

Advanced Three-Phase Fault Detection Techniques for Power Transmission Lines

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Abstract: *Power transmission lines are susceptible to different fault conditions that may interrupt electricity supply and cause equipment damage if not identified promptly. This study presents an improved method for real-time detection and analysis of faults in three-phase transmission lines aimed at enhancing system dependability and response speed. Voltage and current sensors installed along the transmission line continuously track operating conditions to detect any abnormal behavior. Upon the occurrence of a fault, the system instantly triggers a local warning and communicates fault information to operators through text-based alerts for immediate action. The proposed system also determines the specific nature of the fault, including line-to-ground, line-to-line, double-line-to-ground, and three-phase faults. Furthermore, a GPS-assisted fault location mechanism is employed to pinpoint the exact physical location of the faulted section, enabling faster maintenance response and minimizing service interruptions. By integrating real-time monitoring, intelligent fault classification, communication technology, and location tracking, the proposed approach provides a reliable and practical solution for modern power transmission and smart grid systems.*

Keywords: Three-Phase Fault Detection, Power Transmission Lines, Fault Classification, Line-to-Ground Fault, Line-to-Line Fault, GPS-Based Fault Location, Sensor Alarm System, Text Message Notification, Smart Grid, Power System Protection

1. INTRODUCTION

Transmission lines are a vital component of electrical power systems, responsible for transmitting energy from generation units to load centers over long distances. Due to continuous exposure to environmental and operational stresses such as lightning, wind, rainfall, insulation aging, and mechanical loading, these lines are highly prone to fault conditions. In three-phase transmission networks, common faults include line-to-ground, line-to-line, double-line-to-ground, and three-phase faults, which can cause severe voltage disturbances, equipment damage, and prolonged power interruptions if not detected and cleared promptly [1], [2], [5]. Conventional protection schemes mainly rely on overcurrent and distance relays that operate based on measured voltage and current signals. Although these techniques are well established and reliable, they often provide limited information regarding the exact fault type and location, leading to increased fault isolation time and delayed service restoration, especially in large and complex power networks [3], [6], [18].

To overcome these limitations, recent research has focused on advanced fault detection and classification techniques that enhance protection accuracy and system reliability. Intelligent methods such as wavelet-based signal analysis, artificial neural networks, and hybrid expert systems have demonstrated improved performance in extracting fault characteristics from transient signals and accurately identifying affected line sections [15], [19], [20]. In addition, the integration of communication technologies such as GSM and IoT enables real-time fault notification to operators, while GPS-assisted fault location techniques allow precise identification of the faulted section, significantly reducing



maintenance response time and outage duration [12], [14], [17], [20]. With the advancement of smart grid technologies, modern fault detection systems increasingly combine sensing, intelligent processing, communication, and location tracking into a unified framework. This work focuses on advanced fault detection strategies for three-phase transmission lines, emphasizing accurate fault recognition, classification, real-time alerts, and GPS-supported fault localization to improve overall system reliability, safety, and operational efficiency [10], [16].

II. LITERATURE REVIEW

Ref.	Author	Focus Area	Key Contribution	Limitation
[1]	S. H. Ghadge (2025)	Fault detection using voltage & current sensing	Relay-based model for basic fault detection and isolation	No advanced classification or accurate fault location
[8]	Borkhade (2019)	Wavelet-based fault detection	Improved speed and accuracy using transient analysis	Lacks real-time implementation details
[13]	Anonymous (2023)	Practical fault detection	Simple sensing and control-based implementation	No intelligent classification or precise location

III. METHODS AND MATERIAL

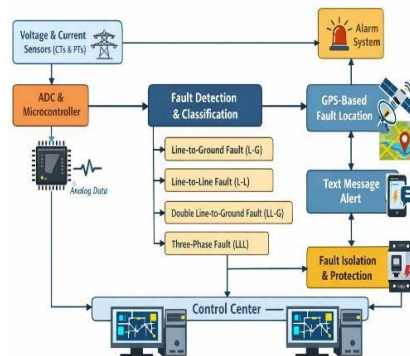


Figure 1:

A. Solar PV–Based Charging Station Method

This approach deploys solar photovoltaic panels at designated sites such as residential premises, parking areas, commercial facilities, and highway charging points. The electrical energy produced is either supplied directly to charge plug-in electric vehicles or stored in battery units for future utilization. Depending on design objectives and reliability needs, the system can function in off-grid, grid-connected, or hybrid operating modes [13], [14].

B. Data Acquisition Using Sensors

Current transformers and potential transformers are employed to measure real-time current and voltage signals from the R-Y-B phases of the transmission line. These analog measurements are digitized using an analog-to-digital converter integrated within a microcontroller or digital processing unit. Continuous signal sampling allows rapid identification of both transient and steady-state fault conditions [2], [3], [7].



C. Fault Detection Logic

Fault detection is performed by evaluating the measured voltage and current signals against predefined threshold levels. The occurrence of a fault is indicated by a sudden rise in current magnitude or a significant reduction in voltage. The detection algorithm is designed for rapid response to abnormal operating conditions in order to reduce fault isolation time and limit system disturbances [4], [9], [16].

D. Fault Classification

After a fault is detected, the system determines the nature of the fault present on the transmission line. Fault classification is carried out by analyzing the characteristic patterns of voltage and current variations across the three phases:

- Line-to-Ground (L-G) Fault: Abnormal current in one phase with ground involvement
- Line-to-Line (L-L) Fault: High current in two phases without ground current
- Double Line-to-Ground (LL-G) Fault: Two phases connected to ground
- Three-Phase (LLL) Fault: High current in all three phases

To enhance fault classification accuracy in the presence of noise, advanced signal processing and intelligent methods such as wavelet-based analysis and artificial neural networks can be employed [7], [8], [11], [19], [20].

E. Alarm Generation

Once a fault is detected and classified, a sensor-driven local alarm is activated to immediately notify personnel at the substation or monitoring site. This alert enables nearby operators and maintenance staff to respond promptly with manual intervention if necessary [6], [14].

F. Communication and Text Message Notification

To improve remote monitoring capabilities, the system incorporates communication modules such as GSM or IoT-enabled devices. When a fault occurs, an automatic text message detailing the fault type and affected phase is sent to operators or maintenance staff. This functionality enhances response times and facilitates centralized supervision of the transmission network [12], [14].

G. GPS-Based Fault Location

The system employs GPS technology to determine the precise location of the faulted segment of the transmission line. By integrating GPS coordinates with distance relay principles, the fault can be pinpointed with higher accuracy. This enables maintenance teams to reach the affected site more quickly, thereby minimizing outage duration and accelerating restoration [17], [18], [20].

H. Fault Isolation and Protection Action

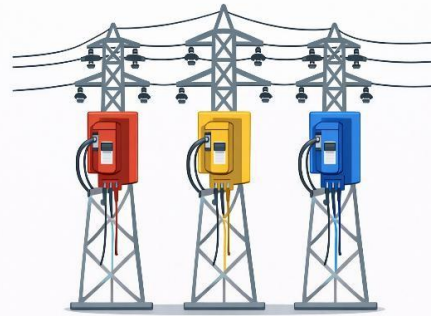
Relays or circuit breakers are activated to isolate the faulted portion of the transmission line. Rapid isolation helps prevent the fault from spreading and safeguards the unaffected sections of the power system from potential damage [3], [6], [18].

Material required.

A. Voltage Sensors / Potential Transformers (PTs)

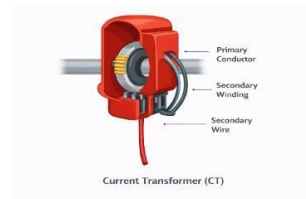
Potential transformers are employed to measure the voltage of each phase (R-Y-B) in the transmission line. They reduce high voltages to safer levels, making them suitable for signal processing and fault detection analysis.





Voltage Sensors / Potential Transformers (PTs)

B. Current Sensors / Current Transformers (CTs) Current transformers are employed to measure line currents in all three phases. Sudden changes in current magnitude are key indicators of fault conditions in transmission lines .



Current Transformer (CT)

C. Micro controller / Processing Unit

A microcontroller (such as Arduino, PIC, or ARM-based controller) is used to process digitized voltage and current signals. It performs fault detection, classification, alarm triggering, communication, and control functions.

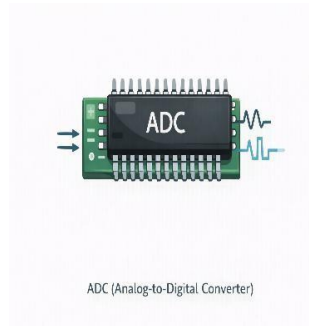


Microcontroller / Processing Unit

D. Analog-to-Digital Converter (ADC)

An ADC is required to convert analog signals from voltage and current sensors into digital data for processing by the microcontroller. In many systems, the ADC is built into the controller.





E. GPS Module

A GPS module is used to obtain real-time geographical coordinates of the faulted section. This enables accurate fault location and faster maintenance response



F. Communication Module (GSM / IoT Module)

A GSM or IoT communication module is used to send text message alerts to operators when a fault is detected. It allows remote monitoring and real-time fault notification.



G. Alarm System

An audible or visual alarm (buzzer or siren) is used to provide immediate local indication of a fault occurrence at the monitoring station or substation.

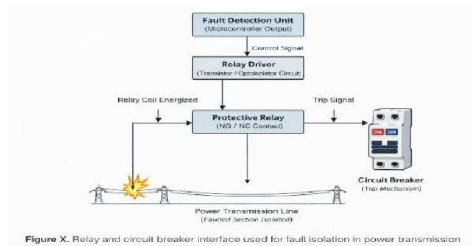


Figure X. Relay and circuit breaker interface used for fault isolation in power transmission

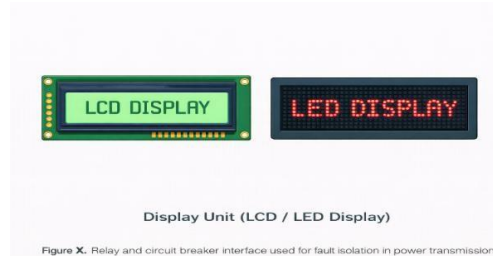
H. Relay and Circuit Breaker Interface

Relays are used to isolate the faulted section of the transmission line by tripping the circuit breaker when a fault is detected. This protects equipment and ensures system safety.



I. Display Unit (LCD / LED Display)

A display unit is used to show fault type, affected phase, and system status locally for monitoring and diagnostic purposes.



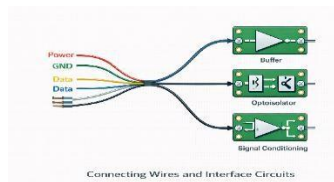
J. Power Supply Unit

A regulated power supply is required to provide appropriate operating voltages to the microcontroller, sensors, communication modules, and other electronic components.



K. Connecting Wires and Interface Circuits

Wires, connectors, signal conditioning circuits, and protection components are used to interconnect sensors, controllers, and modules safely and reliably.



L. Software Tools

Programming software such as Arduino IDE, MATLAB/Simulink, or embedded C compilers are used for algorithm development, simulation, and controller programming.

IV. PROPOSED SYSTEM

Ghadge (2025) introduced a project-based approach for detecting faults in three-phase transmission lines using voltage and current sensors, where abnormal conditions were identified and isolated using protective relays; however, the system lacked advanced communication and accurate fault location features [1]. Phadke and Thorp (2009) emphasized the importance of computer-based relaying and digital signal processing for improving fault detection speed and accuracy, which is reflected in the proposed system through the use of a microcontroller for continuous monitoring and classification of digitized electrical signals [3]. The effectiveness of IoT-enabled fault detection systems in providing real-time alerts was demonstrated by Ali et al. (2025), and similarly, the proposed system integrates GSM/IoT communication to instantly notify operators and maintenance personnel, reducing response time and system downtime



[12], [14]. Furthermore, Kezunovic (2011) highlighted the role of smart grid technologies and GPS-based fault location techniques in accurately identifying faulted sections, which is adopted in the proposed system through GPS integration for precise fault localization [17], [18], [24]. Studies by Soman et al. (2002) and Livani and Evrenosoglu (2013) showed that advanced signal processing and intelligent techniques enhance fault classification accuracy, and these concepts support the system's ability to classify faults into line-to-ground, line-to-line, double line-to-ground, and three-phase categories [7], [20], [20]. In addition, the importance of alarms, display units, and relay interfaces for immediate warning and system protection, as discussed by Ravindranath and Chander (2011), is incorporated through local alerts, LCD/LED displays, and relay-based circuit breaker operation to isolate faulty sections and protect healthy parts of the power network [6], [18].

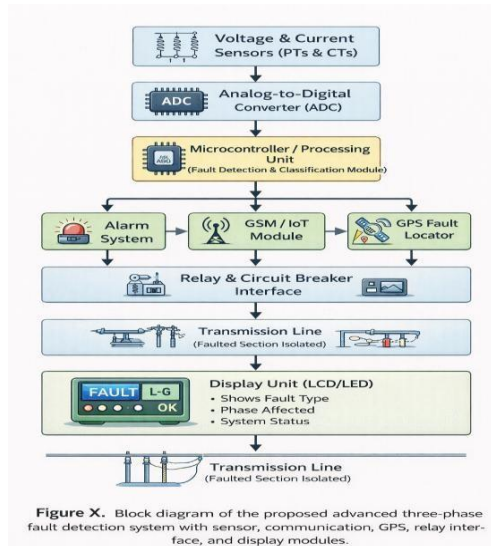


Figure. 9: Proposed System Of Real Time Fault Analysis Of Three Phase Transmission Line

V. WORKING

The proposed advanced three-phase fault detection system continuously monitors the transmission line to ensure reliable and secure power delivery by measuring real-time voltage and current signals using potential transformers and current transformers. These analog signals are converted into digital data through an ADC and processed by a microcontroller, which acts as the core decision-making unit of the system. Under normal conditions, the system operates in monitoring mode, while any abnormal deviation in electrical parameters triggers fault detection and classification for line-to-ground, line-to-line, double line-to-ground, or three-phase faults. Upon fault detection, the system immediately generates local alarm indications and transmits real-time fault information to the control center using GSM or IoT communication. A GPS module provides precise fault location data, enabling faster maintenance response and reduced outage time. Based on the microcontroller's decision, relay and circuit breaker mechanisms isolate the faulty section to protect the remaining network, while an LCD or LED display presents fault type, affected phase, and system status. After fault clearance, the system automatically returns to normal monitoring mode, ensuring continuous and efficient operation suitable for modern smart grid applications.

VI. ADVANTAGES

1. Fast fault detection is achieved through continuous monitoring of voltage and current, allowing quick identification of abnormal conditions.
2. The system accurately identifies different fault types, improving protection reliability and reducing troubleshooting time.



3. Real-time alerts using alarms and GSM/IoT communication immediately inform operators about fault occurrences.
4. Quick isolation and accurate fault location help reduce power outage duration and improve overall system safety.

VII. DISADVANTAGES

1. High initial cost is required due to the use of sensors, GPS modules, communication units, and controllers.
2. The alert system depends on GSM/IoT networks, which may not be reliable in remote or rural areas.
3. The integration of multiple hardware and software components increases overall system complexity

VIII. CONCLUSION

The proposed advanced three-phase fault detection system offers a reliable and efficient solution for enhancing the protection of power transmission lines. By continuously monitoring voltage and current parameters, it enables rapid and precise fault detection. The use of intelligent fault classification techniques allows the system to identify various fault types, including line-to-ground, line-to-line, double line-to-ground, and three-phase faults.

Integration of GSM/IoT communication ensures real-time notifications to operators, while the GPS-based fault location feature accurately pinpoints the affected section. Automatic relay and circuit breaker operation facilitates the swift isolation of faulty lines, improving overall system safety and reliability. Additionally, display units and alarm systems enhance monitoring and provide operators with immediate awareness of system conditions.

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