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The Employing of Wavelet Transform and Classifier Artificial Intelligence (AI) Methods for Detecting Power Transmission Difficulties: A Review

Lokesh Patel[1], Shalini Goad[2,*]

Abstract

Power systems use large interconnections to transmit and distribute electric power. For power transmission, the same voltage levels are used for minimum transmission losses. During power transmission, faults may occur due to natural events such as lightning, strong wind, fire etc. Faults may occur between phase conductors to ground or between the phase conductors. Transmission line protection has been performed using the comparison of voltages and currents and activates the relays at fault. Different ways like phase comparison of voltages, ratio between voltages and currents, and difference between currents are used to find the fault and protect the transmission line. Using methods like phase comparison of voltages, current/voltage ratios, and differential protection helps identify faults accurately and swiftly. These techniques leverage the principles of electrical engineering to differentiate between normal operating conditions and fault scenarios, enabling the system to respond appropriately. Artificial intelligence (AI) and advanced signal processing techniques have become powerful tools for defect diagnosis and detection in response to these challenges. Among these methods, the combination of AI classifiers with wavelet transform offers a reliable approach to identifying power transmission issues. This research examines how AI classifiers enhance the precision of identifying such issues, as well as the role of wavelet transform in processing non-stationary signals. The paper also discusses various approaches, challenges, and potential future directions in this field.

Keywords: Power system, wavelet transform, SVM, ANN, CNN

INTRODUCTION

Analysis and detection of fault in transmission line for balanced faults and unbalanced faults may occur; these phenomena are known as symmetric and asymmetric fault. Mostly, imbalanced problems develop in power transmission [1]. In normal and abnormal circumstances, any power system examines the changes in voltages and current [2]. Additionally, the faults can be categorized as simultaneous, series, and shunt faults. Transmission line imbalanced series impedance circumstances, such as one or two damaged lines or additional impedance injected into the lines, are examples of series faults [3]. These faults are identified by measuring the increase of voltage level, increase in the frequency of electrical power and current reduction.

The shunt faults are due to sorting of power conductors or conductor-to-ground. It can be identified by observing increment the line currents, reduction in voltage and reduction in frequency of power. Shunt faults are categorized as Line-to-ground (LG)

***Author for Correspondence**
Shalini Goad
E-mail: shalini.goad19@gmail.com

[1]Scholar, Department of Electrical and Electronics Engineering, Oriental University, Indore, Madhya Pradesh, India
[2]Assistant Professor, Department of Electrical and Electronics Engineering, Oriental University, Indore, Madhya Pradesh, India

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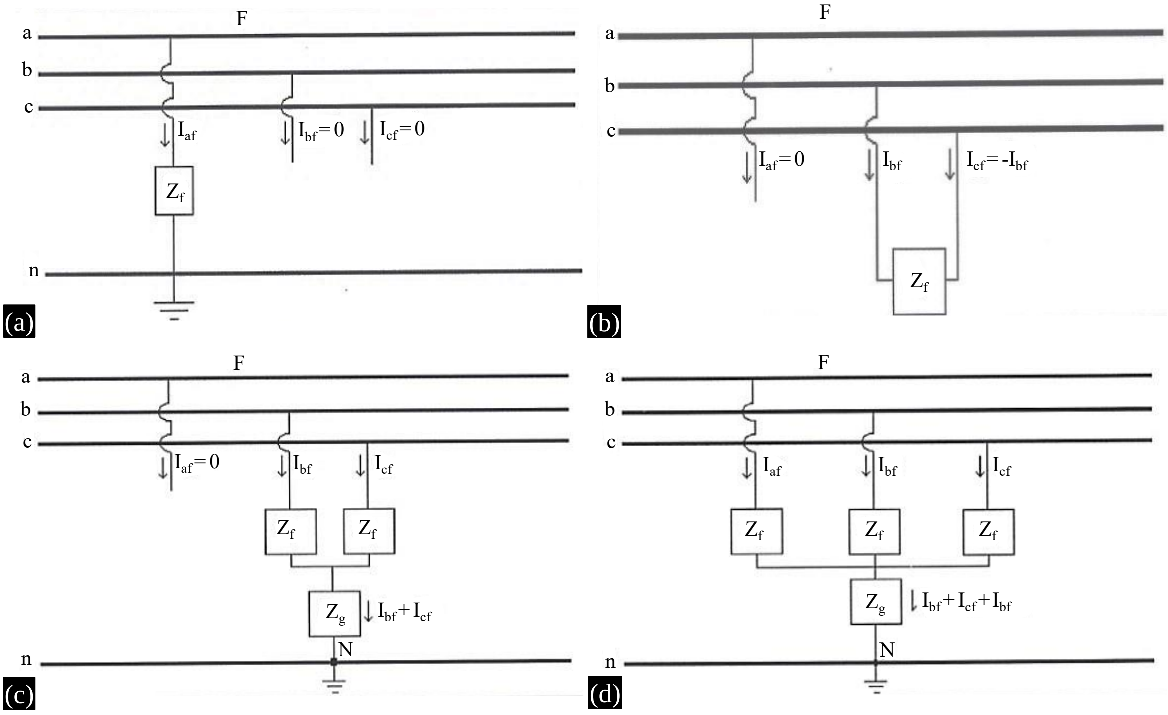

Figure 1. Different shunt faults: (a) LG, (b) LL, (c) LLG, and (d) three phases.

fault, Line-to-line (LL) fault, Double line-to-ground (LLG) and three phase faults. The LG, LL and LLG faults are asymmetrical faults [3]. Figure 1(a)–(d) shows different shunt faults.

INTRODUCTION: POWER SYSTEM FAULT

Power system faults refer to abnormal conditions that occur within an electrical power system, which can disrupt the normal flow of electricity and potentially damage equipment. These faults can occur due to various reasons, including:

1. *Short circuits:* A short circuit happens when two or more conductors meet each other, creating a low-resistance path. This results in a sudden increase in current flow, potentially causing equipment damage and system instability.
2. *Ground faults:* Ground faults occur when one or more phase conductors meet the ground or a grounded object. This can happen due to insulation failure or accidental contact, leading to current leakage and potential safety hazards.
3. *Overloads:* Overloads occur when the electrical load exceeds the capacity of the equipment or the power system. This can lead to overheating of conductors and equipment, potentially causing damage and creating fire hazards.
4. *Lightning strikes:* Lightning strikes can induce high voltage surges in power lines, causing insulation breakdown and equipment damage. Lightning protection measures are essential to mitigate the impact of lightning on power systems.
5. *Switching transients:* Switching transients occur during the operation of switches, circuit breakers, and other switching devices. Rapid changes in voltage and current levels during switching operations can stress equipment and cause temporary disturbances in the power system.

CLASSIFICATION OF FAULTS

Faults in power systems refer to abnormal conditions or disturbances that occur within the electrical network, causing interruptions or deviations from normal operation. These faults can occur due to various reasons and can have significant consequences if not properly managed. Some common types of faults in power systems include:

1. *Short circuit:* A short circuit occurs when there is a low-resistance connection between two conductors, typically resulting in a high current flow. Short circuits can occur due to insulation failure, equipment malfunction, or accidental contact between conductors. They can lead to equipment damage, power outages, and in extreme cases, fire or explosions.
2. *Open circuit:* An open circuit occurs when there is a break or discontinuity in the electrical path, preventing current flow. Open circuits can occur due to broken conductors, loose connections, or equipment failure. They can result in loss of power to downstream loads and disruption of electrical service.
3. *Ground fault:* A ground fault occurs when an unintended electrical connection is made between an energized conductor and the ground. Ground faults can occur due to insulation breakdown, equipment damage, or improper wiring. They can lead to electrical shock hazards, equipment damage, and power system instability.
4. *Phase-to-phase fault:* A phase-to-phase fault occurs when two or more phases of the electrical system come into direct contact with each other. Phase-to-phase faults can occur due to equipment failure, conductor damage, or improper switching. They can cause high currents, equipment damage, and disruption of power supply.
5. *Phase-to-ground fault:* A phase-to-ground fault occurs when one or more phases of the electrical system meet the ground or earth. Phase-to-ground faults can occur due to insulation failure, equipment damage, or environmental conditions. They can result in ground faults, electrical fires, and damage to equipment.
6. *Transient faults:* Transient faults are temporary disturbances in the power system that occur due to lightning strikes, switching operations, or sudden changes in load. Transient faults can cause voltage surges, voltage dips, and fluctuations in power quality. While they are typically short-lived, they can still disrupt equipment operation and cause damage if not properly mitigated.
7. *Intermittent faults:* Intermittent faults are faults that occur sporadically and are not consistently present. Intermittent faults can be challenging to diagnose and may require careful monitoring and analysis to identify the underlying cause.

SHUNT FAULTS

Two categories of shunt faults are ‘short circuit’ and ‘ground circuit’ which help to reduce the voltage and increase the current across the circuit. The Figure 1(a)–(d) shows different shunt faults conditions.

RELATED WORK FOR AI BASED FAULT DETECTION

Fault detection in power transmission systems is a rich area of research, and numerous methods have been explored by researchers to tackle this challenge. These methods often leverage various techniques and approaches, reflecting the diverse nature of the problem and the need for adaptable solutions.

Ray *et al.* [4]: This research work introduces a promising method utilizing Wavelet Transform (WT) and Independent Component Analysis (ICA) for fault detection. By integrating WT and ICA techniques, your approach offers enhanced fault detection capabilities, especially in scenarios involving noise and frequency variations. The thorough testing and simulation validate the robustness and efficacy of the proposed method for ensuring uninterrupted power supply through swift fault detection and mitigation [4].

Dalstein and Kulicke [5]: By leveraging neural networks, the system can effectively classify different types of faults occurring in high-speed protective relaying. Neural networks are capable of learning complex patterns from data, making them suitable for fault classification tasks. This paper’s approach combined digital signal processing (DSP) concepts with neural networks to enhance fault classification accuracy. DSP techniques may involve filtering, feature extraction, or other preprocessing methods to improve the quality of input data for the neural network. This research showcases promising results indicating the capability of the neural network-based approach to accurately classify faults in high-speed protective relaying systems [5].

Jayabharta and Mohanta [6]: presented a novel approach combining wavelet and fuzzy logic techniques for identifying transmission line faults, particularly focusing on digital relaying systems. The proposed approach integrates wavelet transform and fuzzy logic to enhance fault identification in transmission lines. This hybrid method leverages the strengths of both techniques to overcome challenges related to fault inception angle, fault impedance, and fault distance. The algorithm utilizes wavelet MRA coefficients in conjunction with a fuzzy inference system to accurately identify the location of faults along the transmission line. Simulations are conducted using a 300 km 400 kV transmission line to validate the proposed approach. The reported maximum error of 6.5% indicates the effectiveness of the hybrid wavelet-fuzzy approach in fault location identification under various operating conditions [6].

Fernandez and Ghonaim [7]: presented an intriguing advancement in fault detection and direction estimation for high-voltage transmission lines using FIRANNs back in 2002. Their approach, employing finite impulse response artificial neural networks (FIRANNs), yielded promising results. However, it is unfortunate that there does not seem to be further work or follow-up in this specific direction. Advances in this field can greatly enhance the reliability and efficiency of high-voltage transmission systems, so it is a shame that this promising avenue has not been explored further [7].

Aziz *et al*. [8]: Using the adaptive neural fuzzy inference system, Aziz *et al*. introduced a novel method for high-impedance fault analysis (detection, classification, and localization) in distribution networks [8]. The suggested plan was evaluated under various system conditions and trained using data from a distribution system simulation running under several fault scenarios. Discussions were held regarding the specifics of the design procedure and the performance outcomes of the suggested approach. The findings demonstrated the excellent performance of the suggested method in identifying, categorising, and locating high-impedance defects [8].

Jamil *et al*. [9]: concentrated on employing artificial neural networks to detect and categorise defects on electrical power transmission lines. In their suggested method, the three phase currents and voltages of one end are considered as inputs. For analysing each of the three process phases, the feed forward neural network and back propagation algorithm have been used to detect and classify the defect. A thorough examination with different counts of hidden layers has been carried out to confirm the neural network selection. According to the simulation results, the current neural network-based technique is effective at identifying and categorising transmission line defects with respectable performances [9]. The method's adaptability is tested by simulating various defects with varying settings.

Khetarpal *et al*. [10]: The work that has been done up to this point in the subject of power quality disturbance identification and categorization is thoroughly reviewed by Khetarpal *et al*. They provide a comprehensive examination of machine learning approaches for classification, including Neural Networks (NN), Support Vector Machine (SVM), Fuzzy Logic (FL), Neuro Fuzzy (NF) techniques, Deep Learning methods, and others. Additionally, signal processing techniques like Fourier transform (FT) and its variants (STFT, DFT, FFT), S transform (ST), Hilbert Huang transform (HHT), and Wavelet transform (WT) have also been reviewed [10].

Khokhar *et al*. [11]: A thorough assessment of the literature on the use of artificial intelligence, digital signal processing, and optimisation approaches in the classification of PQ disturbances was provided by Khokhar *et al*. They have studied a number of signal processing methods, including the Fourier, wavelet, S-, Hilbert, Gabor, and hybrid transforms, that were utilised to extract features. A detailed review is given of the artificial intelligence methods used for pattern recognition, including support vector machines, fuzzy logic, and artificial neural networks. Additionally reviewed are the optimisation methods like ant colony, particle swarm, and genetic algorithms that are used to select the best features [11].

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Classifier AI Techniques

Improving Identification and Evaluation Machine learning (ML) and deep learning (DL) algorithms are two examples of classifier AI techniques that have greatly enhanced power system analysis capabilities. These techniques are very good at categorising and diagnosing power transmission problems because they can automatically identify patterns and relationships from data.

Deep Learning Methods

Neural networks with several layers (deep neural networks), a subtype of machine learning, are used in deep learning to model intricate correlations in data. Power system applications are a good fit for recurrent neural networks (RNNs) and convolutional neural networks (CNNs) [12]. CNNs are perfect for image-based representations of wavelet-transformed signals because they are excellent at identifying spatial patterns in data. RNNs, on the other hand, can capture temporal dependencies in power system signals and are useful for sequential data processing.

AUTOMATED LEARNING SYSTEMS

Power system analysis frequently makes use of machine learning algorithms like k-nearest neighbours (k-NN), decision trees, and support vector machines (SVM). By using historical data, these algorithms can be trained to identify patterns connected to various transmission problems [13]. SVM, for example, is useful for classifying fault locations and types, while decision trees are useful for providing comprehensible guidelines for diagnosing power quality issues.

Wavelet Transform and Classifier AI Integration

The amalgamation of wavelet transforms, and classifier AI techniques amalgamates the advantages of both methodologies, culminating in a sturdy structure for identifying power transmission challenges. The following steps are usually involved in the process:

- *Signal decomposition:* Power system signals are broken down into their individual frequency components using the wavelet transform [14].
- *Extraction of relevant characteristics:* The wavelet coefficients are used to extract pertinent characteristics. These attributes could consist of energy distribution, statistical measurements, and other traits that encapsulate the core of the signal.
- *Classification:* An AI model (e.g., SVM, CNN, RNN) trained to detect and diagnose transmission issues is given the retrieved features.

There are various benefits to this integrated approach:

- *Enhanced sensitivity:* Classifier AI techniques increase accuracy by learning from prior data, whereas wavelet transform increases sensitivity of detection by offering comprehensive time-frequency information.
- *Real-time Capability:* This combination makes it possible to monitor and identify power transmission problems in real-time, allowing for quick action to stop more problems.
- *Scalability:* Because AI models can process enormous volumes of data and learn from a variety of operational settings, the method is scalable to big power systems.

CONCLUSION

Many approaches have been studied and are present in this study. The trend in fault detection is more towards the use of the artificial intelligent approach for identifying the fault type and their location. Advanced techniques like wavelet transform and DCT are in use to get features from voltage and currents. The mention of distributed power systems as a focal point for analysis is noteworthy as well. With the growing prevalence of distributed generation sources, it is imperative to adapt fault detection methods to suit these evolving systems' complexities.

Exploring these techniques in the context of large, distributed power systems could yield significant advancements in fault detection and contribute to enhancing the overall stability and efficiency of electrical grids. It is exciting to consider the possibilities for further innovation and application in this field.

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