v. 5, n. 2, 2025

Journal of
Engineering
Research

Acceptance date: 21/02/2025

ADVANCEMENTS AND CHALLENGES IN FAULT LOCATION TECHNIQUES FOR POWER DISTRIBUTION SYSTEMS: A COMPREHENSIVE REVIEW

Peterson de Oliveira Batista
UNESP – Universidade Estadual Paulista "Júlio de Mesquita Filho"
Campus São João da Boa Vista/SP/Brasil
http://lattes.cnpq.br/7029361569213411

Afonso José do Prado
UNESP – Universidade Estadual Paulista "Júlio de Mesquita Filho"
Campus São João da Boa Vista/SP/Brasil
http://lattes.cnpq.br/7870647855005820

André Alves Ferreira
UNESP – Universidade Estadual Paulista "Júlio de Mesquita Filho"
Campus São João da Boa Vista/SP/Brasil
http://lattes.cnpq.br/6088395314924945

Abstract: This paper reviews fault location methods in power distribution systems, highlighting impedance techniques, traveling wave methods, intelligent algorithms, and hybrid approaches. Impedance methods are simple and cost-effective but lack precision in complex networks. Traveling wave techniques provide high accuracy by analyzing high-frequency transients but require advanced infrastructure and are sensitive to noise. Intelligent algorithms, including neural networks and support vector machines, improve adaptability and accuracy, although they demand extensive datasets and can lack transparency. Hybrid systems combine traditional and intelligent approaches, leveraging their strengths but facing integration challenges. The study identifies critical gaps, such as improving accuracy under non-ideal conditions, optimizing data handling, and enhancing algorithm interpretability. Future research directions include developing algorithms with reduced data dependency and integrating multidisciplinary approaches to advance fault location precision and efficiency. These efforts aim to enhance the reliability and quality of power distribution networks, fostering continuous innovation in fault location practices worldwide.
Keywords: Power Distribution Systems, Fault Location, Intelligent Algorithms, Traveling Wave Methods, Impedance Techniques.

INTRODUCTION

Fault location in medium voltage distribution networks is important in the current energy scenario, especially due to the significant transformations that distribution systems are undergoing. With the increasing integration of renewable sources such as wind and solar power plants, distribution systems need to adapt to new loading profiles that are often variable and less predictable, as well as to power inverter control systems (Corporation, 2018; Lee, 2024). This change is driven by the global need to reduce dependence on fossil fuel sources and mitigate environmental impacts (Zidan et al, 2017).

In this context, regulatory standards, such as those established by the Brazilian National Electric Energy Agency - ANEEL (2022), have become more stringent, demanding high-quality standards in energy supply. This includes reducing the frequency and duration of interruptions, which are critical to ensuring service continuity and customer satisfaction. Accurate fault location is essential for rapidly restoring the electrical system, reducing downtime and increasing system reliability. These aspects are fundamental to improving energy quality indices, as highlighted by ANEEL (2022).

The earliest fault locators were developed based on apparent impedance calculation. Although they do not require high sampling rates and can be implemented using measurements from one or two terminals, these methods are highly susceptible to variables such as fault resistance and fault type (Das, Sachdev, and Sidhu, 1995). Moreover, the introduction of distributed generation, which significantly alters the dynamics of power flow in networks, further exacerbates these limitations.

With the advancement of power electronics and the development of devices capable of handling high sampling rates, fault location based on traveling wave theory has emerged as a promising solution to overcome the limitations of impedance-based methods. This approach exploits the propagation of electromagnetic waves in the voltage or current signals generated during the fault (Silva, Oleskovicz, and Coury, 2005). It stands out for providing a highly accurate estimate of fault location, regardless of variables such as fault resistance and fault type. However, despite its high accuracy, this method depends on the sampling rate, requiring devices with high sampling capacity at elevated frequencies.

In recent years, intelligent algorithms have emerged as powerful tools for fault location. These methods leverage artificial intelligence, machine learning, and data analytics to improve accuracy and adaptability. Intelligent algorithms, such as neural networks and support vector machines, can analyze vast amounts of data to identify patterns and accurately predict fault locations (Nasiri, Khosravani, and Weinberg, 2017). These techniques are particularly beneficial in scenarios with high uncertainty and variability, where traditional methods may struggle. However, they require extensive training data and computational resources, and their performance can be affected by the quality and quantity of input data.

Hybrid fault location techniques combine traditional and modern approaches to enhance accuracy and robustness in diverse operational conditions. These methods often integrate impedance-based calculations with intelligent algorithms or optimization techniques, leveraging their complementary strengths. For example, impedance-based methods provide a preliminary fault location estimate, which is then refined using artificial intelligence techniques such as neural networks or support vector machines (Liu et al., 2019). Additionally, optimization algorithms, such as genetic algorithms and particle swarm optimization, have been employed to fine-tune fault location estimations by minimizing error functions and adapting to different fault scenarios (Zhang, Zhang, and He, 2021). These hybrid approaches improve fault location accuracy while maintaining computational efficiency, making them highly suitable for modern power distribution systems.

EXISTING TECHNIQUES FOR FAULT LOCATION

Several fault location techniques have been developed to address the challenges in medium voltage distribution networks. These methods can be categorized as follows:

- *Impedance-Based Methods*: These well-established techniques estimate fault location by analyzing voltage and current phasors measured at different points in the network. They are widely used due to their simplicity and ease of implementation in traditional grid setups. However, their accuracy is influenced by network conditions and configurations (Das, Sachdev, and Sidhu, 1995).

- *Traveling Wave Techniques*: Recognized for their high precision, these methods analyze high-frequency transient signals generated by faults. By measuring the time of arrival of these waves at different points, traveling wave techniques can pinpoint fault locations with great accuracy. They are particularly effective in modern networks where rapid fault detection is essential (Silva, Oleskovicz, and Coury, 2005).

- *Intelligent Algorithms*: With advancements in artificial intelligence, machine learning techniques such as neural networks and support vector machines have been applied to fault location. These algorithms analyze large datasets to detect patterns, improving fault localization in complex and dynamic network environments. Their adaptability makes them particularly useful in modern power distribution systems (Nasiri, Khosravani, and Weinberg, 2017). Additionally, fuzzy logic-based techniques have been explored to handle uncertainties in fault diagnosis, offering robustness in scenarios with incomplete or imprecise data.

- *Hybrid Techniques*: To enhance fault location accuracy and robustness, hybrid methods integrate multiple approaches. A common strategy combines impedance-based estimations with intelligent algorithms or optimization techniques, refining the fault location process by leveraging the strengths of each method. For instance, fuzzy logic can be used alongside impedance-based methods to improve decision-making under uncertain conditions, while optimization algorithms such as genetic algorithms and particle swarm optimization can fine-tune fault location estimations (Liu et al., 2019; Zhang, Zhang, and He, 2021). These hybrid approaches offer a balance between computational efficiency and high accuracy, making them well-suited for modern power grids.

CONTRIBUTIONS

Based on the content of this work, the possible contributions of this study may include:

- Provides an in-depth review of fault location methods applied in distribution networks, covering impedance-based techniques, traveling wave methods, and intelligent algorithms. Recent advancements, key challenges, and existing gaps are thoroughly analyzed for each approach.

- Explores the use of artificial intelligence algorithms, such as machine learning, neural networks, and support vector machines, to improve fault location accuracy. Proposed solutions aim to address issues related to multiple fault estimations, optimizing the fault location process in complex and dynamic scenarios.

- Considering the increasing integration of renewable energy sources and the rising complexity of distribution networks, the study critically examines future challenges, such as data dependency, the need for advanced infrastructure, and the integration of hybrid methods.

The remainder of the paper is organized as follows. Section 2 provides a literature review, categorized by technique, of the methods developed for fault location in distribution systems. Section 3 presents the main gaps identified and future work proposals. Finally, Section 4 outlines the conclusions drawn from the study.

FAULT LOCATION METHODS IN DISTRIBUTION SYSTEMS

Fault location methods in distribution systems are essential for optimizing network reliability and efficiency. Traditional impedance-based approaches are limited by their sensitivity to network conditions, prompting the adoption of advanced techniques such as traveling wave analysis and machine learning algorithms, which enhance fault detection accuracy and system resilience in increasingly complex grid environments.

METHODS BASED ON APPARENT IMPEDANCE

Apparent impedance methods have long been fundamental in fault location within distribution systems. These techniques estimate the distance to a fault by calculating impedance from voltage and current phasors measured at specific network points. The core principle involves determining the impedance between the measurement site and the fault, which correlates with the distance in a uniform transmission line (Furqan et al., 2018).

Despite their widespread application, apparent impedance methods encounter several challenges. A significant limitation is their sensitivity to fault resistance, which can lead to substantial errors in estimating fault distance. Moreover, the increasing integration of distributed generation and the evolving dynamics of modern distribution networks further complicate impedance calculations, potentially reducing accuracy (Mukherjee and Ghoshal, 2021).

To address these challenges, recent advancements have been proposed. These include the development of adaptive impedance-based fault location algorithms tailored for active distribution networks, which adjust calculations based on real-time network conditions (Rahman et al., 2022). Additionally, extended formulations utilizing one-terminal measurements have been introduced to enhance fault location accuracy in both overhead and underground systems (Singh and Mohanty, 2020).

In summary, while apparent impedance methods remain integral to fault location strategies in distribution systems, ongoing research and technological innovations are crucial to overcoming their limitations and improving their effectiveness in today's complex grid environments.

- *Single-Terminal Methods*

Single-terminal methods involve measuring voltage and current phasors at only one end of the transmission or distribution line. The apparent impedance is calculated using these measurements, and the fault distance is estimated under the assumption of a uniform line impedance. These methods are widely used due to their simplicity and ease of implementation. However, they are significantly affected by fault resistance, load variations, and network asymmetries, which can introduce errors in the fault location process (Zhu et al., 2018). Recent advancements have focused on improving single-terminal fault location accuracy through enhanced signal processing techniques and machine learning-based corrections, allowing better adaptation to modern power networks (Gupta et al., 2021).

- *Two-Terminal Methods*

Two-terminal methods improve fault location accuracy by utilizing voltage and current measurements from both ends of the transmission or distribution line. By comparing the impedance calculated from each terminal, these methods can more precisely pinpoint the fault location through triangulation. This approach significantly reduces errors caused by load changes, network configuration variations, and fault resistance uncertainties (Bahmanyar and Sanaye-Pasand, 2019). Furthermore, recent research has explored two-terminal fault location techniques that function effectively even with unsynchronized phasor measurements, further increasing their practicality in real-world applications (Wang et al., 2022).

In summary, while single-terminal methods are easier to implement and require fewer infrastructure modifications, two-terminal methods offer enhanced accuracy and robustness, making them particularly valuable in modern, complex power system environments.

CHALLENGES AND LIMITATIONS

Despite their simplicity and ease of implementation, single-terminal methods face several inherent challenges that can compromise their accuracy in fault location:

- **Fault Resistance:** High-resistance faults distort the impedance seen from the measurement point, leading to incorrect fault distance estimates.
- **Load Variations:** Fluctuations in system load alter the voltage and current phasors, impacting the apparent impedance calculation.
- **Network Topology Complexity:** Asymmetrical or meshed network configurations introduce uncertainties that reduce fault location precision.
- **Presence of Distributed Generation:** The integration of distributed energy resources changes power flow characteristics, further complicating impedance-based fault detection.
- **Measurement Noise:** Transient disturbances and sensor inaccuracies introduce noise, affecting the accuracy of phasor measurements.

These factors collectively pose significant challenges to fault distance estimation, particularly in modern and highly dynamic power networks (Zidan et al., 2017).

ENHANCEMENTS AND APPLICATIONS

To address the limitations of single-terminal methods, several advancements have been explored:

- **Wavelet Transform-Based Techniques:** Recent research (Zhang et al., 2021) highlights the efficiency of wavelet transforms in analyzing transient signals, significantly improving the fault location process by isolating high-frequency disturbances associated with faults.
- **Machine Learning Algorithms:** Adaptive approaches using machine learning, as proposed by Kumar et al. (2023), dynamically adjust fault location estimations based on historical system conditions, effectively compensating for load variations and grid complexities.
- **Integration of PMUs:** The deployment of Phasor Measurement Units (PMUs) with synchronized measurements, as discussed by Singh and Verma (2022), provides enhanced network visibility and enables more accurate real-time fault detection.
- **Hybrid Impedance Techniques:** Combining impedance-based and traveling wave methods has been proposed by Chen et al. (2023) to mitigate the impact of fault resistance and measurement noise.

These advancements collectively improve the adaptability and accuracy of apparent impedance methods, ensuring their continued relevance for fault location strategies in modern power systems. Single-terminal measurement methods remain fundamental due to their simplicity and low implementation cost. However, ongoing research and technological progress are essential for overcoming their inherent limitations and enhancing their effectiveness in increasingly complex electrical networks.

METHODS BASED ON TRAVELING WAVE THEORY

Traveling wave theory has become a pivotal tool for fault location in power distribution systems, offering unmatched precision and rapid response capabilities. Unlike traditional methods relying on steady-state measurements, traveling wave techniques exploit high-frequency transient phenomena generated immediately after a fault event. These transient signals propagate along power lines at near-light speeds, providing valuable information for precise fault localization (Chen et al., 2023).

The primary advantage of traveling wave methods lies in their capacity to detect fault-induced transients before they are substantially distorted by network impedance and system dynamics. This makes the approach particularly effective in modern systems characterized by distributed generation and complex network topologies, where conventional methods often struggle to maintain accuracy (Zhang and Liu, 2022). By capturing the time of arrival of these traveling waves at multiple monitoring points, utilities can use time-difference triangulation to pinpoint fault locations with high accuracy.

A significant strength of these methods is their inherent robustness to variations in fault resistance and dynamic load conditions. These factors, which often compromise the effectiveness of impedance-based techniques, have minimal impact on the accuracy of traveling wave approaches (Kumar and Singh, 2023). This robustness is increasingly critical as renewable energy sources continue to proliferate, introducing greater variability into power networks.

CHALLENGES AND LIMITATIONS

Despite their benefits, traveling wave methods face certain implementation challenges:

- High-Speed Data Acquisition: Precise and rapid capture of transient signals requires advanced sensors and high-frequency data acquisition systems.
- Time Synchronization: Accurate time stamping of signals is critical and typically achieved through GPS synchronization, which adds complexity and cost.
- Signal Processing: The presence of noise and wave reflections from system components necessitates sophisticated digital filtering and analysis techniques.

Recent advancements, such as the integration of machine learning models and adaptive filtering, have shown promise in mitigating these challenges and improving the interpretability of transient signals (Patel et al., 2024).

ENHANCEMENTS ENHANCEMENTS

Digital signal processing innovations have significantly augmented the efficacy of traveling wave methods. Wavelet transforms, for instance, have proven effective in isolating high-frequency components associated with faults, even in noisy environments (Singh and Verma, 2023). Furthermore, the adoption of edge-computing frameworks allows faster on--site data processing, reducing latency in fault detection and enhancing real-time response capabilities (Wang et al., 2023).

Traveling wave methods have firmly established themselves as a vital component of fault location strategies in modern power systems. Their precision and adaptability make them indispensable for resilient and efficient network operations. With continuous advancements in signal processing and computing technologies, these techniques are expected to become even more integral to future power system diagnostics.

METHODS BASED ON INTELLIGENT ALGORITHMS

The use of intelligent algorithms for fault location in power distribution systems has gained significant attention due to the increasing complexity and dynamic behavior of modern electrical networks. These advanced computational approaches leverage artificial intelligence (AI), machine learning (ML), and other data-driven techniques to enhance fault detection and localization (Kumar et al., 2023).

Intelligent algorithms replicate human cognitive functions, enabling them to learn from data, recognize patterns, and make autonomous decisions. This adaptability is crucial for power systems, where traditional methods often struggle with variations in operating conditions, high integration of renewable energy sources, and dynamic network topologies (Patel and Singh, 2024). By analyzing vast amounts of historical and real-time data, intelligent algorithms can dynamically adjust to evolving system conditions, providing enhanced fault location accuracy and speed.

- **Machine Learning Techniques:**

  1. Support Vector Machines (SVM): SVMs have been extensively applied for fault classification and location, demonstrating robust performance in identifying fault types based on input data patterns (Zhao and Wang, 2023).

  2. Neural Networks (NNs): These models can generalize from historical fault data to predict fault locations accurately, even under varying system conditions.

- **Deep Learning:**

  Deep learning, a specialized form of ML, employs multi-layered neural networks capable of modeling complex, nonlinear relationships within the data. Its capability to handle large datasets has made it a powerful tool for modern power system diagnostics (Wang et al., 2023).

- **Fuzzy Logic Systems:**

  Fuzzy logic algorithms effectively manage uncertainties inherent in fault data by modeling imprecision, which is particularly useful for complex power system environments (Chen and Liu, 2022).

- **Hybrid Intelligent Systems:**

  Recent advancements suggest combining different intelligent methods, such as hybrid models integrating neural networks and fuzzy logic, to achieve superior fault location accuracy and resilience (Singh and Verma, 2023).

IMPLEMENTATION CHALLENGES

While intelligent algorithms offer numerous benefits, their implementation presents certain challenges:

1. Data Requirements: Large datasets are essential for training robust models, which may not always be readily available.

2. Computational Complexity: Advanced algorithms, particularly deep learning models, demand significant computational resources.

3. Generalization Issues: Ensuring that models generalize effectively to unseen system scenarios remains a persistent challenge.

EMERGING SOLUTIONS

The integration of edge computing and federated learning frameworks offers promising avenues for overcoming these challenges. By enabling distributed processing and collaborative model training, these technologies reduce latency and improve the adaptability of intelligent fault location systems (Patel et al., 2024). Intelligent algorithms represent a transformative approach to fault location in modern power distribution networks. Their adaptability, pattern recognition capabilities, and ability to handle uncertainty make them essential tools for efficient and accurate fault detection. As computational technologies continue to advance, the role of intelligent algorithms in power system diagnostics will become even more pronounced.

MAIN GAPS AND FUTURE PROPOSALS

Significant progress has been made in fault location methods for power distribution systems, particularly with advancements in traveling wave techniques and intelligent algorithms. Despite these achievements, several challenges continue to limit the full potential of these methods. Addressing these issues is essential for developing more accurate, reliable, and adaptive fault location systems.

GAPS IN TRAVELING WAVE METHODS

The apparent impedance method remains one of the most widely used techniques for fault location due to its simplicity and cost-effectiveness. However, several limitations hinder its effectiveness, particularly in modern and complex power systems:

- **Impact of Fault Resistance:** High-resistance faults cause significant deviations in the apparent impedance calculation, leading to inaccurate fault distance estimations. This is particularly problematic for distribution systems with overhead lines or complex grounding conditions.
- **Load Variations:** Changes in load conditions during fault events can distort voltage and current phasors, compromising the accuracy of impedance measurements and fault location.
- **Distributed Generation (DG) Integration:** The growing presence of renewable energy sources introduces bidirectional power flows and changes the system's impedance characteristics, complicating fault localization.

- **Complex Network Topologies:** Asymmetrical and meshed network configurations create additional challenges by introducing multiple potential fault paths, making impedance-based methods less reliable.
- **Measurement Noise and Disturbances:** The presence of transient noise and disturbances in power systems affects the accuracy of voltage and current phasor measurements, impacting fault detection and location.
- **Dynamic System Conditions:** Fluctuations caused by temporary faults, switching operations, or protective device actions can lead to incorrect or unstable fault location results.
- **Single-Terminal Dependency:** Traditional impedance methods typically rely on measurements from a single terminal, limiting their effectiveness in accurately pinpointing fault locations in complex systems.

GAPS IN TRAVELING WAVE METHODS

Traveling wave methods are known for their high accuracy in fault location. However, they present key limitations:

- **High-Speed Data Acquisition:** The requirement for ultra-fast sampling rates to capture fault-induced transients demands sophisticated and expensive data acquisition systems.
- **Time Synchronization:** Achieving precise time synchronization, often dependent on GPS-based technologies, introduces complexity and increases operational costs.
- **Signal Distortion and Noise:** Network noise, reflections from discontinuities, and electromagnetic interference can obscure critical transient signals, reducing detection accuracy.
- **Complex Topologies:** Modern networks with multiple branches and distributed generation complicate the interpretation of traveling wave signals, increasing computational complexity and reducing precision.

GAPS IN INTELLIGENT ALGORITHM-BASED METHODS

Intelligent algorithms offer adaptability and powerful learning capabilities, yet they face several barriers:

- **Data Dependency:** Effective training requires extensive, high-quality datasets representing diverse fault scenarios, which may not be readily available.
- **Computational Complexity:** Algorithms like deep learning are resource-intensive, limiting their real-time application in fault detection systems.
- **Interpretability Issues:** The black-box nature of some models hinders transparency, making it challenging for operators to trust and understand the decision-making process.
- **Generalization Challenges:** Models trained on specific network configurations may perform poorly when applied to unseen or evolving grid conditions.

GAPS IN HYBRID SYSTEMS

Hybrid approaches aim to combine the strengths of traditional and modern techniques, but they are not without challenges:

- **Integration Complexity:** Seamless communication between diverse systems and methods can be difficult to achieve, leading to interoperability issues.
- **Optimization:** Balancing the contributions of different components in hybrid models to maximize accuracy and efficiency is a persistent problem.

- **Dynamic Adaptation:** Ensuring these systems remain adaptable to network changes while maintaining performance is a major challenge.

FUTURE PROPOSALS

To overcome these gaps, the following research directions are proposed:

- **Efficient Algorithms:** Develop lightweight, computationally efficient algorithms that require fewer data inputs, making them more suitable for real-time applications.
- **Data Acquisition Improvements:** Invest in advanced sensors and data acquisition technologies that capture high-quality data with lower latency and reduced noise.
- **Interpretability Enhancements:** Employ explainable AI (XAI) techniques to increase the transparency and trustworthiness of intelligent models.
- **Hybrid Integration Protocols:** Develop standardized communication protocols to facilitate seamless interaction between traditional and modern methods, improving system reliability.
- **Distributed and Edge Computing:** Implement edge-based processing to reduce latency and computational demands, enhancing the scalability of intelligent fault location systems.

Addressing these gaps, future solutions can provide more resilient, adaptable, and accurate fault location systems capable of meeting the demands of modern power distribution networks.

CONCLUSIONS

This study explores the intricate landscape of fault location methods in power distribution systems, emphasizing the strengths and limitations of impedance methods, traveling wave techniques, intelligent algorithms, and hybrid systems. Impedance methods are prized for their simplicity and cost-effectiveness but struggle with accuracy in complex networks due to impedance variations. In contrast, traveling wave methods provide high precision by analyzing high-frequency transients, though they require advanced infrastructure for time synchronization and are vulnerable to noise and signal reflections. The adoption of intelligent algorithms, such as artificial neural networks and support vector machines, has introduced adaptability and improved accuracy, especially in complex and dynamic environments. However, these techniques necessitate large, high-quality datasets for effective training and may present transparency issues due to their black-box nature. Hybrid techniques, which integrate traditional and intelligent methods, demonstrate potential by combining the strengths of each approach, yet they face challenges in integration and communication across diverse technologies. To address these limitations, future research should focus on developing more efficient algorithms with reduced data dependency, enhancing data acquisition and sensor technologies, improving algorithm interpretability, and establishing standardized protocols for hybrid system integration. Ultimately, a multidisciplinary and integrated approach is essential for overcoming the challenges of fault location in distribution systems, ensuring enhanced precision, efficiency, robustness, and adaptability in power systems. This study lays a solid groundwork for further research, contributing to the ongoing evolution of fault location practices and the enhancement of power supply quality and reliability.

REFERENCES

Al-Shaher, M. A., Sabry, M. M., & Saleh, A. S. (2003). "Fault location in multi-ring distribution networks using artificial neural networks." IEEE Transactions on Power Delivery, 18(3), 887-893.

Aparicio, M. J., Grijalva, S., & Reno, M. J. (2021). "Fast fault location method for a distribution system with high penetration of PV." IEEE Power & Energy Society General Meeting, 3205-3213.

Araújo, A. E. D. (2022). Cálculos de transitórios eletromagnéticos em sistemas de energia. São Paulo: Editora USP.

Bahmanyar, A., & Sanaye-Pasand, M. (2019). "Accurate fault location in transmission lines using two-terminal synchronized data and wavelet transform." Electric Power Systems Research, 169, 285-295.

Bewley, L. V. (1931). "Traveling waves on transmission systems." Transactions of the American Institute of Electrical Engineers, 50(2), 532-550.

Bhide, S. (2014). Digital Power System Protection. New Delhi: PHI Learning.

Chen, L., Zhang, T., & Li, P. (2023). "Advanced methods for traveling wave fault location in renewable-integrated grids." Power Systems Research Journal, 27(3), 125-135.

Chen, L., Zhang, X., & Li, P. (2023). "Hybrid fault location techniques for modern power systems: A comprehensive review and new insights." Electrical Power and Systems Research, 205, 113827.

Correa-Tapasco, E., Mora-Flórez, J., & Perez-Londoño, S. (2019). "Performance analysis of a learning structured fault locator for distribution systems in the case of polluted inputs." Electric Power Systems Research, 166, 1-8.

Das, M., Sachdev, M. S., & Sidhu, T. S. (1995). "Impedance-based fault location techniques for power distribution systems." IEEE Transactions on Power Delivery, 10(2), 546-553.

Daubechies, I. (1992). Ten Lectures on Wavelets. Philadelphia: Society for Industrial and Applied Mathematics.

Furqan, M., Iqbal, A., Ullah, M., & Amin, M. (2018). "Impedance-based fault location techniques in modern distribution networks." Applied Sciences, 8(9), 1563.

Girgis, A. A., Lubkeman, D. L., & Fallon, C. M. (1993). "A fault location technique for rural distribution feeders." IEEE Transactions on Industry Applications, 29(6), 1171-1177.

Gupta, A., Kumar, V., & Sharma, R. (2021). "Machine learning-assisted fault location in power distribution networks using single-terminal measurements." IEEE Access, 9, 13456-13467.

Jia, H., et al. (2018). "A novel fault location method for distribution networks with distributed generation." IEEE Transactions on Smart Grid, 9(2), 1347-1356.

Kumar, R., & Singh, P. (2023). "Resilient fault detection techniques for smart grids using traveling wave theory." Energy Systems Analytics, 18(2), 67-79.

Kumar, S., Gupta, R., & Yadav, D. (2023). "Machine learning-based adaptive fault location schemes in smart grids." Energy Systems and Data Analytics Journal, 15(4), 293-312.

Liu, Z., Wang, P., Xu, T., & Zhang, W. (2019). "Hybrid fault location method based on intelligent algorithms and traditional techniques." Electric Power Systems Research, 171, 129-138.

Magnago, F. H., & Abur, A. (1999). "Fault location using wavelets." IEEE Transactions on Power Delivery, 14(4), 1475-1480.

Mora-Flórez, J., Morales-España, G., & Vargas-Torres, H. (2009). "Elimination of multiple estimation for fault location in radial power systems by using fundamental single-end measurements." IEEE Transactions on Power Delivery, 24(2), 508-516.

Moshtagh, J., & Rafinia, A. (2012). "A new approach to high impedance fault location in three-phase underground distribution system using combination of fuzzy logic and wavelet analysis." 11th International Conference on Environment and Electrical Engineering, 90-97.

Mukherjee, A., & Ghoshal, A. (2021). "Impact of distributed generation on impedance-based fault location methods." International Journal of Electrical Power & Energy Systems, 131, 107070.

Patel, M., Gupta, N., & Sharma, V. (2024). "Machine learning applications in transient fault analysis for power networks." IEEE Transactions on Power Systems, 39(1), 55-70.

Rahman, M., Khan, S., & Hussain, S. (2022). "Adaptive impedance-based fault location in active distribution networks." IEEE Transactions on Smart Grid, 13(4), 2874-2883.

Singh, H., & Verma, K. (2023). "Wavelet transform-based signal processing for enhanced fault location accuracy." Electrical Networks Journal, 14(4), 301-315.

Singh, R., & Mohanty, S. (2020). "Enhanced fault location using one-terminal impedance-based techniques for overhead and underground distribution networks." Electric Power Systems Research, 189, 106833.

Singh, R., & Verma, K. (2022). "Integration of synchronized PMU data for real-time fault location in power systems." Journal of Energy Networks and Control Systems, 18(1), 122-135.

Thomas, P., Carvalho, R. N., & Pereira, J. L. R. (2003). "Two-terminal methods for accurate fault detection." Power Transmission Research Reports, 25, 789-803.

Wang, X., Li, J., & Zhang, P. (2022). "A robust two-terminal fault location method based on unsynchronized phasor measurements." IEEE Transactions on Power Delivery, 37(4), 3100-3112.

Wang, Y., Zhao, J., & Liu, X. (2023). "Edge computing for real-time fault detection in power systems." International Journal of Smart Grid Technologies, 12(3), 213-229.

Zhang, T., Wang, Y., & Liu, H. (2021). "Wavelet-based fault analysis for improved transient detection in power systems." International Journal of Smart Grids, 9(5), 45-59.

Zhang, T., & Liu, X. (2022). "Fault location in distributed generation networks using traveling wave techniques." Power Distribution Advances, 16(2), 89-97.

Zhang, Y., Zhang, X., & He, Z. (2021). "Optimization-based hybrid fault location for active distribution networks." IEEE Transactions on Smart Grid, 12(4), 2874-2883.

Zhao, Y., Qi, J., & Jia, H. (2011). "A traveling wave based fault location method for distribution systems." IEEE Transactions on Power Delivery, 26(2), 572-580.

Zhu, J., Wang, Y., & Liu, Z. (2018). "An improved single-terminal fault location method for distribution networks considering fault resistance effects." Energies, 11(8), 2066.