index (NCPI), Harmonic distortion, Voltage stability, Radial distribution system, IEEE 33-bus test system, Collapse prediction.

## I. Introduction

The modern electrical distribution landscape is characterized by an unprecedented integration of non-linear loads, including power electronic devices, variable frequency drives, and renewable energy systems with inverter-based interfaces. This technological evolution, while enhancing system flexibility and efficiency, has introduced significant challenges related to harmonic distortion and

voltage stability deterioration [1, 2]. The cumulative effect of these non-linear loads manifests as distorted voltage and current waveforms, fundamentally altering the voltage stability characteristics of distribution networks and necessitating comprehensive stability assessment methodologies under distorted conditions.

Traditional voltage stability evaluation paradigms, primarily focused on steady-state analysis under sinusoidal conditions, prove inadequate for capturing the complex interactions between harmonic distortions and voltage collapse phenomena [3,4]. The emergence of sophisticated stability indices, such as the Novel Collapse Prediction Index (NCPI), has provided new avenues for quantifying the voltage stability margins of distribution system components under various loading conditions [5,6]. However, existing NCPI formulations predominantly ignore the explicit impact of harmonic distortion on voltage stability assessment, limiting their applicability in contemporary distribution systems where harmonic content significantly influences collapse prediction accuracy[7-9].

The Novel Collapse Prediction Index represents a critical advancement in voltage stability analysis, offering a normalized metric that quantifies how close a system component is to voltage collapse [10, 11]. Unlike traditional voltage stability indices, NCPI provides a component-wise assessment that directly relates to the physical limitations of power transfer capability under stressed conditions. The index value approaches unity as the system approaches its voltage stability limit, making it an invaluable tool for real-time stability monitoring and preventive control actions[12, 13].

The IEEE 33-bus radial distribution system has emerged as a de facto standard for power

quality and stability studies due to its realistic topology and load characteristics that closely represent actual urban distribution networks [14]. Despite extensive research utilizing this test system for various applications, a comprehensive analysis integrating harmonic-aware NCPI formulations for voltage stability assessment remains largely unexplored. This research gap is particularly critical given the growing concern about voltage stability degradation in radial distribution systems, where harmonic distortion effects on collapse prediction can be amplified due to the absence of multiple supply paths.

Recent investigations have highlighted the intricate relationships between harmonic distortion, voltage regulation, and voltage stability margins in distribution systems [15]. However, these studies typically examine these phenomena in isolation, without establishing a unified framework that correlates harmonic content with quantitative voltage stability indices. The absence of such a holistic approach limits the development of evidence-based harmonic mitigation strategies focused on preserving voltage stability margins and impedes the optimization of distribution system operation under distorted conditions[16].

The significance of incorporating harmonic effects into voltage stability analysis becomes particularly evident when considering that harmonic distortion can mask potential voltage instability conditions or, conversely, create false alarms in stability monitoring systems[17]. Traditional NCPI calculations based on fundamental frequency components may underestimate or overestimate the actual proximity to voltage collapse when significant harmonic content is present, leading to inappropriate control actions or missed early warning signals[18].

This study addresses these fundamental limitations by proposing a novel analytical framework that integrates harmonic distortion effects into NCPI calculations, thereby providing a comprehensive assessment tool for voltage stability in radial distribution systems under distorted conditions[18].

## II. Literature Review

### A. Voltage Stability Assessment Methods

Voltage stability assessment in distribution systems has evolved significantly over the past

decades, with various indices developed to quantify the proximity to voltage collapse. The Novel Collapse Prediction Index (NCPI) represents one of the most sophisticated approaches for component-wise stability assessment in radial distribution networks [8]. Unlike conventional voltage stability indices that provide system-wide assessments, NCPI offers detailed insights into individual component performance under stressed conditions.

The conventional NCPI formulation provides a normalized metric that approaches unity as the system approaches voltage collapse, making it particularly suitable for real-time monitoring applications. However, traditional formulations assume sinusoidal operating conditions and do not explicitly account for harmonic distortion effects that are prevalent in modern distribution systems [9].

### B. Harmonic Distortion in Distribution Systems

The proliferation of non-linear loads in distribution systems has led to increased harmonic distortion levels, affecting both voltage and current waveforms. Power electronic converters, variable frequency drives, and distributed generation systems with inverter interfaces contribute significantly to harmonic injection into distribution networks [10, 11].

Harmonic distortion assessment typically employs Total Harmonic Distortion (THD) metrics for both voltage and current, providing quantitative measures of waveform distortion. IEEE Standard 519-2014 establishes limits for acceptable harmonic distortion levels, with voltage THD limited to 5% and current THD limits varying based on system characteristics [19]

### C. IEEE 33-Bus Distribution System

The IEEE 33-bus radial distribution system serves as a standard benchmark for distribution system studies due to its realistic representation of urban distribution networks (Figure 1). The system consists of 33 buses and 32 branches with a total load of 3.72 MW and 2.30 MVAR, operating at 12.66 kV nominal voltage [5]. Its radial topology and diverse load characteristics make it an ideal test platform for comprehensive power quality and stability analyses.

**D. Integration of Power Quality and Stability Assessment**

Recent research trends emphasize the need for integrated approaches that consider both power quality and voltage stability simultaneously. Traditional separate treatment of these phenomena fails to capture their fundamental interdependence in modern distribution systems with significant non-linear loading [17, 20]. This research gap necessitates the development of unified assessment methodologies that explicitly account for harmonic effects in voltage stability evaluation.

**III. Research Methods**

The research methodology employs a comprehensive analytical framework to investigate harmonic impacts on voltage stability assessment using the harmonic-aware NCPI formulation. The methodology encompasses several key phases including theoretical framework development, test system configuration, harmonic distortion modeling, and comprehensive analysis[21].

The fundamental premise of this research is the extension of the classical NCPI formulation to incorporate harmonic distortion effects explicitly. The conventional NCPI formulation for a network component without harmonic considerations is expressed as[18]:

$$NCPI = \frac{4Z^2}{XV_r^2} * \frac{Z^2 P^2}{XV_r^2} + |Q_r| \leq 1 \quad (1)$$

Where Z represents the component impedance magnitude, X denotes the reactance, Vr is the receiving end voltage, P is the active power, and Qr is the reactive power at the receiving end. Where Z represents the component impedance magnitude, X denotes the reactance, Vr is the receiving end voltage, P is the active power, and Qr is the reactive power at the receiving end.

To incorporate harmonic distortion effects, an enhanced NCPI formulation is proposed that introduces harmonic correction factors:

$$NCPI_{THD} = \frac{4Z^2}{XV_r^2(1 + THDv^2)} * \frac{Z^2 P_r^2(1 + THDi^2)}{XV_r^2(1 + THDv^2)} + |Q_r|:1 + THDi^2 \quad (2)$$

Where:

Vr: Fundamental voltage component

Qr: Fundamental Reactive power component  
 THDv: Total Harmonic Distortion of Voltage  
 THDi: Total Harmonic Distortion of Current  
 Z: The Line Impedance  
 X: The line Reactance

This enhanced formulation explicitly accounts for voltage harmonic distortion (THDv) and current harmonic distortion (THDi), providing a more accurate representation of network component performance under distorted conditions.

The IEEE 33-bus radial distribution system serves as the test platform for comprehensive analysis. This system comprises 33 buses and 32 branches with realistic topology and load distribution characteristics typical of urban distribution networks. The system configuration includes multiple lateral feeders emanating from the main trunk, creating realistic harmonic propagation patterns.

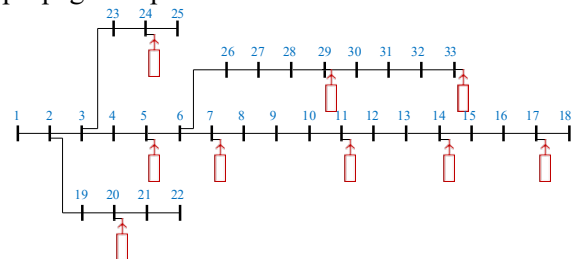


Figure 1. The IEEE 33-bus Radial Distributing

System with Harmonic Source Placement

Harmonic distortion modeling employs a

sophisticated approach considering distance-dependent propagation characteristics (eq. 3)[22]. The harmonic content modeling incorporates distance-based THD variation and load-dependent harmonic generation patterns (eq.4)[23]:

$$THDv(i) = THDvbase(i)x(1 + \frac{d_i}{d_{max}} + \frac{L_i}{L_{max}}) \quad (3)$$

Where:

THDv(i): Total Harmonic distortion of Voltage at bus I

THDvbase(i): Base or nominal THDv at bus I;

Pr: Fundamental active power component

$d_i$ : Distance of bus I from the substation (or Harmonic Source)  
 $d_{max}$ : Maximum distance in the system.  $l_i$ : Load at bus I.

$$\begin{aligned}
 &I_{\max}: \text{Maximum load in the system.} \\
 &THDi(i) = THDi_{base}(i)x\left(1 + \frac{d_i}{2d_{\max}}\right) \\
 &\quad + \frac{NL_i}{NL_{\max}} \quad (4)
 \end{aligned}$$

Where:

THDi(i): Total Harmonic distortion of current at bus I; THDi<sub>base</sub>(i): Base or nominal THDi at bus I; NL<sub>i</sub>: Non Linear Load at bus I; NL<sub>max</sub>: Maximum Non Linear Load at bus i

The analytical methodology encompasses power flow analysis, harmonic distortion assessment, NCPI calculation and comparison, and performance correlation analysis[24, 25]. Advanced computational tools including MATLAB R2024b are employed for numerical analysis and statistical correlation studies.

#### IV. Result and Discussion

##### A. Harmonic Distortion Analysis

The comprehensive analysis of harmonic distortion in the IEEE 33-bus distribution system reveals significant variations in THD levels across the network. The statistical analysis indicates an average THD<sub>v</sub> of 2.714% and average THD<sub>i</sub> of 11.334%, with maximum values reaching 5.000% and 19.389%, respectively. Both voltage and current harmonic distortions remain within IEEE 519-2014 compliance limits (THD<sub>v</sub> ≤ 5% and THD<sub>i</sub> ≤ 20%), demonstrating system operation within acceptable standards while highlighting the presence of measurable harmonic pollution.

The spatial distribution of harmonic distortion exhibits distinct patterns correlating with network topology and loading characteristics. Higher harmonic distortion concentrations occur in the main trunk lines (lines 2-3, 3-4, and 4-5), where cumulative loading effects and electrical distance from the source contribute to elevated THD levels. As shown in Figure 2, the analysis identifies three critical lines with highest THD<sub>i</sub> values: Line 2-3 (15.04%), Line 3-4 (15.47%), and Line 4-5 (13.66%), corresponding to heavily loaded sections of the primary feeder.

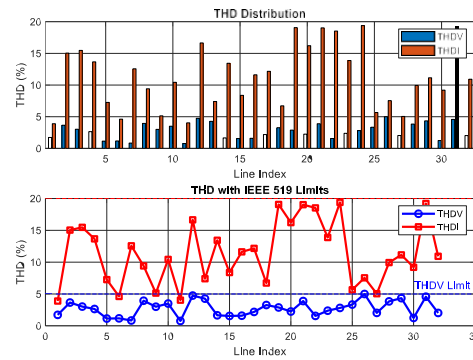


Figure 1

Figure 2. THD distribution across all 32 system branches of IEEE 33-bus system

The voltage harmonic distortion pattern displays more gradual variation, with peak concentrations in the same trunk lines: Line 2-3 (3.66%), Line 3-4 (3.02%), and Line 4-5 (2.64%). This distribution pattern confirms theoretical expectations that harmonic distortion propagates and accumulates along radial feeders, with maximum impact occurring at intermediate distances from the source before attenuation effects become dominant.

##### B. Voltage Profile and Regulation Analysis

The voltage analysis reveals significant challenges in the distribution system's voltage regulation capability. Figure 3 shows the minimum system voltage reaches 0.913100 pu (Bus 18), representing an 8.69% voltage drop from nominal value, which exceeds typical acceptable limits of ±5%. The average system voltage of 0.948461 pu indicates a general undervoltage condition throughout the network.

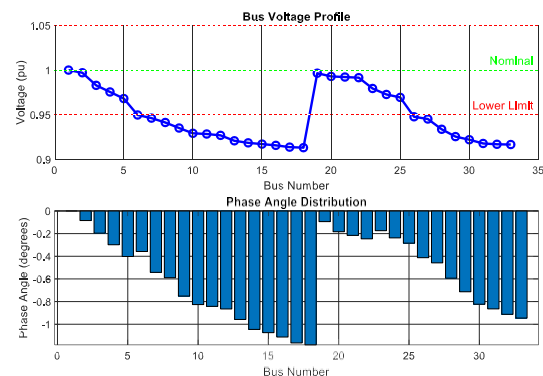


Figure 2

Figure 3. Komprehensif voltage profile and phase angle analysis of IEEE 33-bus system

The voltage profile exhibits distinct patterns corresponding to the system's main feeders. The main feeder (Buses 1-18) shows progressive voltage decline from 1.000 p.u to 0.913 p.u, while lateral feeders demonstrate varying voltage regulation characteristics. The first lateral (Buses 19-22) shows relatively stable voltage around 0.992-0.995 pu, the second lateral (Buses 23-25) exhibits moderate voltage drop to 0.969-0.979 pu, and the third lateral (Buses 26-33) shows significant voltage degradation from 0.948 pu to 0.917 p.u.

Phase angle analysis shows that 32 out of 33 buses exhibit negative phase angles, indicating predominantly inductive loading conditions throughout the system. This extensive inductive loading contributes significantly to voltage regulation challenges and affects voltage stability margins assessed through NCPI calculations.

**C. Power Losses Assessment**

The power losses distribution across the network reveals that the system operates with relatively low losses. Total active losses of 0.067061 MW and reactive losses of 0.020118 MVAR represent only 0.2398% of total system power as shown in Figure 3. This low loss percentage reflects moderate loading conditions and appropriate conductor sizing in the test system.

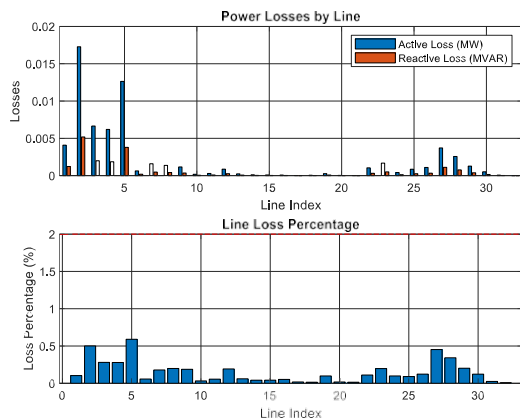


Figure 4 Active and reactive power losses distribution across the network

The spatial distribution of losses correlates strongly with power flow patterns, with highest absolute losses occurring in initial trunk sections (Lines 1-2, 2-3, and 3-4) due to high current magnitudes. No individual line exhibits losses exceeding 2% of its power flow, indicating efficient

power transmission characteristics that contribute to favorable voltage stability conditions.

**D. Novel Collapse Prediction Index Analysis and Harmonic Impact Assessment**

The NCPI analysis represents the core contribution of this research as shown in Figure 5, demonstrating measurable harmonic impacts on voltage stability assessment. Results show an average NCPI increase from 0.018960 (without THD) to 0.019073 (with THD), representing a modest but measurable 0.6746% average harmonic impact on voltage stability margins across the system.

All calculated NCPI values remain well below the critical threshold of 1.0, with maximum values not exceeding 0.08 even in most heavily loaded branches. This indicates that the IEEE 33-bus system operates with significant voltage stability margins under both normal and harmonic-distorted conditions. The low absolute NCPI values reflect conservative design and moderate loading of the test system, providing substantial safety margins against voltage collapse.

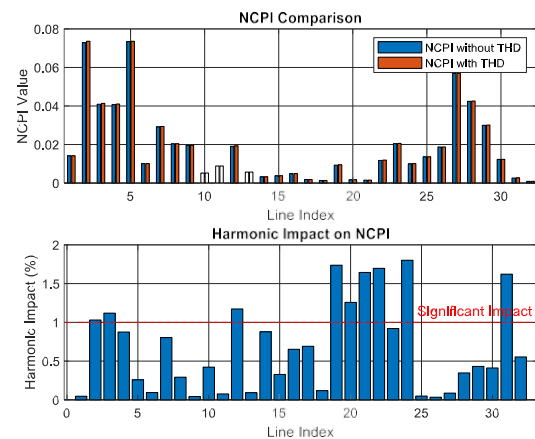


Figure 5. NCPI analysis and harmonic impact assessment on voltage stability

The analysis reveals that 9 out of 32 lines (28.1%) experience significant harmonic impact exceeding 1% threshold on their collapse prediction indices. These critical lines concentrate in main trunk sections (Lines 2-4) where high loading and harmonic content coincide, heavily loaded laterals (Lines 23-24, 26-28) experiencing moderate to high current distortion, and distal branches (Lines 19-22)

where combined voltage and current distortion effects become pronounced.

Strong correlations are established between harmonic distortion levels and NCPI impact on voltage stability. Lines with THDi > 15% consistently show harmonic impacts exceeding 1.5% on collapse prediction indices, THDv values above 3% correlate with measurable NCPI increases affecting stability margins, and combined effects of high THDi and THDv produce maximum impacts reaching 1.8% in lines 19-22.

**E. Comprehensive Power Quality Assessment**

The integrated power quality assessment confirms system-wide compliance with IEEE 519 standards while highlighting areas requiring attention (Figure 6). The THD statistics indicate moderate harmonic pollution requiring monitoring, with average values (2.71% THDv, 11.33% THDi) approaching regulatory considerations and maximum values near regulatory limits.

Voltage issues assessment reveals that approximately two-thirds of system buses experience voltage regulation issues, primarily undervoltage conditions. This widespread voltage depression correlates with reduced voltage stability margins and emphasizes the importance of harmonic-aware NCPI analysis for accurate collapse prediction.

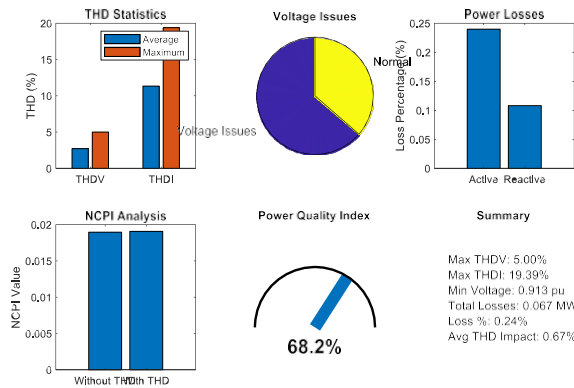


Figure 6. Comprehensive power quality and voltage stability assessment dashboard

The integrated Power Quality Index of 68.2% reflects acceptable but improvable system conditions, resulting from the combination of acceptable harmonic levels, significant voltage regulation challenges, excellent efficiency (low losses), and moderate NCPI impacts.

**v. Conclusion**

This research successfully developed and validated a comprehensive analytical framework for assessing voltage stability in radial distribution systems under harmonic distortion conditions through integration of harmonic effects into the Novel Collapse Prediction Index (NCPI) formulation. The proposed harmonic-aware NCPI represents a significant advancement by incorporating THDv and THDi correction factors into classical NCPI calculations. Analysis of the IEEE 33-bus test system reveals that harmonic distortion introduces measurable but manageable impacts on voltage stability assessment, with average harmonic impacts of 0.67% on NCPI values and maximum impacts reaching 1.8% in critical lines, demonstrating that while harmonic effects are typically modest, they become significant in heavily loaded branches with high distortion levels.

The research establishes important thresholds for harmonic-induced stability concerns where THDi > 15% and THDv > 3% consistently produce measurable impacts on collapse prediction accuracy, providing practical guidelines for power system operators to prioritize harmonic mitigation efforts based on stability considerations. Despite widespread voltage regulation challenges, the IEEE 33-bus system maintains adequate voltage stability margins with all NCPI values remaining well below critical thresholds, indicating well-designed infrastructure that benefits from the proposed enhanced stability assessment methodology. The integration of harmonic considerations into voltage stability assessment provides power system engineers with enhanced diagnostic capabilities for modern distribution networks, enabling more informed decision-making regarding harmonic mitigation investments that improve both power quality and voltage stability margins simultaneously.

**References**

[1] "Advanced Harmonic Assessment," in *Power System Harmonics*, 2003, pp. 351-389.  
 [2] "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems - Redline," *IEEE Std 519-2014 (Revision of IEEE Std 519-1992) - Redline*, pp. 1-213, 2014.

- [3] M. Chen, W. Hao, and D. Gan, "An improved decomposition-aggregation strategy for analyzing power systems stability," *International Journal of Electrical Power & Energy Systems*, vol. 168, p. 110728, 2025/07/01/ 2025, doi: <https://doi.org/10.1016/j.ijepes.2025.110728>.
- [4] W. Zhang, Y. Wang, M. Zeeshan, F. Han, and K. Song, "Super-twisting sliding mode control of grid-side inverters for wind power generation systems with parameter perturbation," *International Journal of Electrical Power & Energy Systems*, vol. 165, p. 110501, 2025/04/01/ 2025, doi: <https://doi.org/10.1016/j.ijepes.2025.110501>.
- [5] M. Moghavvemi and O. Faruque, "Real-time contingency evaluation and ranking technique," *IEE Proceedings-Generation, Transmission and Distribution*, vol. 145, no. 5, pp. 517-524, 1998.
- [6] J. C. Das, *Power system harmonics and passive filter designs*. John Wiley & Sons, 2015.
- [7] D. Kumar, R. Bhushan, and K. Chatterjee, "Improving the dynamic response of frequency and power in a wind integrated power system by optimal design of compensated superconducting magnetic energy storage," *International Journal of Green Energy*, vol. 15, no. 3, pp. 208-221, 2018.
- [8] H. Gao, R. Diao, Y. Zhong, R. Zeng, Q. Wu, and S. Jin, "Optimal allocation of distributed generation in active distribution power network considering HELM-based stability index," *International Journal of Electrical Power & Energy Systems*, vol. 155, p. 109508, 2024/01/01/ 2024, doi: <https://doi.org/10.1016/j.ijepes.2023.109508>.
- [9] J. C. Olives-Camps, Á. Rodríguez del Nozal, J. M. Mauricio, and J. M. Maza-Ortega, "A systemic and model-less approach for real-time optimal control of unbalanced AC microgrids dominated by power electronics," *International Journal of Electrical Power & Energy Systems*, vol. 165, p. 110443, 2025/04/01/ 2025, doi: <https://doi.org/10.1016/j.ijepes.2024.110443>.
- [10] J. C. Sarmiento-Vintimilla, D. Marene Larruskain, E. Torres, and O. Abarategi, "Assessment of the operational flexibility of virtual power plants to facilitate the integration of distributed energy resources and decision-making under uncertainty," *International Journal of Electrical Power & Energy Systems*, vol. 155, p. 109611, 2024/01/01/ 2024, doi: <https://doi.org/10.1016/j.ijepes.2023.109611>.
- [11] X.-y. Xiao, G.-s. Song, W.-X. Hu, and X.-y. Song, "Voltage sag assessment method considering low-voltage ride-through of inverter-interfaced distributed generators," *International Journal of Electrical Power & Energy Systems*, vol. 165, p. 110486, 2025/04/01/ 2025, doi: <https://doi.org/10.1016/j.ijepes.2025.110486>.
- [12] J. Caballero-Peña, C. Cadena-Zarate, A. Parrado-Duque, and G. Osma-Pinto, "Distributed energy resources on distribution networks: A systematic review of modelling, simulation, metrics, and impacts," *International Journal of Electrical Power & Energy Systems*, vol. 138, p. 107900, 2022/06/01/ 2022, doi: <https://doi.org/10.1016/j.ijepes.2021.107900>.
- [13] S. Li, Q. Xu, Y. Yang, Y. Xia, and K. Hua, "Study on distributed renewable energy generation aggregation application based on energy storage," *International Journal of Electrical Power & Energy Systems*, vol. 158, p. 109935, 2024/07/01/ 2024, doi: <https://doi.org/10.1016/j.ijepes.2024.109935>.
- [14] P. Megantoro, S. A. Halim, N. A. Mohamed Kamari, L. J. Awalim, R. Mohamed, and H. M. Rosli, "An enhanced multi-objective reactive power dispatch for hybrid Wind-Solar power system using Archimedes optimization algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 168, p. 110676, 2025/07/01/ 2025, doi: <https://doi.org/10.1016/j.ijepes.2025.110676>.
- [15] P. Gupta and Y. P. Verma, "Improving Voltage Stability Margins of Radial Distribution System Using DR Based P-Q Control," in *2022 22nd National Power Systems Conference (NPSC)*, 17-19 Dec. 2022 2022, pp. 749-754, doi: 10.1109/NPSC57038.2022.10069767.
- [16] A. K. Bharati and V. Ajjarapu, "Investigation of Relevant Distribution System Representation With DG for Voltage Stability Margin Assessment," *IEEE Transactions on Power Systems*, vol. 35, no. 3, pp. 2072-2081, 2020, doi: 10.1109/TPWRS.2019.2950132.
- [17] M. Gonda *et al.*, "Investigating the Effectiveness of a Voltage Stability Index for Analyzing the Impact of Contingencies Scenarios on an Electricity Transmission Network," in *2024 IEEE 22nd Student Conference on Research and Development (SCORED)*, 19-20 Dec. 2024 2024, pp. 394-399, doi: 10.1109/SCORED64708.2024.10872726.
- [18] S. Mokred, Y. Wang, and T. Chen, "A Novel Collapse Prediction Index for Voltage Stability Analysis and Contingency Ranking in Power Systems," *Protection and Control of Modern Power Systems*, vol. 8, no. 1, pp. 1-27, 2023, doi: 10.1186/s41601-023-00279-w.
- [19] "IEEE Draft Standard for Harmonic Control in Electric Power Systems," *IEEE P519/D5.1, January 2021*, pp. 1-30, 2021.
- [20] Q. Wang, W. Qin, X. Han, P. Wang, L. Wang, and Y. Zhang, "Robustness evaluation for harmonic suppression of LCL-type converter based on converter-side current feedback strategy under weak and distorted grid," *CPSS Transactions on Power Electronics and Applications*, vol. 6, no. 2, pp. 166-177, 2021, doi: 10.24295/CPSS/PEA.2021.00015.
- [21] L. Chen, Y. Jiang, X. Deng, S. Zheng, H. Chen, and M. Rabiul Islam, "A multi-period restoration approach for resilience increase of active distribution networks by considering fault rapid recovery and component repair," *International Journal of Electrical Power & Energy Systems*, vol. 161, p. 110181, 2024/10/01/ 2024, doi: <https://doi.org/10.1016/j.ijepes.2024.110181>.
- [22] N. Gnanam and R. Krishna, "A Sliding Mode Control Approach for Maximum Power Point Tracking and Efficiency Optimization of Photovoltaic Systems in Isolated Microgrids," in *2024 IEEE 1st International Conference on Green Industrial Electronics and Sustainable Technologies*

- (*GUEST*), 25-26 Oct. 2024 2024, pp. 1-6, doi: 10.1109/GUEST62955.2024.10959797.
- [23] N. Lin, S. Orfanoudakis, N. O. Cardenas, J. S. Giraldo, and P. P. Vergara, "PowerFlowNet: Power flow approximation using message passing Graph Neural Networks," *International Journal of Electrical Power & Energy Systems*, vol. 160, p. 110112, 2024/09/01/ 2024, doi: <https://doi.org/10.1016/j.ijepes.2024.110112>.
- [24] A. Lei, Y. Mei, H. Chen, Y. Chu, C. Jiang, and K. Shi, "Harmonic Power Flow Calculation Method Based on VSC AC/DC Harmonic Interaction Model," in *2024 21st International Conference on Harmonics and Quality of Power (ICHQP)*, 15-18 Oct. 2024 2024, pp. 368-373, doi: 10.1109/ICHQP61174.2024.10768818.
- [25] Y. Liu *et al.*, "Improved Multi-Point Estimate Probabilistic Harmonic Power Flow Algorithm Based On Dynamic Harmonic Model," in *2023 International Conference on Power System Technology (PowerCon)*, 21-22 Sept. 2023 2023, pp. 1-6, doi: 10.1109/PowerCon58120.2023.10331513.