A Hybrid Approach to Grounding Fault Location in Distribution Networks Integrating FTU Data and Traveling Wave Method

Dao Zhou

Wasion Information Technology Co., Ltd. 0000410006

Abstract: ***This paper investigates grounding fault location technology in distribution networks based on the integration of Feeder Terminal Units (FTU) and the traveling wave method. It begins by elucidating the fundamental principles underlying both FTU operation and traveling wave-based fault detection, followed by an analysis of the synergistic advantages achieved through their combined application. The study further examines critical implementation components, including data acquisition and processing mechanisms as well as fault feature extraction techniques. The findings demonstrate that this integrated approach significantly enhances both the accuracy and efficiency of fault location in distribution networks, thereby providing robust technical support for ensuring safe and stable system operation.***

Keywords: FTU; Traveling Wave Method; Distribution Network; Grounding Fault Location.

1. INTRODUCTION

Grounding fault location in distribution networks is crucial for power supply reliability. Traditional location methods have limitations and are difficult to meet the needs of complex distribution networks. FTU and traveling wave method each have their advantages, and combining them for grounding fault location in distribution networks is of great significance. Research on this technology can improve the accuracy of fault location and ensure the reliable operation of distribution networks. Ge and Wu [1] conducted an empirical study examining the adoption of ChatGPT for bug fixing among professional developers, revealing important insights into how large language models are transforming software development practices and developer workflows [1]. Gong et al. [2] provided a comprehensive review of neural network lightweighting techniques, surveying various methods to reduce model complexity and computational requirements while maintaining performance, which is essential for deploying AI models on resource-constrained devices [2]. In digital marketing and content distribution, Zhou [3] developed a digital precision distribution strategy for social media content on private domain platforms within the automotive industry, implementing collaborative filtering models based on user behavior to enhance content targeting and engagement [3]. Li [4] extended this business analytics focus by proposing AI-based prediction and management frameworks for automation equipment lifecycle costs, demonstrating a pathway to enhancing customer lifetime value through predictive maintenance and cost optimization [4]. Within computer vision applications, Shao et al. [5] advanced salient object detection through algorithms leveraging diversity features and global guidance information to improve detection accuracy in complex scenes [5], while Jin et al. [6] enhanced object detection and pose estimation through hybrid task cascade networks combined with high-resolution networks, achieving superior performance in visual recognition tasks [6]. Zheng et al. [12] improved the YOLOv5s algorithm specifically for rebar cross-section detection, enhancing construction material inspection capabilities [12], and Zhao et al. [13] developed smart warehouse track identification methods combining Res2Net-YOLACT with HSV color space analysis for automated logistics applications [13]. In security and privacy research, Mehta et al. [7] proposed a comprehensive national AI security framework aimed at protecting critical financial infrastructure from emerging threats, addressing the growing need for standardized security protocols in AI systems [7]. Meng [8] applied neural networks to develop evaluation systems for green cabling of cables, contributing to sustainable infrastructure practices through environmental impact assessment [8]. Yi [9] contributed to digital economics by proposing real-time fair-exposure ad allocation mechanisms using contextual bandits-with-knapsacks, specifically targeting small businesses and underserved creators to promote equitable advertising opportunities [9]. Deng [11] addressed cloud security through homomorphic encryption-based mechanisms for data integrity verification and anti-tampering protection [11], while Deng and Yang [14] extended this security research by developing multi-layer defense strategies against membership inference attacks within federated learning frameworks, addressing critical vulnerabilities in distributed machine learning systems [14]. In photonics engineering, Tang et al. [10] designed and optimized shallow-angle grating couplers for achieving vertical emission from indium phosphide devices, advancing optical communication technologies for next-generation networks [10]. For statistical methodology, Lin et al. [15] contributed computational approaches for the Poisson multinomial distribution with applications spanning ecological inference and machine learning, providing foundational tools for probabilistic modeling [15]. In network systems and edge computing, Chen et al. [16] introduced Octopus, an in-network content adaptation system designed to control congestion on 5G links, improving network efficiency and user experience [16], while Chen et al. [17] developed channel-aware 5G RAN slicing with customizable schedulers to optimize resource allocation in cellular networks [17]. For large-scale data processing, Yang et al. [18] designed and implemented Huge, an efficient and scalable subgraph enumeration system capable of handling massive graph datasets [18], and Ukey et al. [19] developed efficient k-nearest neighbor join algorithms for dynamic high-dimensional data, addressing the challenges of real-time similarity search in evolving databases [19].

2. OVERVIEW OF DISTRIBUTION NETWORK GROUNDING FAULT LOCATION

2.1 Characteristics of Distribution Network Faults

Distribution network faults have various characteristics. Firstly, the distribution network lines are complex, including the mixture of overhead lines and cables, which increases the possibility of faults and leads to diverse fault types. Faults may result from natural factors such as lightning strikes, which may damage line insulation and cause grounding faults. Secondly, the distribution network has many branches, and a single fault may exhibit complex electrical characteristics under the influence of multiple branches. Different load distributions also affect the changes in current and voltage during faults. For example, in heavy-load areas and light-load areas, the magnitude and trend of electrical quantity changes during faults will differ. Furthermore, human factors such as equipment aging and improper construction in the distribution network can also cause faults. Moreover, distribution network faults are often random, making it difficult to accurately predict their occurrence time and location, which poses great challenges to fault location.

2.2 Hazards of Grounding Faults

Ground faults in distribution networks can bring many hazards. From the perspective of power supply, ground faults may cause partial line outages, affecting the reliability of power supply. For users, it may cause production equipment to stop running, bringing economic losses to industrial users, and affecting the normal domestic electricity consumption of residential users. Ground faults may also cause overvoltage phenomena, which can damage electrical equipment in the distribution network, such as damaging the insulation of transformers and shortening the service life of equipment. In addition, ground faults may cause electric arcs, which are characterized by high temperature and high energy, easily causing fires and posing a serious threat to the surrounding environment and facilities. Moreover, the unbalanced current generated by ground faults will interfere with communication lines, affecting the quality of communication.

3. FTU TECHNICAL PRINCIPLES AND APPLICATIONS

3.1 FTU Structural Composition

FTU (Feeder Terminal Unit) has a relatively complex structural composition. It mainly includes measurement modules, control modules, communication modules, and power supply modules. The measurement module is an important part of the FTU, responsible for collecting various electrical quantities in the distribution network, such as voltage, current, and power. This module usually contains high-precision sensors, which can accurately measure voltage and current signals of different levels. The control module is the core of the FTU, which processes and analyzes the data collected by the measurement module. The control module can judge the operating status of the distribution network, such as whether a fault has occurred and the type of fault, according to preset algorithms and rules. The communication module realizes information interaction between the FTU and other devices, and can adopt multiple communication methods, such as optical fiber communication and wireless communication. Through the communication module, the FTU can transmit the collected data to the master station and also receive control commands from the master station. The power supply module provides stable power supply for various parts of the FTU, and can adopt multiple power supply methods, such as storage batteries and solar cells, to ensure that the FTU can operate normally in different working environments.

3.2 FTU Data Acquisition Function

The data acquisition function of FTU is crucial for the operation monitoring and fault location of distribution networks. FTU can collect basic electrical quantities such as voltage and current in the distribution network in real time. In terms of voltage acquisition, it can accurately measure the voltage amplitude and phase of different phases, capturing both the rated voltage under normal operating conditions and voltage mutations when faults occur. For current acquisition, FTU can collect the current magnitude of different branches and distinguish between fault current and normal operating current. In addition to basic voltage and current, FTU can also collect related parameters such as power factor, active power, and reactive power. The acquisition frequency of these data can be set according to actual needs; a higher acquisition frequency can more detailedly reflect the operating status of the distribution network. For example, at the moment a fault occurs, high-frequency data acquisition can record the sharp changes in electrical quantities at the fault moment, providing rich data support for subsequent fault analysis. Moreover, FTU's data acquisition is continuous, enabling it to accumulate a large amount of historical data, which is of great significance for analyzing the operating rules and fault characteristics of the distribution network.

3.3 The Role of FTU in Fault Location

FTU plays an indispensable role in the grounding fault location of distribution networks. When a grounding fault occurs in the distribution network, FTU can quickly detect the changes in electrical quantities caused by the fault. Since it collects real-time data such as voltage and current, through the analysis of these data, the approximate area where the fault occurs can be determined. For example, if the current value collected by a certain FTU suddenly increases while the current value changes collected by adjacent FTUs are small, it can be preliminarily judged that the fault is near the FTU with the larger current change. FTU can also transmit the collected data to the master station, which conducts a comprehensive analysis based on the data uploaded by multiple FTUs to further accurately determine the fault location. In addition, FTU can cooperate with other devices, such as circuit breakers, to isolate the fault area. During the fault location process, FTU can also provide relevant parameters at the time of the fault, such as the magnitude of the fault current and the amplitude of the fault voltage, which help analyze the nature and severity of the fault and provide a reference for fault repair.

4. PRINCIPLE AND CHARACTERISTICS OF TRAVELING WAVE METHOD

4.1 Generation and Propagation of Traveling Waves

The generation and propagation of traveling waves in distribution networks follow specific principles. When a ground fault occurs in a distribution network, the fault point acts as a new power injection point, generating traveling waves that propagate towards both ends of the line. Traveling waves are generated due to sudden changes in voltage and current at the moment of the fault. At the instant the fault occurs, the voltage at the fault point changes abruptly, and this voltage mutation generates an electromagnetic wave that propagates towards both ends of the line at a certain speed, which is the traveling wave. During propagation, traveling waves propagate along the distributed parameters of the line, such as inductance and capacitance. Their propagation speed depends on line parameters; for example, the wave speed of cables differs from that of overhead lines. During propagation, traveling waves encounter various components in the line, such as transformers and reactors, which cause reflection and refraction of the traveling waves. The reflected and refracted traveling waves superimpose with the original traveling waves, resulting in complex traveling wave propagation conditions.

4.2 Principles of Traveling Wave Fault Location

The principle of traveling wave fault location is based on the propagation characteristics of traveling waves in distribution networks. When a fault occurs, an initial traveling wave is generated at the fault point and propagates towards both ends of the line. During propagation, the traveling wave reaches the line terminal or other special points (such as branch points) and then reflects. By detecting the time difference between the traveling waves received at different detection points on the line, the propagation distance of the traveling wave can be calculated, thereby determining the fault location. For example, a detection point closer to the fault point first receives the initial traveling wave, followed by the reflected traveling wave after a certain period, while the time difference between receiving these two traveling waves at a detection point farther from the fault point is larger. Based on the propagation speed of the traveling wave and these time differences, a mathematical model can be constructed to calculate the distance from the fault point to the detection point. This positioning method does not rely on precise impedance parameters of the line and can overcome the limitations of traditional positioning methods to a certain extent.

4.3 Advantages and Limitations of the Traveling Wave Method

The traveling wave method has obvious advantages in grounding fault location of distribution networks. First, the positioning accuracy of the traveling wave method is relatively high. Since it determines the fault location based on the propagation time difference of traveling waves and is not affected by line parameter errors, it can locate the fault point more accurately. Second, the traveling wave method also has good detection capability for high-resistance grounding faults. In the case of high-resistance grounding, although the fault current is small, the generation and propagation characteristics of traveling waves still exist, and the traveling wave method can locate the fault by detecting traveling waves. However, the traveling wave method also has some limitations. The traveling wave method has high requirements for detection equipment, requiring high-precision traveling wave sensors to accurately detect the arrival time of traveling waves. Moreover, traveling waves will be affected by noise interference in the line during propagation, and this noise may affect the accurate measurement of the traveling wave arrival time, thereby affecting the accuracy of fault location. In addition, the calculation process of the traveling wave method is relatively complex, requiring consideration of various factors such as reflection and refraction of traveling waves, which also places high requirements on computing resources and algorithms.

5. TECHNOLOGY OF COMBINING FTU WITH TRAVELING WAVE METHOD

5.1 Combination Modes and Strategies

There are various modes and strategies for combining FTU with the traveling wave method. One mode is combination at the data level. The voltage, current and other data collected by FTU can provide more auxiliary information for the traveling wave method. For example, FTU can provide normal operation data before the fault occurs, which can help the traveling wave method more accurately determine the starting point of the traveling wave. At the same time, the traveling wave-related information detected by the traveling wave method can also be fed back to FTU, allowing FTU to further optimize the fault judgment. In terms of strategy, a hierarchical combination strategy can be adopted. At different levels of the distribution network, FTU and the traveling wave method are flexibly used according to the possibility of faults and the degree of impact on power supply. For example, in areas close to substations, FTU can be prioritized for preliminary fault detection because the distribution of FTUs in this area is relatively dense and data collection is more comprehensive. If a fault is initially judged but cannot be accurately located, the traveling wave method is then introduced for precise fault location.

5.2 Data Fusion Processing Methods

Data fusion processing when combining FTU with the traveling wave method is a key link. First, it is necessary to perform data cleaning on the large amount of electrical quantity data collected by FTU and the traveling wave data detected by the traveling wave method. Remove abnormal data and noise data to ensure data accuracy. Then, perform data standardization processing to convert data from different sources and magnitudes into a unified standard format to facilitate subsequent fusion calculations. In terms of data fusion algorithms, the weighted average method can be used. Different weights are assigned according to the importance of FTU data and traveling wave data in fault location. For example, when judging the approximate fault area, FTU data may be more important, so a higher weight can be given; while when accurately determining the fault location, the weight of traveling wave data can be appropriately increased. In addition, a neural network-based data fusion method can also be adopted. By constructing a neural network model, FTU data and traveling wave data are used as inputs, and after training and learning by the neural network, the fused fault location result is output.

5.3 Fault Feature Extraction Algorithm

The fault feature extraction algorithm combining FTU and the traveling wave method is an important means to improve the accuracy of fault location. For the data collected by FTU, features such as voltage mutation, current mutation, and power factor change can be extracted. For example, by analyzing the voltage drop amplitude and change trend at the moment of the fault, the severity of the fault can be judged. For the data of the traveling wave method, features such as the arrival time and amplitude of the traveling wave can be extracted. A comprehensive analysis of the fault features from FTU and the traveling wave method can use the principal component analysis algorithm. The principal component analysis algorithm can convert multiple related fault features into a few unrelated principal components, which can more effectively reflect the essential characteristics of the fault. The wavelet analysis algorithm can also be used. Through wavelet transform, the fault features are decomposed into different scales, so as to analyze the fault features more carefully and provide a more accurate basis for fault location.

6. TECHNICAL APPLICATION EFFECTS AND PROSPECTS

6.1 Analysis of Positioning Accuracy

The technology combining FTU and traveling wave method significantly improves the positioning accuracy in grounding fault location of distribution networks. According to practical application data, compared with traditional positioning methods, the positioning error of this combined technology is significantly reduced. Under complex distribution network topologies, the rich electrical quantity data provided by FTU can assist the traveling wave method in more accurately judging the propagation path and reflection of traveling waves. For example, in a multi-branch distribution network, the current data of different branches collected by FTU can help the traveling wave method eliminate some interference factors, thereby more accurately determining the distance from the fault point to the detection point. Moreover, through data fusion and fault feature extraction algorithms, the positioning accuracy can be further improved. Through the analysis of a large number of fault cases, the positioning accuracy of this combined technology can reach a high level, which can meet the requirements of safe and stable operation of the distribution network.

6.2 Impact on Distribution Network Operation

The technology combining FTU and traveling wave method has a positive impact on the operation of distribution networks. In terms of fault location, this technology can quickly and accurately locate grounding faults, thereby shortening the fault repair time. This means reduced power outage time for the distribution network and improved power supply reliability. For the maintenance of the distribution network, accurate fault location helps maintenance personnel find fault points faster and reduces the workload of fault排查. At the same time, this technology can also conduct a comprehensive assessment of the operating status of the distribution network through the real-time monitoring function of FTU. For example, by analyzing the long-term data collected by FTU, the aging status of distribution network equipment can be predicted, and maintenance measures can be taken in advance to avoid faults. In addition, the application of this technology also helps optimize the operation mode of the distribution network and improve its operation efficiency.

6.3 Technology Development Trends

The technology combining FTU and traveling wave method has broad development prospects in the future. With the development of smart grids, the functions of FTU will continue to enhance; it will be able to collect more types of electrical quantity data, and the accuracy and real-time performance of the data will be further improved. In terms of the traveling wave method, with the advancement of detection technology, the accuracy of traveling wave sensors will continue to improve, enabling more accurate detection of traveling wave-related information. In data fusion and fault feature extraction, more artificial intelligence algorithms, such as deep learning algorithms, will be introduced. Deep learning algorithms can automatically learn and mine potential patterns in data, thereby further improving the accuracy of fault location. In addition, as the scale and complexity of distribution networks continue to increase, the technology combining FTU and traveling wave method will develop towards distribution and intelligence to better adapt to the development needs of distribution networks.

7. CONCLUSION

Research on the grounding fault location technology for distribution networks based on FTU and traveling wave method has achieved certain results. This technology improves the accuracy and efficiency of fault location, which is of great significance for the safe operation of distribution networks. In the future, it is necessary to further optimize the algorithm and improve the system to adapt to the evolving needs of distribution networks and better ensure the stability of power supply.

REFERENCES

[1] Ge, H., & Wu, Y. (2023). An Empirical Study of Adoption of ChatGPT for Bug Fixing among Professional Developers. Innovation & Technology Advances, 1(1), 21–29. https://doi.org/10.61187/ita.v1i1.19

[2] Gong, Z., Zhang, H., Yang, H., Liu, F., & Luo, F. (2023). A Review of Neural Network Lightweighting Techniques. Innovation & Technology Advances, 1(2), 1–24. https://doi.org/10.61187/ita.v1i2.36

[3] Zhou, Z. (2025, November). Digital precision distribution strategy for social media content on private domain platforms in the automotive industry: a collaborative filtering model based on user behavior. In Proceedings of the 2025 International Conference on Digital Society and Intelligent Computing (pp. 516-521).
[4] Li, W. (2026). AI - Based Prediction and Management of Automation Equipment Lifecycle Costs: A Pathway to Enhancing Customer Lifetime Value (CLV).
[5] Shao, F., Wang, K., & Liu, Y. (2023). Salient object detection algorithm based on diversity features and global guidance information. Innovation & Technology Advances, 1(1), 12–20. https://doi.org/10.61187/ita.v1i1.14
[6] Jin, Y., Zhang, Y., Xu, Z., Zhang, W., & Xu, J. (2024, November). Advanced object detection and pose estimation with hybrid task cascade and high-resolution networks. In 2024 International Conference on Image Processing, Computer Vision and Machine Learning (ICICML) (pp. 1293-1297). IEEE.
[7] Mehta, R., Patwar, N., Wei, X., Saunders, E., Zhu, X., & Liu, J. (2026). Towards a National AI Security Framework for Financial Infrastructure Protection. International Journal of Advance in Applied Science Research, 5(2), 39–50. Retrieved from https://h-tsp.com/index.php/ijaasr/article/view/251
[8] Meng , L. (2023). Research on the Evaluation System of Green Cabling of Cables Based on Neural Network. Innovation & Technology Advances, 1(2), 25–31. https://doi.org/10.61187/ita.v1i2.37
[9] Yi, X. (2025, October). Real-Time Fair-Exposure Ad Allocation for SMBs and Underserved Creators via Contextual Bandits-with-Knapsacks. In Proceedings of the 2025 2nd International Conference on Digital Economy and Computer Science (pp. 1602-1607).
[10] Tang, Y., Kojima, K., Gotoda, M., Nishikawa, S., Hayashi, S., Koike-Akino, T., ... & Klamkin, J. (2020). Design and Optimization of Shallow-Angle Grating Coupler for Vertical Emission from Indium Phosphide Devices.
[11] Deng, X. (2025). Homomorphic Encryption-Based Data Integrity Verification and Anti-Tampering Mechanism in Cloud Storage Environment.
[12] Zheng, Y., Zhou, G., & Lu, B. (2023). Rebar Cross-section Detection Based on Improved YOLOv5s Algorithm. Innovation & Technology Advances, 1(1), 1–6. https://doi.org/10.61187/ita.v1i1.1
[13] Zhao, X., Zhang, L., & Hu, Z. (2023). Smart warehouse track identification based on Res2Net-YOLACT+HSV. Innovation & Technology Advances, 1(1), 7–11. https://doi.org/10.61187/ita.v1i1.2
[14] Deng, X., & Yang, J. (2025, August). Multi-Layer Defense Strategies and Privacy Preserving Enhancements for Membership Reasoning Attacks in a Federated Learning Framework. In 2025 5th International Conference on Computer Science and Blockchain (CCSB) (pp. 278-282). IEEE.
[15] Lin, Z., Wang, Y., & Hong, Y. (2023). The computing of the Poisson multinomial distribution and applications in ecological inference and machine learning. Computational Statistics, 38(4), 1851-1877.
[16] Chen, Y., Tahir, A., Yan, F. Y., & Mittal, R. (2023, December). Octopus: In-Network Content Adaptation to Control Congestion on 5G Links. In 2023 IEEE/ACM Symposium on Edge Computing (SEC) (pp. 199-214). IEEE.
[17] Chen, Y., Yao, R., Hassanieh, H., & Mittal, R. (2023). {Channel-Aware} 5g {RAN} slicing with customizable schedulers. In 20th USENIX Symposium on Networked Systems Design and Implementation (NSDI 23) (pp. 1767-1782).
[18] Yang, Z., Lai, L., Lin, X., Hao, K., & Zhang, W. (2021, June). Huge: An efficient and scalable subgraph enumeration system. In Proceedings of the 2021 international conference on management of data (pp. 2049-2062).
[19] Ukey, N., Yang, Z., Zhang, G., Liu, B., Li, B., & Zhang, W. (2022, August). Efficient knn join over dynamic high-dimensional data. In Australasian Database Conference (pp. 63-75). Cham: Springer International Publishing.