International Journal of Scientific Research and Modern Education (IJSRME)
International Peer Reviewed - Refereed Research Journal, Website: www.crystalpen.in
Impact Factor: 7.137, ISSN (Online): 2455 - 5630, Volume 11, Issue 1, January - June, 2026

AI ENABLED FAULT DETECTION, CLASSIFICATION, AND LOCALIZATION IN HIGH VOLTAGE TRANSMISSION LINES USING HYBRID MACHINE LEARNING MODELS

P. Suriya*, J. Umesh, K. Praveen Kumar**, S. Sanjai** & R. Vijayakumar****

* Assistant Professor, Department of Electrical and Electronics Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, Tamil Nadu, India

** UG Student, Department of Electrical and Electronics Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, Tamil Nadu, India

Cite This Article: P. Suriya, J. Umesh, K. Praveen Kumar, S. Sanjai & R. Vijayakumar, "AI Enabled Fault Detection, Classification, and Localization in High Voltage Transmission Lines Using Hybrid Machine Learning Models", International Journal of Scientific Research and Modern Education, Volume 11, Issue 1, January - June, Page Number 79-81, 2026.

Type of Review: Peer Reviewed as per |C|O|P|E| Guidance.

DOI: https://doi.org/10.5281/zenodo.19861273

Abstract:

High-voltage transmission lines are critical components of modern power systems, responsible for transmitting electrical energy over long distances. However, these lines are highly vulnerable to faults caused by lightning strikes, insulation failures, equipment malfunctions, and environmental disturbances. Conventional protection methods, such as relay-based and impedance-based techniques, often struggle to provide accurate and fast fault identification under complex and dynamic operating conditions. This paper proposes an advanced hybrid machine learning framework for real-time fault detection, classification, and localization in high-voltage transmission lines. The system utilizes voltage and current signals, which are preprocessed and analyzed using wavelet transform techniques to extract both time-domain and frequency-domain features. A Convolutional Neural Network (CNN) is employed for deep feature learning, while a Random Forest (RF) classifier performs accurate fault classification. Additionally, a regression model is used to estimate the precise fault location. The system is further integrated with an IoT-based hardware implementation using an ESP32 microcontroller for real-time monitoring and fault management. Simulation and experimental results demonstrate high accuracy, robustness against noise, reduced response time, and improved reliability. The proposed approach enhances the resilience and efficiency of smart grid systems.

Key Words: Fault Detection, Transmission Lines, Convolutional Neural Network, Random Forest, IoT, ESP32, Wavelet Transform, Smart Grid

1. Introduction:

High-voltage transmission lines form the backbone of electrical power systems, ensuring efficient delivery of electricity from generation sources to consumers. The uninterrupted operation of these lines is essential for maintaining grid stability and economic reliability. However, transmission lines are prone to various faults, including line-to-ground faults, line-to-line faults, and three-phase faults, which may arise due to lightning, insulation failure, equipment damage, or environmental conditions such as wind and vegetation interference.

Failure to detect and isolate these faults promptly can lead to severe consequences, including equipment damage, cascading failures, and large-scale blackouts. Traditional protection systems rely on relays and impedance-based calculations, which are limited in handling complex scenarios such as high-impedance faults, noisy environments, and multi-fault conditions.

With the advancement of artificial intelligence and machine learning, there is a growing interest in developing intelligent fault detection systems capable of learning from data and adapting to dynamic conditions. This paper presents a hybrid AI-based approach combining deep learning and ensemble learning techniques to improve the accuracy and speed of fault detection and localization.

2. Literature Review

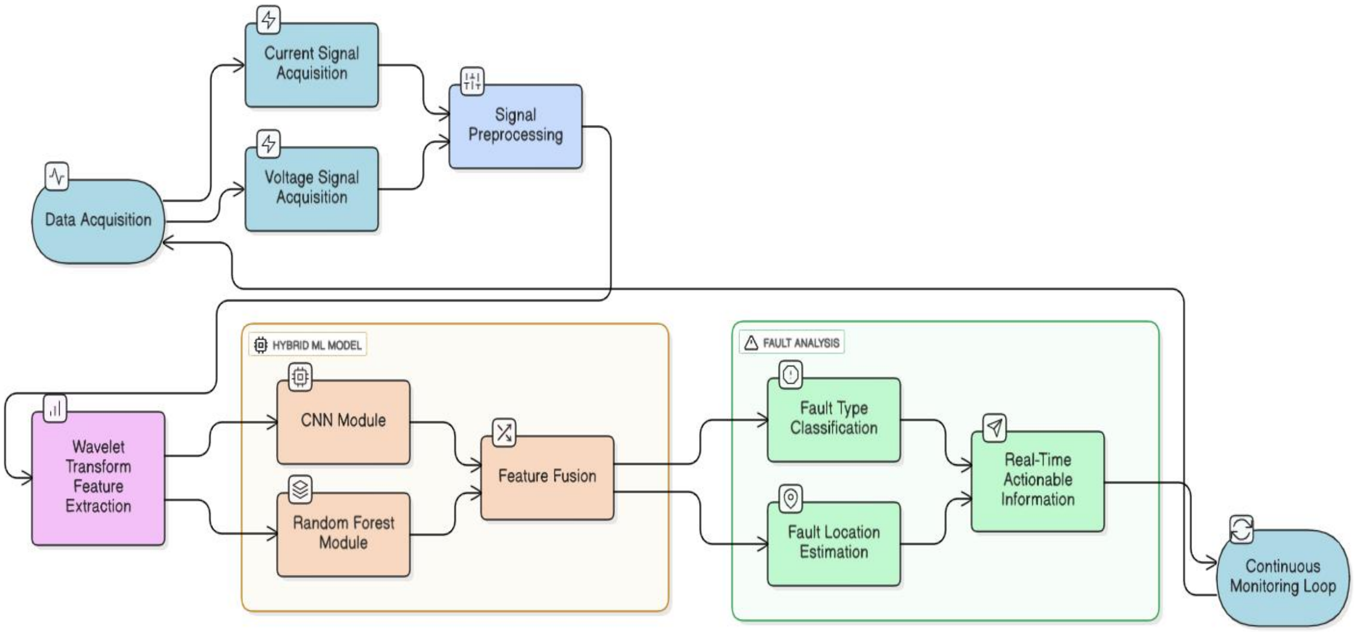
Conventional fault detection methods primarily depend on distance relays and overcurrent protection schemes. While these techniques are widely used, they suffer from limitations such as dependency on fixed thresholds and sensitivity to measurement errors.

Recent studies have explored machine learning techniques such as Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Decision Trees for fault classification. Deep learning approaches, particularly Convolutional Neural Networks (CNNs), have shown promising results in extracting complex patterns from electrical signals.

However, many existing models focus only on fault detection or classification and fail to provide an integrated solution for detection, classification, and localization. Additionally, challenges such as noise robustness, computational efficiency, and real-time implementation remain unresolved.

3. Proposed Methodology:

The proposed system introduces a hybrid machine learning framework that combines signal processing techniques with advanced learning models to achieve efficient fault detection, classification, and localization. Initially, voltage and current signals are acquired from the transmission line using current transformers and potential transformers. These signals are subjected to preprocessing techniques such as filtering and normalization to remove noise and improve data quality. Following preprocessing, wavelet transform is applied to extract features from the signals, as it provides effective time-frequency analysis and captures transient disturbances associated with faults. The extracted features are then fed into a Convolutional Neural Network, which automatically learns complex patterns and representations from the data. The output of the CNN is further processed using a Random Forest classifier, which classifies the type of fault into categories such as single line-to-ground, line-to-line, double line-to-ground, and three-phase faults. In addition to classification, a regression model is employed to estimate the exact location of the fault along the transmission line. This hybrid approach leverages the strengths of both deep learning and ensemble learning techniques, resulting in improved accuracy and robustness.



4. Hardware Implementation:

The hardware implementation of the proposed system is based on an IoT-enabled architecture using the ESP32 microcontroller as the central processing unit. The system includes voltage and current sensors that continuously monitor the electrical parameters of the transmission line. The acquired signals are processed in real time by the ESP32, which executes the fault detection algorithm to identify abnormal conditions. Once a fault is detected, the microcontroller sends a control signal to a relay module that isolates the faulty section of the transmission line, thereby preventing further damage and ensuring system safety. Simultaneously, an alert system consisting of a buzzer and an LCD display provides immediate local notifications to operators. The ESP32 also utilizes its built-in Wi-Fi capability to transmit fault data and system status to a cloud platform, enabling remote monitoring and data analysis. This integration of sensing, processing, communication, and protection components creates a fully automated and intelligent monitoring system.

5. Results and Discussion:

The performance evaluation of the proposed system demonstrates its effectiveness in detecting and classifying faults with high accuracy and speed. The system shows significant improvement compared to conventional protection methods, particularly in terms of response time and reliability. The use of wavelet-based feature extraction and hybrid machine learning models enhances the system's ability to accurately identify different types of faults even under noisy conditions. The integration of IoT technology enables continuous monitoring and real-time data transmission, which supports predictive maintenance and efficient fault management. Experimental results indicate that the system achieves high classification accuracy and precise fault localization, reducing downtime and improving overall grid performance. The results validate the robustness and practicality of the proposed approach for real-world applications.

5. Results and Discussion

The performance evaluation of the proposed system demonstrates its effectiveness in detecting and classifying faults with high accuracy and speed. The system shows significant improvement compared to conventional protection methods, particularly in terms of response time and reliability. The use of wavelet-based feature extraction and hybrid machine learning models enhances the system's ability to accurately identify different types of faults even under noisy conditions. The integration of IoT technology enables continuous monitoring and real-time data transmission, which supports predictive maintenance and efficient fault management. Experimental results indicate that the system achieves high classification accuracy and precise fault localization, reducing downtime and improving overall grid performance. The results validate the robustness and practicality of the proposed approach for real-world applications.

6. Conclusion:

This paper presents an AI-enabled hybrid machine learning approach for fault detection, classification, and localization in high-voltage transmission lines. By combining wavelet transform, Convolutional Neural Networks, and Random Forest algorithms, the system achieves high accuracy and reliability in identifying and locating faults. The integration of an IoT-based hardware platform using the ESP32 microcontroller further enhances the system's capability for real-time monitoring and automated fault management. The proposed solution effectively addresses the limitations of traditional protection methods and provides a scalable and cost-effective approach for modern power systems. The results demonstrate that the system can significantly improve fault response time, reduce operational risks, and enhance the stability of transmission networks.

7. Future Scope:

Future work can focus on extending the proposed system by incorporating advanced deep learning models such as Long Short-Term Memory networks and transformer-based architectures for improved temporal analysis. The integration of cloud-based analytics and big data techniques can further enhance predictive maintenance capabilities. Additionally, implementing cybersecurity measures for IoT communication and deploying the system in large-scale smart grid environments will contribute to the development of more secure, efficient, and intelligent power systems.

References:

1. J. G. Nielsen and F. Blaabjerg, "A detailed comparison of system topologies for dynamic voltage restorers," IEEE Trans. Industry Applications, 2005.
2. A. B. Kumbhar et al., "Compensation of voltage sag/swell using DVR," Int. Journal of Electronics, 2014.
3. S. R. Samantaray, "Decision tree-based fault classification," IEEE Trans. Power Delivery, 2008.
4. M. Kezunovic, "Smart fault location for smart grids," IEEE Smart Grid, 2011.
5. Y. Lecun et al., "Deep learning," Nature, 2015.
6. L. Breiman, "Random forests," Machine Learning, 2001.
7. S. Mallat, "Wavelet transform and signal processing," IEEE, 1989.
8. H. He et al., "Machine learning in power systems," IEEE, 2013.
9. ESP32 Technical Reference Manual, Espressif Systems.
10. A. Phadke and J. Thorp, "Synchronized phasor measurements," Springer, 2008.