International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 5; May 2025
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Underground Cable Fault Detection System Using ESP32

Dr. Sarin Vijay Mythry[1], S. Jayanth[2], M. Sri Charan[3], Sk. Abu Bakar[4], P. Lokesh[5]

[1,2,3,4,5]Department of ECE, Vignan Institute of Technology and Science, Hyderabad, India.

Corresponding Author: Sk. Abu Bakar

DOI: https://doi.org/10.52403/ijrr.20250565

ABSTRACT

The "Underground Cable Fault Detection System using ESP32" is an innovative solution aimed at accurately identifying and localizing faults in underground electrical cables. Traditional methods of fault detection are time-consuming and require extensive manual effort. This system leverages the ESP32 microcontroller, known for its advanced processing capabilities and wireless connectivity, to provide a cost-effective and efficient alternative.

The system operates by injecting a low DC voltage into the cable network and measuring the resulting impedance at regular intervals. Voltage dividers and sensors are used to detect abnormalities in resistance values, which indicate the presence of a fault. The ESP32 processes this data and determines the exact distance to the fault location using the principle of Ohm's Law. Real-time fault data is transmitted wirelessly to a monitoring system or displayed on an LCD for quick reference.

This approach reduces downtime by enabling precise fault localization and minimizing excavation and repair costs. The system is scalable, suitable for various industrial and domestic applications, and can be integrated with IoT platforms for enhanced monitoring. This project significantly improves the maintenance and management of underground cable networks by providing a reliable, real-time solution for fault detection.

Keywords: Cable Fault Detection, ESP32, Time-Domain Reflectometry, Fault Localisation, IoT based monitoring.

INTRODUCTION

In modern infrastructure, underground cables are widely used for electrical and communication networks due to their safety, reliability, and aesthetic advantages. These cables are less prone to damage from environmental factors such as storms and accidents, making them an essential component of urban and rural infrastructure. However, despite these benefits, one of the key challenges with underground cables is the difficulty of detecting and diagnosing faults. Locating faults in underground cables is often a complex and time-consuming process, requiring extensive manual effort, specialized equipment, and often invasive digging to access the cables. Faults in underground cables, whether due to wear and tear, accidental damage, or environmental factors, can result in power outages, disruptions in communication, increased repair costs, and operational delays. Such issues not only impact service providers but can also inconvenience users and compromise safety.

This project proposes an innovative, IoT-enabled system designed to automate and streamline the fault detection process for underground cables. By leveraging an ESP32 microcontroller, a GPS module, and a variety of sensors, this system can detect faults in real-time and accurately determine their location. The system continuously monitors the condition of the cables, and when a fault is detected, the GPS coordinates of the fault are instantly captured and transmitted to designated personnel via email. This real-time notification reduces the time required for fault diagnosis and accelerates the response time for repairs. By automating the fault detection process, this approach minimizes the need for manual inspection, reduces the risk of prolonged downtime, and ultimately enhances the efficiency of maintenance operations. The integration of IoT technology with traditional infrastructure makes the process more cost-effective, faster, and reliable, ensuring that systems remain operational with minimal disruptions.

LITERATURE REVIEW

Several researchers have designed IoT-based underground cable fault detection systems using ESP32. Kumar et al. (2020) proposed a system that uses ESP32 for fault detection in underground cables, integrating sensors to monitor cable conditions in real-time. Their system allows the detection of faults such as open circuits, short circuits, and voltage fluctuations, providing timely information to operators for prompt intervention [1].

Bansal et al. (2021) introduced a system that combines ESP32 with GSM for real-time fault detection and remote communication. Upon detection of a fault, the system sends SMS notifications to the operators, enabling quick responses even in remote areas. This feature greatly enhances the fault management process and ensures minimal downtime [5]. Agarwal et al. (2021) extended this approach by adding data logging capabilities and remote monitoring, enabling operators to access historical data to analyze trends and predict potential future faults [8].

Yang et al. (2020) designed a system that employs ESP32 for continuous monitoring of cable parameters such as temperature, current, and voltage. The system continuously sends this data to the cloud for real-time monitoring, enabling operators to observe any abnormal conditions that could lead to faults [9]. Mahajan et al. (2020) further emphasized the importance of data logging, where the system logs cable conditions over time, allowing for historical analysis and predictive maintenance, which is crucial for managing aging cable infrastructure and anticipating potential failures [12].

MATERIALS & METHODS

The methodology of the *Underground Cable Fault Detection System Using ESP32* combines both hardware and software elements to detect, localize, and report faults in underground electrical cables. The design follows a modular architecture, allowing each component to work both independently and cohesively. The process includes simulation of faults, real-time resistance measurement, fault localization using Ohm's Law, and communication of results via display and location modules. Below are the detailed explanations of each part of the methodology:

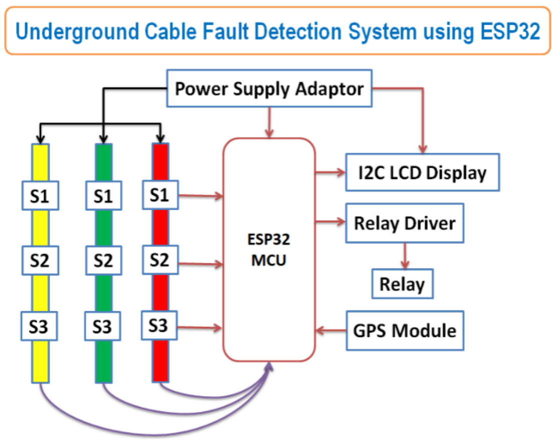

Fig. 1 Block Diagram

The IoT-based Underground Cable Fault Detection System utilizes an ESP32 microcontroller to monitor the status of underground cable lines and detect faults in real-time. Each cable line (red, blue, and yellow) is simulated with a set of push buttons corresponding to predefined fault distances (1 km, 2 km, and 4 km). When a fault is simulated by pressing a button, the system identifies the affected line and distance and deactivates the relay to isolate the faulted section. The system then captures the GPS location of the fault and displays it along with the fault status on an LCD screen for immediate visual reference.

Simultaneously, the system employs an SMTP email client to send an alert notification to a predefined email address. This notification includes the cable line color, the fault distance, and the precise GPS coordinates in a format that can be directly viewed on mapping services such as Google Maps. The email ensures that maintenance personnel are informed promptly, reducing the response time for repair operations. If no fault is detected, the relay remains active, and the LCDs the normal operating status, ensuring the system operates only when necessary.

Fault Monitoring:

The system starts by continuously monitoring the three key underground cables (Red, Blue, and Yellow) using voltage and current sensors. These sensors are connected to the analog pins of the ESP32, where they provide real-time data about the condition of the cables. The sensors measure:

- Voltage levels: Ensuring they remain within expected ranges.
- Current flows: Checking for abnormalities such as an unexpected surge or drop in current, which could indicate a fault. If the measured voltage or current strays from the normal operating range, the system identifies that a fault has occurred.
-

Fault Detection Logic:

The ESP32 processes the data from the sensors, comparing the real-time readings with predefined thresholds to detect faults. The fault detection criteria can be based on:

- ✓ Open Circuit: If the voltage level drops significantly or current becomes zero, the system flags it as an open circuit.
- ✓ Short Circuit: If there is a sudden spike in current or an extremely low voltage drop, the system detects a potential short circuit.
- ✓ Insulation Failure or Leakage: In some cases, abnormal current flows due to insulation failure might also be detected.

GPS Integration:

When a fault is detected, the ESP32 triggers the GPS module (e.g., NEO-6M) to get the exact geographical coordinates of the fault location. The GPS module communicates with the ESP32 to retrieve latitude and longitude values. These coordinates are crucial for locating the fault in the field, especially when dealing with large networks of underground cables.

1. ESP32 Microcontroller

The ESP32 serves as the core of the system, managing input and output operations, analyzing voltage signals to detect cable faults, and initiating appropriate responses. With built-in Wi-Fi and Bluetooth, it supports future IoT integration for remote monitoring. Programmed via the Arduino IDE with various libraries, the ESP32 offers low power consumption and high processing speed, making it well-suited for real-time embedded applications.

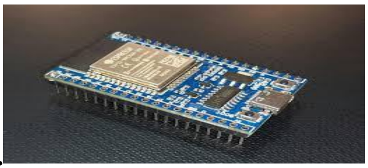

Fig.2 ESP32 Microcontroller

2. Resistor-Based Cable Simulation

Resistors are used to simulate underground cable segments, with predefined resistance values representing real cable conditions. By applying Ohm’s Law, deviations in voltage drop across the resistors indicate fault conditions. This allows for safe, controlled, and repeatable testing of the fault detection system. The system calculates the fault location by comparing expected and actual voltage drops.

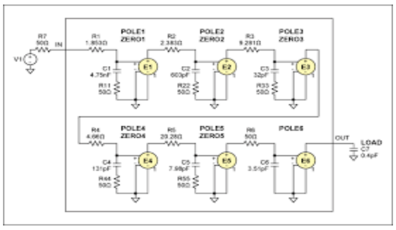

Fig. 3 Cable Network

3. Relay Module

Relays act as electronic switches in the system, controlling the connection and disconnection of cable segments when a fault is detected. Each relay is controlled by the ESP32, which deactivates the relay to isolate the faulty segment, simulating real-world fault isolation. Relays used are typically 5V or 12V and are driven through optocouplers to ensure electrical isolation and system safety.

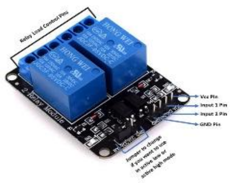

Fig. 4 Relay Module

4. GPS Module (e.g., NEO-6M)

The GPS module provides real-time location data to the system, enabling accurate fault localization in field deployments. It communicates with the ESP32 via UART using NMEA format and tags detected faults with precise coordinates. This is especially useful for long-distance or outdoor applications, and the location data can be wirelessly transmitted for remote monitoring and diagnostics.

Fig.5 GPS Module

5. I2C LCD Display (16x2 or 20x4)

The LCD provides real-time visual output, displaying fault status, segment number, GPS coordinates, and voltage readings. Connected via the I2C interface to conserve ESP32 GPIO pins, it also shows system startup and readiness messages. This enhances user interaction, making the system useful for both educational and industrial demonstrations.

Fig. 6 LCD Module

6. Push Buttons (for Fault Simulation)

Push buttons are used to manually simulate faults in specific cable segments by altering voltage or resistance paths. Connected to the ESP32's digital inputs, they help test the system’s fault detection accuracy. Software debouncing ensures stable and reliable simulation, making them useful for validating system responsiveness.

Fig. 7 Push Buttons

RESULT AND DISCUSSION

The discussion highlights the system's efficiency in reducing the time and resources needed for fault detection in underground cables. The combination of IoT and GPS technologies offers a scalable and cost-effective alternative to traditional methods. However, further improvements can be made, such as incorporating additional fault detection mechanisms, increasing the GPS accuracy for smaller fault distances, and enabling cloud integration for data storage and analysis. Overall, the project proved to be a practical and reliable solution for modernizing fault detection in underground cable networks.

Fig. 8 Underground Connection

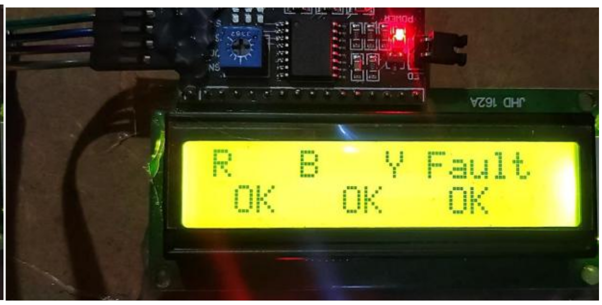

Fig. 9 RBY Connected No-fault

Fig. 10 Longitude and Latitude

Fig. 11 Fault Information sent to Mail

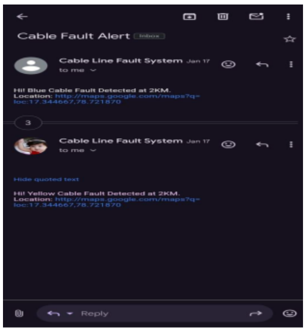

Fig. 12 Email Received

No Fault (Good Condition): The voltages or resistance values on the red, blue, and yellow wires remain within normal ranges, so the ESP32 will send an "OK" signal to the LCD.
Fault Detected: If there is a short circuit or open circuit in any of the wires, the ESP32 could detect an abnormal value (like no voltage or a drastic change in current) and then trigger an error message or display a warning instead of "OK."
The system utilizes an LCD screen to display the operational status of underground cables and the geographical location of any detected faults. During normal operation, when all monitored cables (Red, Blue, and Yellow) are functioning correctly, the LCD shows the message “All wires OK.” If a fault such as a short or open circuit is detected in any cable, the LCD switches to display “FAULT DETECTED” on the first line, followed by the precise latitude and longitude (up to six decimal places) of the fault location, as obtained from a GPS module. Additionally, an email is sent with the subject “Underground Cable Fault Detected,” and the body includes a fault status message along with the fault’s latitude.

APPLICATIONS, ADVANTAGES AND DISCUSSION

The underground cable fault detection system using ESP32 is widely applicable in power distribution, smart grids, and urban infrastructure. It quickly identifies fault locations, reducing downtime and speeding up maintenance. ESP32 offers advantages like low cost, built-in Wi-Fi/Bluetooth, and easy sensor integration, enabling real-time remote monitoring. This improves power delivery efficiency, safety, and reduces manual effort and maintenance costs.
This project has strong future potential, with improvements expected in accuracy, connectivity, and automation. Integration with IoT and machine learning can enable predictive maintenance and smarter fault analysis. Enhanced GPS and sensors will improve fault localization, while mobile or web interfaces will support real-time remote monitoring. As smart cities evolve, this system will be vital for efficient and intelligent power distribution.

CONCLUSION

The IoT-based Underground Cable Fault Detection System is a reliable and efficient solution for identifying and localizing faults in underground cable networks. By leveraging the ESP32 microcontroller, GPS technology, and real-time email alerts, the system automates the traditionally time-consuming and resource-intensive process of fault detection. The ability to display fault locations and GPS coordinates on an LCD, combined with automated notifications, ensures rapid response and minimizes downtime, enhancing the reliability of power and communication networks.

In conclusion, this system represents a significant advancement over conventional methods, offering a modern, automated, and accurate means of managing underground cable networks. It not only reduces operational costs but also improves the efficiency of maintenance processes, ensuring uninterrupted service delivery and increased infrastructure reliability.

Declaration by Authors
Acknowledgement: None
Source of Funding: None
Conflict of Interest: No conflicts of interest declared.

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How to cite this article: Sarin Vijay Mythry, S. Jayanth, M. Sri Charan, Sk. Abu Bakar, P. Lokesh. Underground cable fault detection system using ESP32. *International Journal of Research and Review*. 2025; 12(5): 625-630. DOI: *https://doi.org/10.52403/ijrr.20250565*

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