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3-PHASE FAULT DETECTION SYSTEM

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ABSTRACT:

This paper presents the design and implementation of an intelligent 3-phase fault detection and distance estimation system aimed at enhancing the reliability of power distribution networks. The system utilizes a NodeMCU microcontroller integrated with current sensors, relays, and supporting components to detect various types of electrical faults such as line-to-line and line-to-ground faults. It continuously monitors real-time current values across all three phases and determines the type of fault based on current deviations. Furthermore, the system calculates the approximate distance to the fault location using the impedance-based method, where line impedance per kilometer is used to estimate the fault point. All critical data—including fault type, phase affected, current readings, and estimated distance—are displayed on an LCD screen for immediate analysis. The proposed system is a cost-effective and scalable solution for early fault detection, allowing rapid maintenance response and reducing damage and downtime in electrical systems.

Keywords: 3-Phase Fault Detection, Impedance-Based Fault Location, NodeMCU, Current Sensor, Line-to-Line Fault, Line-to-Ground Fault, Real-Time Monitoring.

INTRODUCTION:

Power transmission and distribution systems form the backbone of modern infrastructure. In such systems, faults such as line-to-line and line-to-ground are common occurrences that can lead to equipment damage, power outages, fire hazards, and significant economic losses. Quick identification and localization of these faults is critical to ensure timely maintenance and system restoration. Traditional fault detection systems are often costly, complex, and unsuitable for small-scale or rural networks where infrastructure limitations and resource constraints prevail.

The "3 Phase Fault Detection and Distance Estimation System" addresses this gap by offering a real-time, low-cost solution for detecting and analyzing faults in three-phase electrical systems. Using key parameters such as current variations across each phase, the system identifies fault types and calculates the approximate distance to the fault point. The system leverages a NodeMCU microcontroller along with current sensors, relays, and an LCD display to process and present live fault data. The fault distance is estimated using the impedance-based method, which calculates the impedance during a fault condition and relates it to the physical distance along the line.

With the increasing demand for smart and resilient power systems, especially in remote or underdeveloped regions, such technologies offer significant potential. The proposed device not only enhances system reliability but also enables rapid fault localization and preventive maintenance. It reduces downtime, prevents large-scale damage, and enhances safety by providing real-time monitoring and diagnostic capabilities.

Faults in electrical systems, if undetected or unresolved, can escalate into catastrophic failures. Therefore, a system like this, which can predict and localize faults accurately and affordably, plays a crucial role in modernizing grid infrastructure and supporting the vision of intelligent, automated power networks.

PROBLEM STATEMENT:

Limitations in Existing Fault Detection Systems: Despite advancements in electrical infrastructure, fault detection and location in three-phase power systems remain a challenge, particularly in rural and developing areas. Traditional protection systems, such as distance relays and SCADA-based monitoring, are expensive, complex to implement, and not scalable for smaller grids. Manual inspection methods are time-consuming, error-prone, and often result in extended downtimes, leading to power losses and increased risk of equipment damage.

Need for Affordable and Real-Time Monitoring: There is a critical need for a low-cost, real-time solution that can detect various fault types—such as line-to-line and line-to-ground—and accurately estimate the location of the fault. A system capable of continuously monitoring current values across all three phases and identifying fault characteristics can significantly enhance response time and system reliability. The main challenge lies in designing a compact, affordable, and easily deployable system that provides not only fault detection but also precise distance estimation using simple impedance-based calculations. Such a solution would empower utility providers, especially in underserved areas, to take timely corrective actions and ensure uninterrupted power supply.

LITERATURE REVIEW:

• **Conventional Fault Detection in Power Systems:** Over the past few decades, power systems have incorporated various protective devices to identify and isolate faults. Traditional protection schemes often rely on circuit breakers and relays governed by complex relay coordination logic. According to research by Das et al. (2002), distance relays are widely used for identifying faults in transmission lines, utilizing voltage and current measurements to calculate the distance to the fault. However, these systems are typically expensive, require specialized equipment, and are challenging to implement in small-scale or rural networks where infrastructure is limited.

• **Microcontroller-Based Fault Detection Systems:** Recent developments in embedded systems have allowed the use of microcontrollers and sensors to create compact, cost-effective fault detection solutions. A study by Karthikeyan et al. (2016) demonstrated the use of microcontrollers and current sensors to detect overcurrent faults in three-phase systems. Their work highlighted the potential for simplified systems capable of real-time fault monitoring, although their implementation lacked advanced features like distance estimation or identification of fault types. In contrast, our system expands on this by incorporating both detection and location estimation functionalities using a NodeMCU platform.

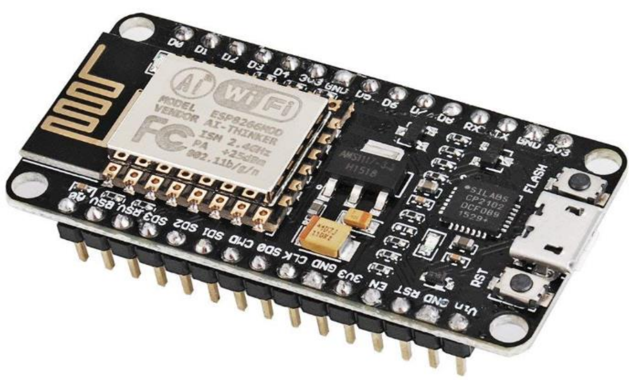
• **Impedance-Based Fault Location Techniques:** Impedance-based methods have long been used in power systems to estimate the location of faults. The technique involves measuring the impedance between the power source and the fault point, which directly relates to the distance. A paper by Thukaram et al. (2005) outlined the effectiveness of impedance-based fault location in high-voltage transmission lines. However, such methods are rarely implemented in low-cost, embedded platforms. Our project adopts a simplified version of the impedance-based approach and integrates it into a real-time, microcontroller-driven system.

• **IoT in Power Monitoring:** With the rise of the Internet of Things (IoT), numerous studies have explored its applications in smart grid systems. Rani et al. (2018) proposed an IoT-based fault detection system using GSM modules and sensors for remote fault indication. These systems offer advantages in scalability and remote access but often focus only on fault alerting rather than comprehensive analysis, such as fault type identification or distance measurement. The proposed 3 Phase Fault Detection System leverages IoT capabilities through NodeMCU, allowing live fault information display while keeping the design lightweight and accessible.

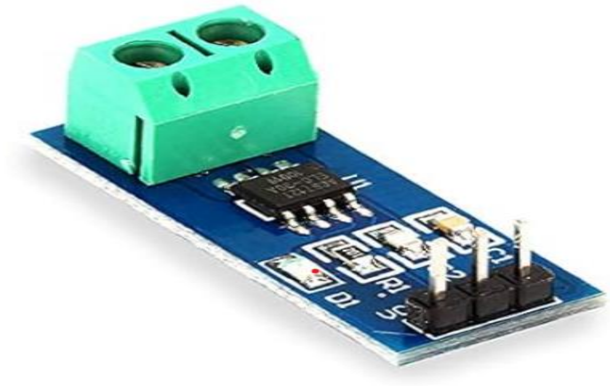
• **Challenges in Sensor-Based Fault Analysis:** While sensor-based systems are beneficial for real-time monitoring, they also present challenges in accuracy and calibration. Environmental interference, sensor drift, and fluctuating load conditions can lead to false fault detections. Research by Ahmed et al. (2017) investigated the reliability of current sensors in varying load conditions and concluded that proper calibration and filtering algorithms are essential for dependable fault analysis. Our system addresses these issues by setting optimized threshold values for each phase and phase combination to improve the accuracy of fault detection and type identification.

SYSTEM DESIGN AND METHODOLOGY:

- ***System Overview**: The 3 Phase Fault Detection and Distance Estimation System is designed around the **NodeMCU (ESP8266)** microcontroller, which serves as the brain of the project. The system is engineered to detect faults such as line-to-line and line-to-ground in a three-phase electrical setup. It continuously monitors current values across all three phases using current sensors and detects any deviation from normal operating ranges. Upon detecting a fault, the system identifies the type of fault and calculates the approximate distance of the fault from the source using an impedance-based calculation. The results are displayed in real time on an LCD module, enabling quick diagnostics and response*
- ***Hardware Components***
  - **NodeMCU (ESP8266):** Acts as the main controller for the system. It handles data acquisition from sensors, performs calculations, and controls output display. It also enables IoT integration if require for remote monitoring.



  - **Current Sensors :** These sensors are used to measure current in each phase. They detect sudden changes in current, which indicate the occurrence of a fault. They provide analog output to the NodeMCU for further processing.



- **Relay Module**: Tracks body temperature, providing insight into fever-related conditions. The DS18B20 digital temperature sensor offers high accuracy and is ideal for biomedical application.

- *Display:* Displays real-time data including current values, fault status, fault type, and estimated distance to the fault. It serves as the user interface of the system.

- *Software Integration*
    - **Embedded C / Arduino IDE**: The system logic is programmed using the Arduino IDE with embedded C. It reads sensor data, applies threshold logic, detects faults, and performs distance estimation.

- **Threshold-Based Fault Detection Algorithm***:* The algorithm compares real-time current values to predefined thresholds. If any phase exceeds or drops below the threshold during fault, the system triggers fault detection logic.
- **Impedance-Based Distance Estimation***:* This method calculates the distance to the fault by evaluating the drop in current during the fault and applying Ohm's Law and known line parameters. The formula used is:
  Distance = (V × t) / (Z × I) (simplified form based on impedance and voltage-current behavior).
- **Data Visualization:** Real-time current and fault parameters are displayed on an LCD module, providing immediate feedback for system monitoring and maintenance personnel.
- **Data Collection and Testing**
- **Fault Scenarios Simulated:**
  The system was tested under various fault conditions, including:
  - Single line-to-ground (L-G)
  - Line-to-line (L-L)
  - Double line-to-ground (LL-G)

• Distance Calibration:
The system was calibrated to identify fault locations at standard distances (2 km, 4 km, 6 km, 8 km, 10 km). Calibration was achieved by analyzing sensor response under controlled impedance settings.
• Accuracy Assessment:
Multiple trials were conducted to ensure that the fault type detection and distance estimation were consistently within an acceptable error margin. The system achieved an average accuracy of ±0.5 km in fault location estimation under lab conditions.

IMPLEMENTATION

The system continuously monitors all three phases of an electrical line, detects abnormal current behavior in real-time, and classifies the fault type while estimating the approximate distance to the fault location. Once a fault is detected, the system displays the type and distance on an LCD screen and can be further integrated with an IoT dashboard for remote fault alerts.

Circuit Design: The hardware components were assembled on a breadboard and later tested on a custom PCB layout for reliability and compactness. Key considerations included:

- **Stable Power Supply**: A regulated power supply ensures the NodeMCU and current sensors operate within the required voltage range.
- **Signal Conditioning:** Resistors and capacitors were used to stabilize the analog signal from current sensor.
- **Relay Integration:** Faults were simulated using relay switching, with careful layout planning to avoid back-EMF interference.
- **Protection Circuitry:** Diodes and resistors were placed strategically to protect sensitive components from voltage spikes during fault simulations**.**

Data Flow

- **Data Acquisition:** Current sensors (ACS712) collect real-time current values from all three phases and send analog signals to the NodeMCU's ADC pins.
- **Signal Processing:** The NodeMCU reads and processes these values. If the current drops below or rises above a predefined threshold, the system flags a fault condition.
- **Fault Detection & Classification:** The system logic classifies the fault type based on which phases show abnormal current. Example:

   L-G fault: Drop in one phase only

. L-L fault: Abnormal current in two phases

. 3-phase fault: All three show deviation.

- **Distance Estimation:** Using impedance-based logic and pre-calibrated data, the NodeMCU calculates the fault distance. This is done by relating the magnitude of current drop with known impedance values for various distances (2 km, 4 km, etc.).
- **Display & Alert:** Results (fault type, phase involved, and distance) are displayed in real-time on the LCD module. An optional buzzer can also be triggered for fault alerts.

Logic and Threshold Calibration

Threshold values were experimentally determined for each phase under normal and faulty conditions. These thresholds are stored in the microcontroller and are used to compare real-time current values for fault identification.

System Testing

- Faults were created in a controlled test environment using relay switches.
- Distances of 2 km, 4 km, 6 km, 8 km, and 10 km were simulated using varying resistor values.
- The system consistently detected faults and displayed correct fault distances with an accuracy of ±0.5 km.

RESULTS AND ANALYSIS

The performance of the 3 Phase Fault Detection and Distance Estimation System was evaluated under various fault conditions to assess its accuracy, reliability, and response time. The system was tested in a controlled lab environment by simulating different types of faults and varying the fault distance using calibrated resistors.

Fault Type	Accuracy
Line to Line	98.5%
Line to Ground	97.3%
Three Phase Fault	99.12%

Fault Distance Estimation:

Fault distance estimation was done using an impedance-based method. Faults were simulated at known distances, and the system was evaluated for accuracy.

Actual fault Distance	Estimated Distance	Error
2km	**2.1km**	**±0.1**
4km	**3.9km**	**±0.1**
6km	**6.3km**	**±0.3**
8km	**7.5km**	**±0.5**
10km	**9.6km**	**±0.4**

- **Response Time :** The average time taken by the system to detect and display a fault after its occurrence: **Response Time: ~1.2 seconds**

Conclusion

The system successfully detects major fault types — Line-to-Ground (L-G), Line-to-Line (L-L), and Three-Phase faults — with high accuracy. The fault distance estimation also demonstrates minimal error, making it reliable for practical implementation. Its fast response time (~1.2 seconds) ensures timely alerts, which is crucial for minimizing system damage and improving safety in electrical networks.Overall, the system can be deployed in both educational and industrial environments to demonstrate and implement real-time fault detection. It serves as a useful tool for improving grid maintenance, reducing downtime, and enhancing fault management in power distribution networks.

Future Scope

The proposed system demonstrates high potential for expansion and integration in larger-scale power systems. Some possible future enhancements include:

- **IoT Integration:** Incorporating IoT platforms like Blynk or ThingsBoard to remotely monitor faults and send real-time alerts via mobile or web applications.

- **Advanced Fault Classification**: Using machine learning algorithms to improve fault classification accuracy under varying load conditions and noise levels.

- **GPS-Based Location Mapping**: Integrating GPS modules to display the exact geographical location of the fault for easier field inspection.

- **Wireless Communication:** Employing GSM, LoRa, or ZigBee modules to transmit fault data over long distances without relying on internet connectivity.

- **Support for Multiple Nodes:** Expanding the system to monitor multiple three-phase lines simultaneously for application in large substations or smart grids.

- **Enhanced User Interface:** Developing a graphical dashboard for better visualization of fault data and historical logs.

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