A Review paper on fault detection using artificial neural networks in HVDC transmission systems

Vipin Dubey[1], Raghunandan Singh Bhagel[2]
[1]*M. Tech Scholar, School of Engineering & Technology, Vikram University, Ujjain (MP)*
[2]*Assistant Professor, School of Engineering & Technology, Vikram University, Ujjain (MP)*

***Abstract*—The reliable functioning of AC-DC systems hinges on prompt monitoring and precise classification of system signals. For fast-acting HVDC transmission systems, decisions often need to be made within tens of milliseconds to prevent disturbances like commutation failures. Effective fault detection and clearance are vital for optimal power system operation. Detecting faults in HVDC systems is a significant challenge. Traditional methods, such as pure frequency or time-domain analysis, have limitations. Frequency-domain methods struggle with time-varying transients, while time-domain methods are susceptible to noise. Recent advancements in power electronics and artificial intelligence (AI) have transformed fault detection in HVDC systems. AI techniques like fuzzy logic, neural networks, and artificial neural networks (ANNs) have shown promise in identifying faults. This overview explores the application of AI techniques for fault detection in HVDC transmission systems, highlighting their potential to enhance system reliability and efficiency.**

***Index Terms*—ANN, Fuzzy, Wavelet Transformation, Fault Identification, Genetic Algorithms.**

I. INTRODUCTION

Advanced Control Strategies for HVDC Systems
HVDC systems have traditionally employed PI controllers with fixed gains, which, despite their ruggedness, have limitations in handling perturbations beyond a small operating range. Artificial neural network (ANN) controllers, on the other hand, offer flexibility and fault tolerance, making them an attractive alternative.
Hybrid Approaches: Neuro-fuzzy systems, which combine the strengths of fuzzy logic and neural networks, have emerged as a promising solution. These systems leverage the pattern recognition capabilities of ANNs and the subjective, heuristic nature of fuzzy logic. Adaptive Neuro-Fuzzy Inference System (ANFIS) is a notable example, offering improved performance and flexibility.
ANFIS-Based Fault Identification and Protection: This paper explores the application of ANFIS-based fault identification and protection in HVDC converters. The proposed system utilizes an ANFIS-based fault identifier (ANFLBI) and a fuzzy logic-based current controller (ANFLBC) to achieve fast and flexible control of HVDC transmission links. By integrating ANFLBI and ANFLBC, power system reliability can be significantly improved.
Soft computing techniques, including fuzzy logic, neural networks, and genetic algorithms, have gained traction in power system applications. These approaches offer promising solutions for fault diagnosis, protection, and control, enabling more efficient and reliable operation of power systems.

II. FAULT IDENTIFICATION IN HVDC

A. Faults in Electric Power Systems
Electric power systems are susceptible to unexpected failures in transmission lines due to various random causes. These failures disrupt system operation, and prompt restoration of service is essential. Developing new technologies to locate faults and ensure network reliability has become crucial.
B. Fault Location Algorithms
Fault location algorithms can be developed for relay protection or fault location systems. These algorithms aim to identify fault locations accurately, enabling efficient repair and maintenance operations. In HVDC systems, fault identification is particularly challenging due to the complexity of fault types and the need for rapid decision-making.
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C. Challenges in Fault Identification

Traditional methods, such as pure frequency or time-domain analysis, have limitations in identifying HVDC faults. Wavelet transform offers a promising approach for analyzing time-varying transients and has shown potential in fault identification and protection.

D. Fault Location Methodologies

Existing fault location methods are based on traveling wave theory or assessment of electric magnitudes at fundamental frequency. These methodologies use voltage and current signals to determine fault distances. Accurate fault location is essential for efficient repair and maintenance operations, as well as identifying weak points in the system.

E. Importance of Accurate Fault Location

Accurate fault location enables utilities to restore power quickly, reducing downtime and economic losses. It also helps identify areas prone to faults, allowing for targeted maintenance and upgrades.

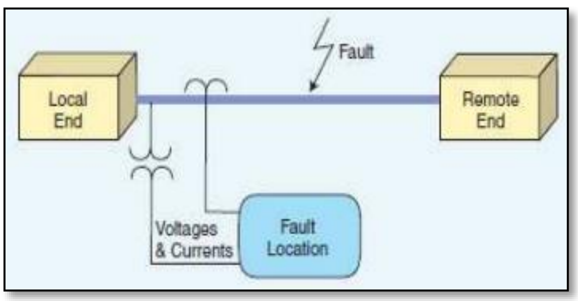

Fig.-1 Fault condition in transmission lines

Wavelet Transformation: Wavelet Analysis for Fault Classification in HVDC Systems

Wavelet analysis has emerged as a powerful tool for classifying faults in HVDC systems. This technique offers improved efficiency compared to traditional Fourier transforms. Wavelets are mathematical functions that provide time and frequency localization, making them well-suited for analyzing complex signals.

Properties of Wavelets

Wavelets have several key properties, including:

1. Oscillatory behavior: Wavelets exhibit oscillatory behavior, allowing them to capture signal patterns.
2. Rapid decay: Wavelets decay quickly to zero, enabling efficient signal representation.
3. Zero average value: Wavelets have an average value of zero, ensuring that they can effectively capture signal variations.

Applications of Wavelet Analysis

Wavelet analysis has been successfully applied in various fields, including:

1. Signal analysis: Wavelet analysis is used to analyze complex signals and extract relevant information.
2. Image processing: Wavelet analysis is used in image processing techniques, such as image compression and denoising.
3. Fault detection: Wavelet analysis has been proposed as a tool for fault detection, localization, and classification in power systems.

Advantages of Wavelet Transform

The wavelet transform offers several advantages, including:

1. Fast calculation algorithms: Wavelet transform algorithms, such as those based on filter bank structures, enable fast and efficient calculations.
2. Time-frequency localization: Wavelet analysis provides both time and frequency localization, allowing for detailed signal analysis.

À Trous Structure

The à trous structure is a wavelet transform algorithm that offers improved time localization and information preservation.

This structure is particularly useful for analyzing complex signals and detecting faults in HVDC systems.

III. ARTIFICIAL INTELLIGENCE TECHNIQUES FOR IDENTIFICATION OF FAULTS

Advanced Control Techniques for HVDC Systems: Modern control techniques, including Artificial Neural Networks (ANNs), Fuzzy Logic, and Genetic Algorithms, have proven to be fast, reliable, and effective in protecting against line and converter faults in HVDC transmission systems. These artificial intelligence techniques are gaining popularity in the field of HVDC transmission.

(i) Artificial Neural Network (ANN):

Applications of Artificial Neural Networks

ANNs have been extensively used in power systems for fault diagnosis, load forecasting, system identification, and state estimation. They offer several benefits, including:

1. Pattern recognition: ANNs can recognize complex patterns in electrical circuits and systems.
2. Fault identification: ANNs can identify faults in AC-DC systems and HVDC converter systems.

3. Controller design: ANNs can be used to design controllers for HVDC systems.

Advantages of ANNs in HVDC Systems

ANNs offer several advantages in HVDC systems, including:

1. Non-linearity handling: ANNs can handle non-linear relationships between system variables.
2. Adaptability: ANNs can adapt to changing system conditions.
3. Robustness: ANNs can provide robust control and protection in HVDC systems.

Fuzzy Logic and Expert Systems

Fuzzy logic and expert systems can also be used in HVDC systems to overcome limitations of traditional digital techniques. These techniques offer benefits such as:

1.Improved decision-making: Fuzzy logic and expert systems can make decisions based on uncertain or incomplete information.

2. Enhanced control: Fuzzy logic and expert systems can provide advanced control and protection in HVDC systems.

Conclusion

Artificial intelligence techniques, including ANNs and fuzzy logic, are being increasingly used in HVDC systems to improve control, protection, and reliability. These techniques offer several benefits, including improved pattern recognition, fault identification, and adaptability.

(ii) Neuro Fuzzy: Control for HVDC Systems

Neuro-fuzzy control combines the benefits of fuzzy logic and artificial neural networks to provide advanced control solutions for complex systems like HVDC links. Fuzzy logic controllers offer a simple, rule-based approach to control, while neural networks provide adaptability and learning capabilities.

Advantages of Neuro-Fuzzy Control

Neuro-fuzzy control offers several advantages, including:

1. Improved adaptability: Neuro-fuzzy controllers can adapt to changing system conditions and performance criteria.
2. Robustness: Neuro-fuzzy controllers can tolerate disturbances and component failures.
3. Flexibility: Neuro-fuzzy controllers can be designed to handle complex and nonlinear systems.

Comparison with Traditional Controllers

Studies have shown that neuro-fuzzy controllers can outperform traditional PI controllers in HVDC systems. Fuzzy logic controllers can provide improved performance under various fault conditions and operating point changes.

(iii) Adaptive Neuro-Fuzzy Inference System (ANFIS):

Combining Fuzzy Systems and Neural Networks

Fuzzy systems and neural networks have complementary strengths and weaknesses. Fuzzy systems can describe complex processes using fuzzy rules, but require expert input to define these rules and can be time-consuming to tune. Neural networks, on the other hand, can learn from data, but it's challenging to incorporate prior knowledge or explain their behavior.

(iv) Genetic Algorithms

Impact of HVDC on Electricity Markets

The integration of High Voltage Direct Current (HVDC) transmission systems into AC transmission networks has transformed the electricity market landscape in developing countries. This shift has brought about significant technical and commercial changes.

IV. COMPARISON OF VARIOUS ARTIFICIAL INTELLIGENCE TECHNIQUES

Control Strategies for HVDC Systems

HVDC systems typically employ PI controllers with fixed gains, which offer robustness but limited flexibility. In contrast, Artificial Neural Network (ANN) controllers provide adaptability and fault tolerance, making them attractive for HVDC control.

ANN and Fuzzy Logic: Complementary Technologies

ANNs and fuzzy logic systems are complementary approaches that can be combined to create adaptive intelligence systems. ANNs learn from data, while fuzzy logic systems use fuzzy set theory and fuzzy reasoning to make decisions.

Fuzzy Logic Control for HVDC

Fuzzy logic controllers can stabilize transient oscillations in HVDC transmission lines without requiring an accurate system model. This approach is useful for handling complex systems with uncertainty.

Neuro-Fuzzy Systems

Neuro-fuzzy systems combine the strengths of ANNs and fuzzy logic systems. By training fuzzy inference systems using neural network algorithms, neuro-fuzzy systems can fine-tune the underlying fuzzy logic rules and improve performance.

Benefits and Challenges

Neuro-fuzzy systems offer several benefits, including adaptability and improved performance. However, they also face challenges, such as defining fuzzy rules and selecting membership functions. By leveraging neural techniques, some of these challenges can be addressed.

V. CONCLUSION

Artificial Intelligence in HVDC Fault Analysis

This overview explores various artificial intelligence techniques for fault analysis in HVDC transmission systems. Key approaches include:

1. Neural Networks: Effective for pattern recognition and fault detection.
2. Neuro-Fuzzy Systems: Combine neural networks and fuzzy logic for improved adaptability.
3. Adaptive Neuro-Fuzzy Inference System (ANFIS): A powerful tool for fault analysis and control.

Benefits of ANFIS-Based Control

ANFIS-based controllers offer superior performance and advantages, including:

1. Improved dynamic response: Enhanced stability and control of HVDC systems.
2. No mathematical model required: ANFIS controllers can operate without detailed system models.

Future Research Directions

Ongoing research explores the potential of Genetic Algorithms for fault identification in HVDC systems, offering promising results. This overview aims to provide a concise reference for researchers, engineers, and academics working on HVDC fault analysis.

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