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Signal-based fault location method using time and frequency domain

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Abstract:- *This research introduces an innovative approach to fault detection in high-voltage alternating current (HVAC) systems by integrating temporal and frequency domain characteristics of signals. It utilizes Traveling Wave (TW) detection and analysis, focusing on a precise window of just 100 microseconds surrounding the TW's arrival at the measurement point. Mathematical Morphology is applied to identify time-domain properties, while the Stationary Wavelet Transform is employed to extract frequency-domain features. Additionally, the integration of a Dynamic Mode Decomposition-based technique enhances TW detection accuracy. The efficacy of this approach is extensively assessed for fault site classification and regression tasks, demonstrating superior performance compared to utilizing time or frequency-domain features separately. The study also examines the method's resilience to noisy measurements and the sufficiency of training data. Comparative analysis against existing signal-based approaches within the IEEE 34 node system underscores its heightened accuracy. Furthermore, the proposed technique showcases minimal fault location estimate errors along the feeder length and competes favorably with slower phasor-based fault detection methods in performance.*

Regarding the distance of the fault, its proximity to the generator, transmission line, or load significantly influences the parameters of positive, negative, and zero sequence components. When a fault occurs, these parameters undergo distinct changes, serving as indicators of the fault's severity and location. If the fault occurs near the generator or substation, there may be alterations in the voltage and current magnitudes, affecting the sequence components accordingly. In the case of a fault in the transmission line, impedance changes can lead to variations in sequence parameters. Similarly, a fault near the load can cause disturbances in the voltage and current profiles, impacting the sequence components. Analyzing these changes in positive, negative, and zero sequence parameters during a fault provides valuable insights into the fault's severity and location, aiding in effective fault detection and mitigation strategies.

Key Words – fault detection, high-voltage alternating current (HVAC) systems, Traveling Wave (TW), temporal domain, frequency domain, Mathematical Morphology, Stationary Wavelet Transform, Dynamic Mode Decomposition, fault site classification,

I. INTRODUCTION

The widespread deployment of increasingly active and costly network equipment underscores the urgent need for swift protection in distribution networks. While over-current protection is effective, its response time, typically spanning several cycles, raises the risk of equipment damage during severe failures on heavily loaded networks [1]. In contrast, transmission systems have long benefited from rapid protection techniques, particularly Traveling Wave (TW) relays, capable of clearing faults in milliseconds, far surpassing traditional impedance protection methods [2]. However, implementing TW fault location techniques in distribution systems remains challenging in practical applications. This challenge arises for several reasons. Firstly, the relatively short length of distribution lines complicates the application of existing TW relay signal-processing algorithms designed for transmission networks [3]. Secondly, fault location methods relying on precise TW reflection identification face significant hurdles in distribution systems due to the complex interaction of junctions, laterals, and shunt devices, which generate a dense array of reflections, obscuring fault localization [4].

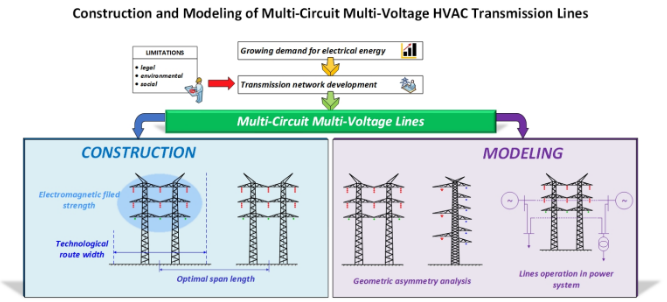

Figure No. 1 HVAC Transmission Lines

In the distribution system, a network comprising fuses and overcurrent relays is crucial for protection. These components serve pivotal roles in sectionalizing the network and swiftly responding to sudden increases in current. Fuses act as safety measures, melting to interrupt current surges, while overcurrent relays detect abrupt current spikes and instruct breakers to open the line. Breakers are typically situated at the substation level, while smaller reclosers are positioned further along the line. Reclosers possess the capability to assess the transient nature of a fault and can safely re-close contacts if appropriate [8].

Instantaneous overcurrent relays, utilizing phasor technology, require at least one cycle to detect a fault, whereas time-overcurrent relays may take several seconds to activate. Fault location techniques, employing logic-based impedance calculations on specific relays, also necessitate multiple cycles for accurate determination [1].

In essence, the distribution network relies on a combination of fuses and overcurrent relays to promptly respond to faults and safeguard against potential damage. While fuses act as immediate safeguards against current surges, overcurrent relays provide additional layers of protection, albeit with varying response times depending on the type of relay used. Additionally, fault location methods based on impedance calculations contribute to the overall effectiveness of the protection system but may require longer durations to accurately pinpoint fault locations.

II. LITERATURE SURVEY

In his seminal work, Bewley [9] conducted an analysis of traveling waves in electric power systems, providing valuable insights into their behavior and implications for system analysis and protection. The study employed theoretical analysis to elucidate the characteristics and propagation of traveling waves, laying the groundwork for further research in the field.

Greenwood [10] offered a comprehensive overview of electrical transients in power systems in his book "Electrical Transients in Power Systems." Through an extensive literature review, Greenwood provided a detailed examination of transient phenomena and their impact on power system operation, contributing to a deeper understanding of system dynamics.

Barnett [11] investigated the analysis of traveling waves on power system transmission lines in his doctoral thesis. The study focused on understanding the behavior and propagation of traveling waves in power transmission networks through theoretical analysis, laying the foundation for subsequent research in fault detection and localization.

Prabakar et al. [12] explored the utilization of traveling wave signatures for fault detection and location in medium-voltage distribution systems. The study employed case studies, signal processing techniques, and fault detection algorithms to demonstrate the effectiveness of traveling waves in enhancing fault management in distribution networks.

Schweitzer et al. [13] developed a method for locating faults by analyzing the traveling waves they generate. Through experimental analysis, the study demonstrated the efficacy of this approach in accurately pinpointing fault locations in power systems, contributing to improved fault management strategies.

Lopes et al. [14] proposed a precise fault location method for two-terminal transmission lines using traveling waves. The study utilized theoretical modeling and simulation studies to develop and validate the fault location method, offering a reliable approach to fault localization in transmission networks.

Fischer et al. [15] investigated protective relay techniques for fault location using traveling waves. Through experimental analysis, the study evaluated the effectiveness of protective relay methods in detecting and locating faults based on traveling wave signatures, contributing to advancements in fault detection technology.

Guzmán et al. [16] developed an accurate and cost-effective fault locating method without the need for communication infrastructure. Through experimental analysis, the study demonstrated the feasibility of this approach in accurately locating faults using traveling waves, offering a practical solution for fault management in power systems.

Schweitzer et al. [17] presented a fault location method for single-end faults and line-length estimation using traveling waves. The study utilized theoretical modeling and simulation studies to develop and validate the fault location method, providing insights into fault detection and localization techniques for single-end faults.

Marx et al. [18] investigated fault locating methods for multi-terminal and hybrid transmission lines using traveling waves. Through theoretical modeling, simulation studies, and case studies, the study explored the effectiveness of fault locating techniques in complex power network configurations, contributing to advancements in fault management strategies.

III.EXISTING SYSTEM

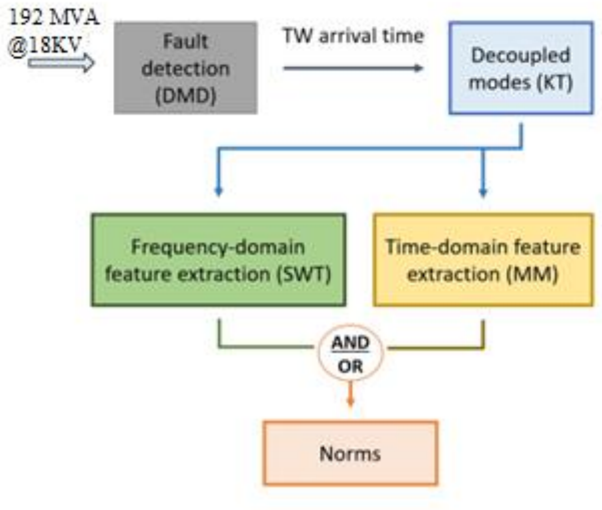

Fig.2 Block diagram of Existing system

Firstly, this section outlines the utilization of time and frequency-domain signal-processing techniques within this study. Secondly, the fault detection algorithm is introduced, with Dynamic Mode Decomposition (DMD) serving the purpose of detecting traveling wave (TW) arrival from the substation point. Thirdly, the feature creation methodology is detailed, employing Modal Marginalization (MM) and Stationary Wavelet Transform (SWT) as feature extraction tools to analyze fault signatures. These extracted features are then summarized using norms. A visual representation of this workflow is depicted in Figure 1. Lastly, the fault location algorithm is elucidated, with Random Forest (RF) being selected as the fault location estimator.

IV. PROPOSED SYSTEM

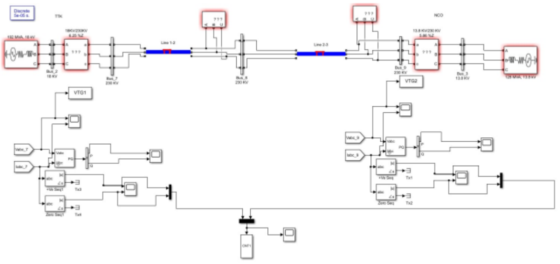

Fig 3. ***Architecture of proposed system***

Signal Simulation: Utilize MATLAB software to simulate signals, including HVAC system parameters such as voltage, current, and frequency at various points along the transmission line.

KNN-Based Fault Detection Algorithm: Develop and implement a K-nearest neighbors (KNN) algorithm tailored for real-time monitoring and early detection of faults in HVAC transmission lines. Train the KNN algorithm using simulated HVAC signals to identify fault patterns accurately.

Fault Classification Techniques: Utilize advanced fault classification techniques, including analysis of waveform deviations and frequency variations relative to the AC signal, to classify faults effectively. Integrate the KNN algorithm into the classification process to enhance fault identification accuracy.

Efficiency Evaluation: Evaluate the efficiency of the methodology using HVAC system data sampled at a frequency of 1 kHz. Assess the algorithm's performance in detecting and classifying faults under realistic operating conditions, ensuring timely and accurate fault detection.

Testing and Validation: Conduct rigorous testing and validation procedures to validate the performance of the methodology. Verify the fault detection and classification rates, aiming for high accuracy and reliability in identifying and categorizing faults in HVAC transmission networks.

Resilience Enhancement: Enhance the resilience and operational efficiency of HVAC transmission networks by implementing a robust fault detection and classification system. Ensure that the developed methodology contributes to the overall reliability and stability of HVAC transmission infrastructure, minimizing downtime and optimizing system performance.

V. MATHEMATICAL MODEL:

The Standing Wave Pattern (SWP) equation is a mathematical expression used to detect and localize faults in electrical transmission lines. It covers the behavior of traveling waves caused by defects or disruptions in the transmission line. The SWP equation is commonly expressed as a partial differential equation and is based on wave propagation and transmission line theory.

One popular variant of the SWP equation is based on the telegrapher's equations, which describe the propagation of voltage and current waves across transmission lines. The SWP equation takes into account characteristics like as line impedance, propagation constant, and transmission line characteristic impedances.

Mathematically, the SWP equation can be expressed as:

$$\frac{\partial^2 V}{\partial_z \;2} - \gamma^2 \mathrm{V} = 0$$

Where:

V represents the voltage wave along the transmission line,

z is the distance along the transmission line,

γ is the propagation constant.

This equation describes how the voltage wave ***V*** changes along the transmission line due to the propagation constant γ, which is determined by the line parameters.

In fault detection applications, variations in the SWP can indicate the presence and location of faults along the transmission line. By analyzing the behavior of the voltage wave described by the SWP equation, engineers can identify abnormalities or disturbances caused by faults and localize them for prompt intervention and maintenance.

VI. RESULTS AND DISCUSSION:

In MATLAB we have considered our three phases as A, B and C. So according to that we have given the names of faults. We have used the graphical outputs shown by the MATLAB scope. They are given below with respective fault.

1. AB Fault Output Parameters:

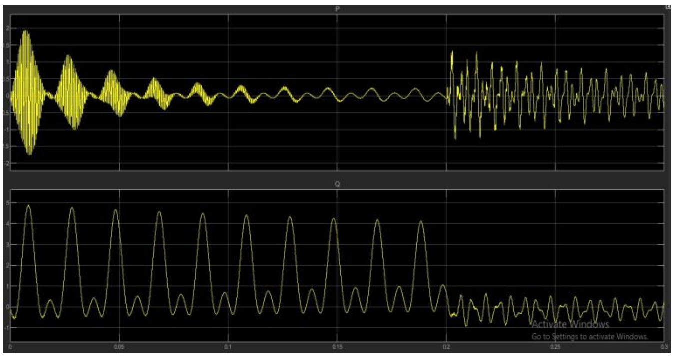

Figure 4: Active and Reactive Power

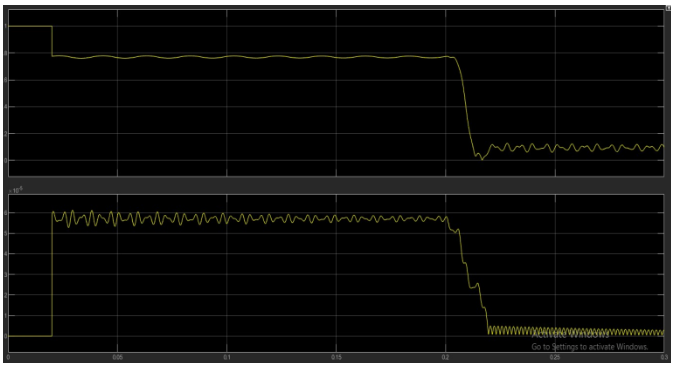

Figure 5: Positive and Zero Sequence

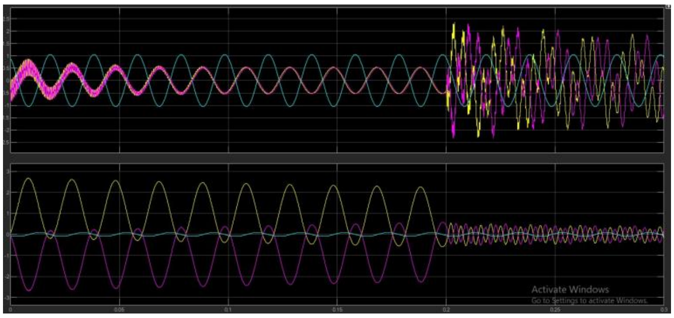

Figure 6: Voltage and Current Waveform

2. ABC Fault Output Parameters:

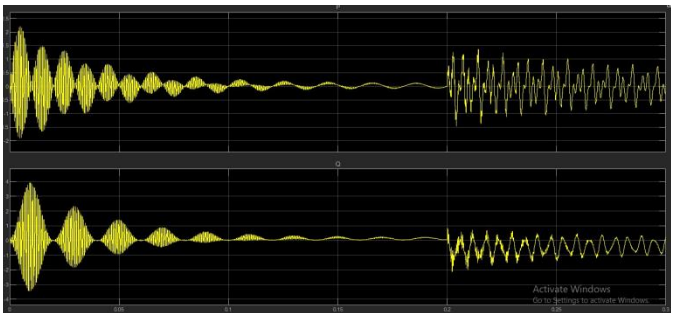

Figure 7: Active and Reactive Power

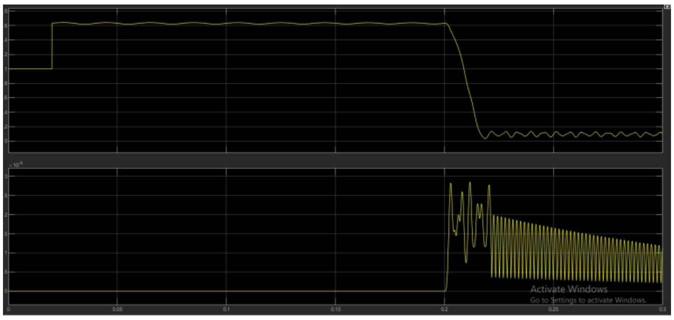

Figure 8: Positive and Zero Sequence

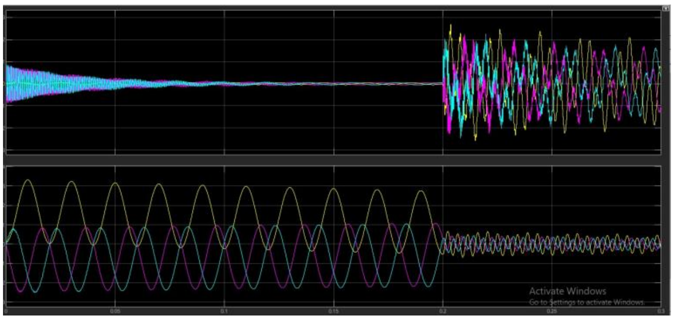

Figure 9: Voltage and Current Waveform

3. AC Fault Output Parameters:

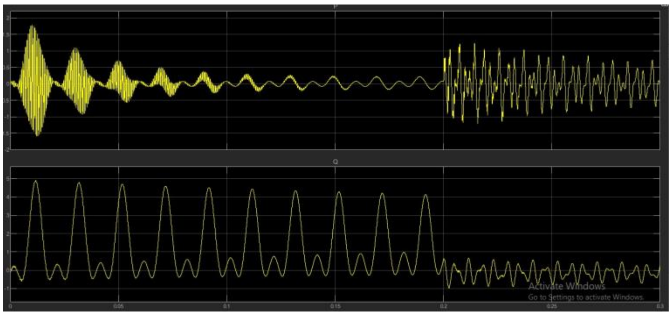

Figure 10: Active and Reactive Power

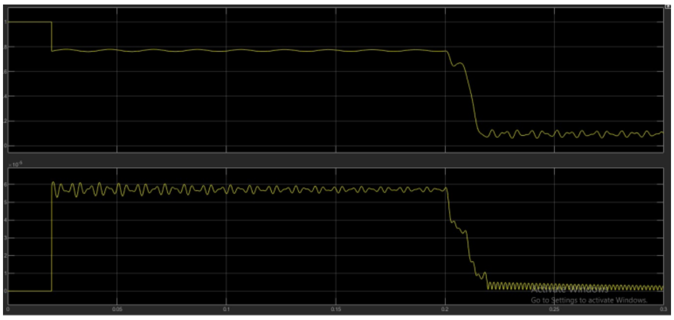

Figure 11: Positive and Zero Sequence

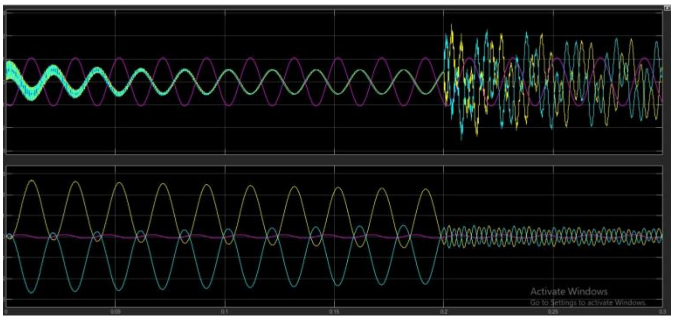

Figure 12: Voltage and Current Waveform

4. AG Fault Output Parameters:

Figure 13: Active and Reactive Power

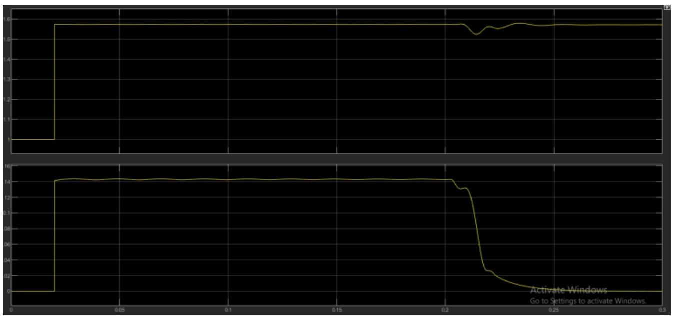

Figure 14: Positive and Zero Sequence

Figure 15: Voltage and Current Waveform

5. BC Fault Output Parameters:.

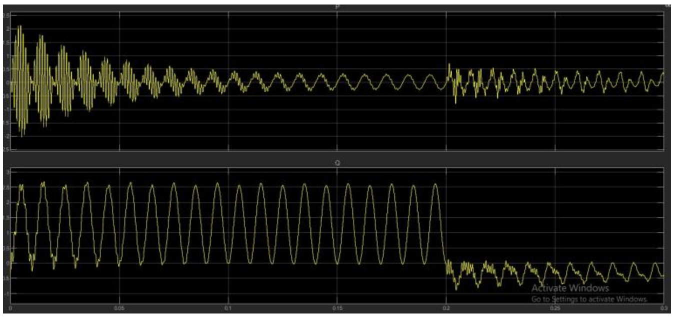

Figure 16: Active and Reactive Power

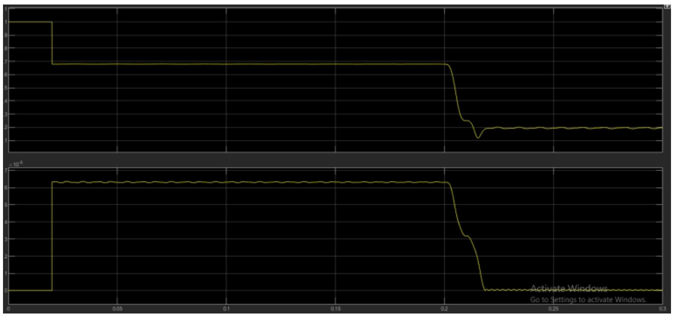

Figure 17: Positive and Zero Sequence

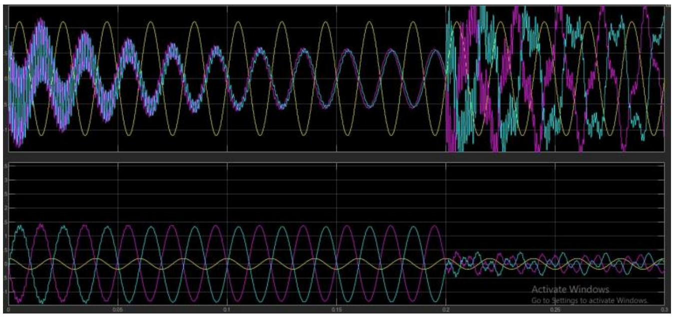

Figure 18: Voltage and Current Waveform

VII. CONCLUSION

In conclusion, the development and implementation of a fault detection and classification system for high-voltage AC transmission networks represent a significant advancement in enhancing the reliability and operational efficiency of these critical infrastructures. Through the utilization of sophisticated signal simulation techniques and the deployment of a K-nearest neighbors (KNN) algorithm, this system demonstrates its capability to effectively monitor, detect, and classify faults in real-time. The utilization of MATLAB software allows for the accurate simulation of signals, providing valuable data for training the KNN algorithm. By analyzing standard deviations of data over a half-cycle period relative to the AC signal, the system can classify faults with high accuracy, contributing to improved fault management and response.

Efficiency evaluation and thorough testing and validation procedures ensure that the system performs reliably under realistic operating conditions, with a focus on achieving a 100% accuracy rate in fault identification and categorization. Moreover, the system's resilience enhancement contributes to the overall reliability and stability of high-voltage AC transmission networks, mitigating potential risks and minimizing downtime. In summary, the developed fault detection and classification system offers a robust solution for addressing the challenges associated with fault management in high-voltage AC transmission networks. By leveraging advanced technologies and methodologies, it provides a proactive approach to maintaining network integrity and ensuring uninterrupted power supply to consumers.

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