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Cost-Effective Detection of Low Voltage Overhead Power Line Breakage in rural areas.

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Abstract
Electrical power transmission systems need reliable and fast fault detection to keep the power supply running smoothly and to protect electrical infrastructure. Faults in transmission lines can lead to serious disruptions, damage to equipment, and longer maintenance times if they are not found and fixed quickly. This paper describes a system created to detect and analyze faults in a three-phase transmission line while estimating the fault's location along the line. The system continuously monitors the current in the transmission line and identifies key fault conditions, including single line-to-ground, line-to-line, double line-to-ground, and three-phase faults. By examining changes in current due to abnormal conditions, the system figures out the type of fault and estimates the distance to the fault based on the electrical properties of the transmission line. Additionally, the system enables real-time monitoring and alert generation, allowing fault information and location details to be sent to a remote platform for quick action by maintenance teams. Testing shows that the system can effectively detect various fault types and provide precise location information. This system offers a reliable and budget-friendly method for better fault management, reducing response times, and improving the overall reliability of power transmission networks.

Keywords: *Three-Phase Transmission Line, Fault Detection, Fault Location Estimation, IoT Monitoring, Power System Protection, Real-Time Analysis.*

1. Introduction
Electrical energy is generated at power plants using generators driven by sources like thermal, hydro, nuclear, or renewable energy systems. Typically, this electrical power is produced at medium voltage levels ranging from about 11 kV to 25 kV. To transmit this power efficiently over long distances, the voltage is increased with step-up transformers at the generating station. The voltage is raised to high transmission levels such as 132 kV, 220 kV, 400 kV, or higher. This significantly reduces transmission losses by lowering the current in the conductors. The electrical power is then sent through high-voltage transmission lines that connect generating stations to major substations across the power network. These transmission lines are usually overhead lines supported by towers and have three conductors for the three phases of the electrical system. Three-phase power transmission is common in modern electrical networks because it is efficient and can deliver large amounts of power. In a three-phase system, three sinusoidal voltages of equal size are generated with a 120-degree phase difference. The three-phase conductors carry power together, ensuring continuous and balanced power delivery to the grid. At receiving substations, the high transmission voltage is lowered through step-down transformers to levels like 33 kV or 11 kV for distribution. From these substations, electrical power goes through distribution lines, which can be overhead or underground based on the application and location. The distribution network further reduces the voltage with distribution transformers near residential, commercial, or

industrial areas. These transformers change the voltage to usage levels like 415 V for three-phase supply and 230 V for single-phase supply, which are suitable for end users. The electricity is then delivered to homes, industries, and commercial buildings through low-voltage distribution lines. Throughout this process, it is vital to maintain the reliability and stability of transmission and distribution lines to ensure a steady power supply to consumers. Several research studies have focused on improving monitoring and protection of transmission lines using modern electronics and communication technologies. With advancements in embedded systems and microcontrollers, intelligent monitoring systems can be developed to continuously check electrical parameters and spot abnormal conditions. Microcontroller-based protection systems offer benefits like real-time monitoring, low cost, compact design, and easy integration with communication networks. These systems can detect different types of faults that often occur in three-phase transmission lines, including single line-to-ground, line-to-line, double line-to-ground, and three-phase faults. Quick detection of these faults helps engineers locate problems and restore normal operation of the power system. In recent years, several methods have been suggested for detecting and locating faults on transmission lines. Traditional protection techniques depend on circuit breaker protection schemes and impedance-based methods to identify fault conditions in power systems. However, these conventional methods may need complex infrastructure and may not provide real-time monitoring for distributed systems. Modern solutions use sensors, microcontrollers, and wireless communication technologies to enhance monitoring and fault management. Current sensing devices and digital processing techniques allow the system to analyze changes in electrical parameters and identify abnormal conditions along the transmission line. With the growth of Internet of Things (IoT) technologies, remote monitoring of power systems is becoming more practical. IoT-based monitoring systems allow real-time data transfer from the transmission line to a cloud platform, enabling engineers and maintenance teams to monitor system conditions from afar. The use of location tracking technologies improves the efficiency of fault management by providing information about the geographical location of faults. This capability greatly decreases the time needed to identify and fix faults in transmission networks. In this work, a monitoring system is developed to detect various types of faults in a three-phase transmission line and estimate the distance to the fault location. The system continuously monitors current changes in the transmission line and identifies abnormal conditions related to different fault types. The proposed approach also supports remote monitoring and alert generation, allowing maintenance teams to receive fault information and location details through a cloud-based platform. The effectiveness of the proposed system is tested experimentally to demonstrate its ability to detect faults and enhance the efficiency of transmission line fault management.

2. Literature Review

Fault detection and analysis in power transmission lines have been widely studied due to their importance in maintaining system reliability and minimizing power outages. Traditional methods for fault detection relied on impedance-based techniques and protective relays; however, these methods often lack real-time monitoring capabilities and adaptability to modern smart grid systems. Recent advancements have focused on integrating intelligent algorithms, sensor networks, and IoT technologies to enhance the efficiency and accuracy of fault detection systems. Several studies have explored the application of machine learning and deep learning techniques for fault diagnosis in power transmission systems. In [1], a comprehensive review of deep learning approaches highlights their effectiveness in identifying complex fault patterns, while also discussing challenges such as data dependency and computational requirements. Similarly, works in [3], [12], and [14] propose advanced models using temporal convolution neural networks and supervised learning techniques for accurate fault classification and localization. These approaches improve detection accuracy but require large datasets and high computational resources, which may not be suitable for low-cost embedded implementations. Additionally, studies such as [11] and [17] provide insights into various classification algorithms and machine learning-based fault detection strategies, emphasizing their growing importance in modern power systems. Another significant area of research involves the use of wireless sensor networks (WSNs) and communication technologies for monitoring transmission lines. The survey presented in [2] discusses the role of WSNs in smart grid applications, highlighting their ability to provide real-time data collection and monitoring. Similarly, [4] and [5] explore efficient communication strategies for sensor networks used in condition monitoring of large-scale systems, including transmission lines. These approaches enable remote monitoring but may face challenges related to energy consumption, network reliability, and scalability. Research has also been conducted on sensor-based and non-intrusive fault detection techniques. In [6], surface wave sensors are utilized for non-intrusive fault detection, offering a novel approach to monitoring without direct electrical contact. Furthermore, [7] provides a detailed review of various fault diagnosis techniques used in electrical systems, emphasizing the importance of accurate sensing and signal analysis. The work in [15] focuses on high-impedance fault detection in combined transmission and distribution systems, which is a critical challenge in real-world applications due to the subtle nature of such faults. With the rapid development of IoT and smart monitoring systems, recent research has shifted towards integrating communication technologies with fault detection mechanisms. In [10] and [16], IoT-based systems are proposed for real-time monitoring and fault identification in transmission lines, demonstrating improved accessibility and faster response times. Additionally, [9] introduces a blockchain-based federated learning approach for device failure detection in industrial IoT environments, highlighting the potential of secure and distributed data processing in modern power systems. The study in [8] also explores enhanced communication techniques for power line systems, contributing to improved data transmission efficiency. Recent literature reviews such as [13] summarize advancements in fault detection techniques, emphasizing the transition from conventional methods to intelligent and hybrid approaches. These studies indicate that while advanced techniques like machine learning and IoT provide high accuracy and real-time capabilities, they often involve increased complexity, cost, and dependency on communication infrastructure. From the reviewed literature, it is evident that although numerous advanced methods exist for fault detection and classification, there is still a need for cost-effective, simple, and real-time monitoring systems that can be implemented using embedded platforms. Most existing solutions either focus on high computational techniques or require complex infrastructure. Therefore, the proposed system aims to bridge this gap by developing a microcontroller-based fault detection and analysis system integrated with IoT capabilities, providing a practical and efficient solution for real-time fault monitoring and location identification in three-phase transmission

Table 1 **Existing Fault Detection**

S. No	Methodology	Working Principle	Advantages	Limitations
1	Overcurrent Relay Method	Detects faults based on excessive current flow	Simple and widely used	Cannot identify exact fault location
2	Distance Protection Method	Uses impedance to estimate fault distance	Provides approximate location	Expensive and complex setup

3	Earth Fault (Ground Rod) Method	Provides path for fault current to ground	Ensures system safety	No fault classification or monitoring
4	Traveling Wave Method	Detects faults using wave propagation signals	High accuracy in location	Requires high-speed devices and costly equipment
5	Wireless Sensor Networks	Uses distributed sensors for monitoring	Real-time monitoring capability	Network delay and reliability issues

3. Proposed System Architecture and Methodology

A sensing unit, processing unit, protection unit, and communication module are all integrated into a single framework to form the overall system architecture of the suggested three-phase transmission line fault detection and analysis system. Using current sensors, the system keeps an eye on the current flowing through each phase of the transmission line. A microcontroller then processes the measured data to determine the location of fault conditions. The faulty portion of the line is isolated using a relay-based protection unit, and faults are immediately indicated by an alert mechanism. Furthermore, a GPS-capable communication module allows location data and fault information to be transmitted to a remote platform, enabling authorized personnel to monitor and react to faults in real time. [9]

3.1. Modelling of Three Phase Transmission Lines

The modeling of the three-phase transmission line in the proposed system is carried out using a simplified resistive network and Transformers to emulate the electrical behavior of an actual power transmission line. Each phase is represented individually, and the line is divided into multiple sections using resistors of equal value, where each section corresponds to a fixed distance. This approach allows the representation of line impedance in a controlled and measurable manner. The three phases are configured to replicate practical operating conditions, enabling the simulation of various fault scenarios. [10]

3.2. Fault Detection and Classification

The proposed system employs a current-based fault detection strategy by continuously monitoring the current in each phase of the transmission line. Any abnormal variation in current beyond predefined threshold levels is identified as a fault condition. Based on the amperes across the three phases, the system classifies faults into single line-to-ground, line-to-line, double line-to-ground, and three-phase faults. This approach ensures reliable and fast identification of fault types under different operating conditions.

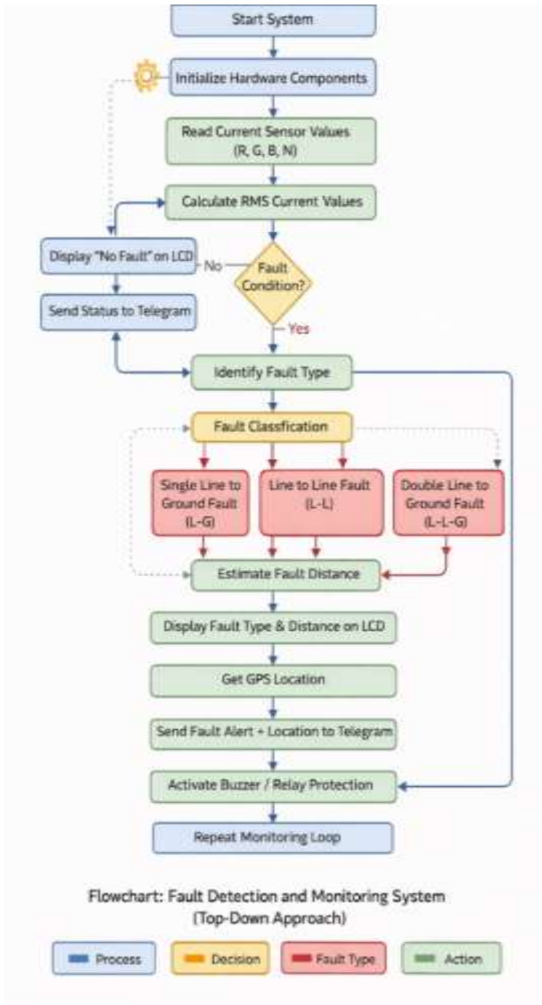

Figure 1 Proposed Flow Chart

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3.3. Fault Location Estimation

The fault location is estimated using the relationship between current, resistance, and distance along the transmission line. Since the line is modeled with known resistance per unit length, the system calculates the approximate distance of the fault by analyzing the change in current during fault conditions. This method provides a simple yet effective approach for locating faults within the transmission line, enabling quicker identification of the affected section.

3.4. Protection and Control Mechanism

To ensure system safety, a relay-based protection mechanism is implemented to isolate the faulty section of the transmission line at the pole level. In the proposed system, each pole or line segment is controlled by a dedicated relay that manages all three phases collectively. When a fault occurs in any one of the phases within a particular section, the control unit detects the abnormal current condition and activates the corresponding relay, which disconnects the entire pole containing the fault. This results in the isolation of only the affected section, while the remaining poles or line segments continue to operate normally without interruption. Although this approach does not provide selective phase isolation within a pole, it ensures localized fault clearance and prevents the fault from propagating to other sections of the transmission line. Additionally, a buzzer is used to provide immediate indication of the fault condition for local monitoring.

3.5. IoT-Enabled Monitoring and Notification Framework

The system incorporates an IoT-based communication framework to enable real-time monitoring and remote accessibility. Fault-related data, including fault type and estimated location, is transmitted to a cloud platform through a wireless communication module. Additionally, location information obtained from the GPS module is used to provide precise fault location details, which are shared with users through mobile notifications and dashboards, allowing timely response from maintenance personnel.[11]

4. Experimental Setup and Results Analysis

4.1. Setup Description

The experimental setup consists of a three-phase transmission line model implemented using resistive elements to represent different sections of the line. Each phase relates to current sensors to continuously monitor the line current. The sensed data is fed into a microcontroller for processing and analysis. A relay unit is integrated into the system to isolate faulty sections during abnormal conditions. The entire system is powered using a regulated DC supply to ensure stable operation.[12]

4.2. System Configuration and Calibration

The system is configured by calibrating the current sensors to obtain accurate and consistent measurements across all phases. A relationship between current variation and line distance is established based on the known resistance values of the transmission line model. Threshold limits are carefully defined to distinguish between normal and fault conditions. This calibration ensures reliable fault detection and improves the accuracy of fault location estimation.[13]

4.3. Test Case Scenarios for Fault Analysis

The performance of the system is evaluated under different operating conditions, including normal operation and multiple fault scenarios. The considered fault cases include single line-to-ground (L-G), line-to-line (L-L), double line-to-ground (L-L-G), and three-phase (L-L-L) faults. Each fault is introduced at different locations along the transmission line model to verify the system’s ability to detect and classify faults accurately. [14]

4.4. Observed Results and Performance Evaluation

During testing, the system records the current values corresponding to each fault condition and processes them to identify the fault type. The estimated fault distance is calculated based on the observed electrical variations. The obtained results are compared with expected values to evaluate the effectiveness of the system. The performance is further validated through consistent detection across multiple test cases.[15]

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4.4.1. Double Line-to-Ground Fault (L–L–G)

In this fault, two phase conductors simultaneously come into contact with the ground. It is more severe than single line faults and leads to a higher fault current and greater system disturbance. [16]

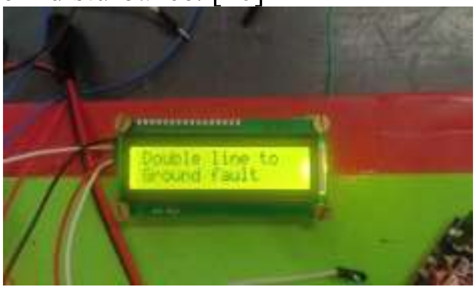

Figure 2 Double Line-to-Ground Fault

4.4.2. Line-to-Line Fault (L–L)

This fault happens when two phase conductors touch each other due to insulation failure or external conditions. It results in a high current flow between the two lines and causes system imbalance.

Figure 3 Line-to-Line Fault

4.4.3. Single Line-to-Ground Fault (L–G)

This occurs when one phase conductor comes into contact with the ground or an earthed object. It is the most common type of fault and causes unbalanced current flow in the system. It can lead to equipment damage if not detected quickly.

Figure 4 Single Line to Ground Fault

4.5. Fault Location Estimation

Fault location estimation is the process of determining the distance or position of a fault along the transmission line. In this project, it is achieved by analyzing the magnitude of the fault current measured by the sensors. Since the transmission line is modeled using resistors, the current varies depending on how far the fault occurs from the source. By comparing the measured current with predefined threshold ranges, the system estimates the approximate distance of the fault (e.g., 2 km, 4 km, etc.). This helps in quickly identifying the fault location and reduces the time required for maintenance and repair.

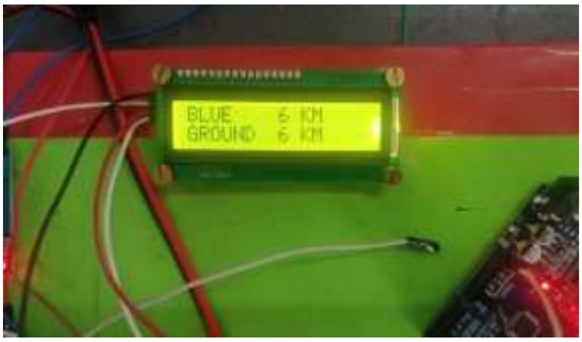

Figure 5 Distance Estimation of the Faults

4.6. Fault Detection Accuracy and Error Analysis

The accuracy of the system is assessed by comparing the estimated fault location with the actual fault position. The deviation between these values is used to calculate the percentage error for each test case. This analysis helps in understanding the reliability and precision of the proposed method. The results indicate that the system maintains acceptable accuracy within the limits of the experimental setup.[17]

4.7. IoT Monitoring and Notification Performance

The system incorporates an IoT module to transmit fault-related data to a cloud platform for remote monitoring. Notifications are generated and sent to users through a messaging interface like a Telegram Bot, enabling quick awareness of fault conditions. The response time of data transmission and the reliability of communication are evaluated to ensure effective real-time monitoring. GPS integration further enhances the system by providing location-based information. Fault Alert will be given to the Executive Officer of TNEB. [17]

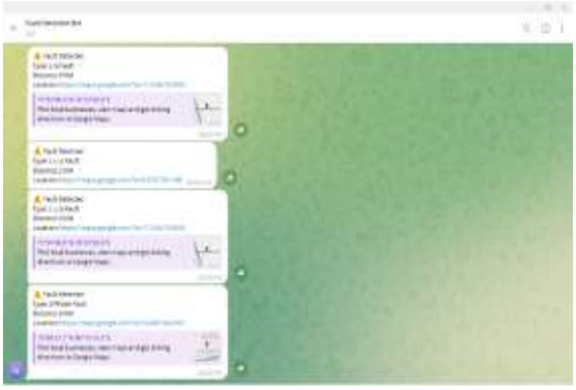

Figure 6 Telegram Bot Alert System

Future Work

The proposed system can be further enhanced by extending its application to modern renewable energy environments such as solar and wind-based grids, where fault characteristics are more dynamic, thereby improving compatibility with decentralized power systems. Additionally, a dedicated mobile application can be developed to replace basic messaging platforms, enabling real-time monitoring, fault history tracking, and structured alert notifications through an intuitive interface. Future improvements may also focus on hardware optimization by incorporating industrial-grade sensors, improved noise immunity techniques, and compact PCB-based designs to ensure higher reliability and robustness in practical deployments. Furthermore, the system can be made more scalable and efficient by adopting advanced communication protocols and architecture, allowing reliable monitoring of large-scale transmission networks with improved accuracy and performance.

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