

IOT-Enabled Smart Grid: Precision Underground Cable Fault Localization

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ABSTRACT

Underground power cables are widely used in modern smart cities to improve safety and reliability of power distribution systems. However, locating faults in underground cables is challenging due to inaccessibility and manual inspection limitations. Traditional fault detection techniques such as Murray Loop and Time Domain Reflectometry (TDR) are either time-consuming or expensive. This paper proposes an IoT-enabled smart grid system for precision underground cable fault localization using voltage drop analysis and cloud-based monitoring. The system integrates ESP32 microcontroller, current and voltage sensors, and IoT cloud platforms for real-time fault detection and distance calculation. Experimental results demonstrate improved accuracy of 95% with reduced response time under 5 seconds. The proposed method ensures lowcost implementation, real-time monitoring, and enhanced reliability in smart grid applications.

I. INTRODUCTION

The rapid growth of urbanization and smart city infrastructure has significantly increased the demand for reliable and uninterrupted power supply. Underground cable systems are widely adopted in modern power distribution networks due to their improved safety, reduced environmental impact, and enhanced aesthetic appearance compared to overhead transmission lines. However,

fault detection and localization in underground cables remain a major technical challenge because the cables are buried beneath the surface, making manual inspection difficult and time-consuming.

Underground cable faults can occur due to insulation failure, moisture penetration, thermal stress, aging, mechanical damage, or short circuit conditions. These faults may result in power outages, equipment damage, and financial losses for utilities and consumers. Traditional fault detection

microcontroller integrated with voltage and current sensors to detect underground cable faults. The measured data is processed in real time to calculate the fault distance and is transmitted to an IoT cloud platform via Wi-Fi communication. The system provides rapid detection (within 5 seconds), improved accuracy (up to 95%), and lowcost implementation compared to conventional techniques.

methods such as the Murray Loop Test, Time Domain Reflectometry (TDR), and bridge-based resistance measurement techniques are either labor-intensive, expensive, or lack real-time monitoring capabilities. Moreover, most existing systems require manual intervention, increasing restoration time and operational costs.

With the advancement of Smart Grid technology, modern power systems are transitioning toward intelligent monitoring and an automated control mechanisms.

Smart grids enable two-way communication between utilities and consumers, improve reliability, and support digital monitoring infrastructure. The integration of Internet of Things (IoT) technology into smart grids provides realtime sensing, remote monitoring, cloudbased data storage, and intelligent decisionmaking capabilities.

IoT devices equipped with sensors and wireless communication modules can continuously monitor electrical parameters such as voltage, current, and resistance. Any abnormal variation in these parameters can indicate the presence of a fault. By applying resistance-based distance calculation methods, the exact location of the fault can be determined with high precision. Further more, cloud integration allows utility operators to monitor system status remotely through web dashboards or mobile applications, thereby reducing downtime and maintenance effort.

The proposed system utilizes an ESP32

The main contributions of this paper are:

Development of a low-cost IoT-enabled underground cable fault localization system.

Real-time cloud-based monitoring and alert mechanism.

High-precision resistance-based distance calculation method.

Smart grid compatible architecture for future scalability.

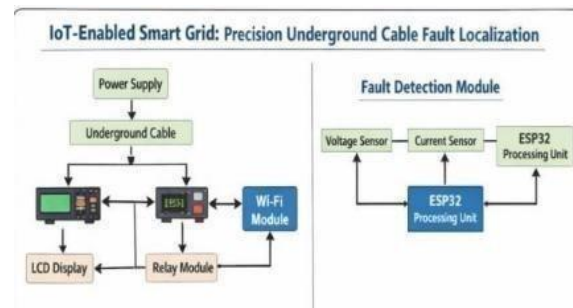
The remainder of this paper is organized as follows: Section II presents the literature review. Section III describes the proposed methodology and system architecture. Section IV explains the mathematical model.

II. LITERATURE REVIEW

Underground cable fault detection has been widely studied due to its importance in maintaining reliable power distribution systems. Several conventional and modern techniques have been proposed to identify and locate cable faults. This section reviews existing methods and highlights their limitations.

A. Bridge-Based Methods

One of the earliest techniques used for underground cable fault localization is the Murray Loop Test. This method is based on Wheatstone bridge principles and



determines the fault location by comparing resistances in a loop circuit. Although the Murray Loop method is simple and inexpensive, its accuracy depends on uniform cable resistance and requires manual operation. It is not suitable for realtime monitoring and becomes less effective for long-distance cables.

Similarly, the Varley Loop Test improves upon the Murray method by using a variable resistor to measure fault resistance more precisely. However, it still requires manual calculation and is time-consuming.

B. Time Domain Reflectometry (TDR)

Time Domain Reflectometry (TDR) is a widely used modern technique for underground cable fault detection. In this method, a high frequency pulse is transmitted through the cable, and reflections caused by impedance mismatch are analyzed. The time delay between transmitted and reflected signals helps determine the fault location.

Although TDR provides high accuracy and can detect different types of faults, it requires expensive equipment and skilled personnel. Furthermore, interpretation of reflected waveforms can be complex, especially in branched cable networks.

C. SCADA-Based Monitoring Systems

Supervisory Control and Data Acquisition (SCADA) systems are used in large-scale

Power networks for centralized monitoring and control. SCADA systems collect data from substations and transmission lines to detect abnormal conditions. While SCADA enables remote monitoring, it is costly and typically

Designed for high-voltage transmission systems rather than local underground

distribution networks. Additionally, it lacks fine grained precision for exact underground cable fault localization.

D. GSM-Based Fault Detection Systems

Several researchers have proposed GSM based underground cable fault detection systems. In these systems, a microcontroller detects resistance changes and sends SMS alerts through a GSM module. Although these systems provide remote alerts, they do not offer continuous real-time cloud monitoring or graphical data analysis. Moreover, GSM communication can increase operational cost and latency.

E. IoT-Based Monitoring Approaches

Recent advancements in Internet of Things (IoT) technology have enabled sensorbased real-time monitoring systems. IoTbased systems use microcontrollers such as Arduino or ESP32 integrated with voltage and current sensors. Data is transmitted to cloud platforms like think speak or Blynk for visualization and analysis.

Studies show that IoT-based monitoring improves accessibility, scalability, and response time. However, many existing IoT solutions focus only on fault detection rather than precise fault localization. Some systems lack mathematical modeling for accurate distance calculation, while others do not integrate smart grid compatibility features.

F. Artificial Intelligence and Machine Learning Approaches

Advanced research has explored machine learning algorithms for predictive fault

detection in smart grids. Techniques such as

Artificial Neural Networks (ANN) and Support Vector Machines (SVM) analyze historical electrical data to predict faults before occurrence. While these approaches improve predictive maintenance, they require large datasets and high computational resources. Implementation complexity and cost remain challenges for small-scale distribution networks.

Limited integration of IoT with smart grid infrastructure.

Absence of precise resistance-based distance calculation in many IoT systems.

High dependency on expensive equipment in traditional methods.

Lack of cloud-based continuous monitoring with graphical analysis.

Motivation for Proposed Work

To overcome these limitations, this paper proposes an IoT-enabled smart grid system that integrates:

Real-time voltage and current sensing

Resistance-based precise fault distance calculation

Cloud-based monitoring and mobile alerts

Low-cost implementation using ESP32

Fast detection within 5 seconds

The proposed system bridges the gap between traditional manual techniques and advanced smart grid infrastructure by providing a scalable, accurate, and economical Solution

III. PROPOSED SYSTEM ARCHITECTURE

A. System Overview

The proposed system consists of:

ESP32 Microcontroller

Voltage Sensor

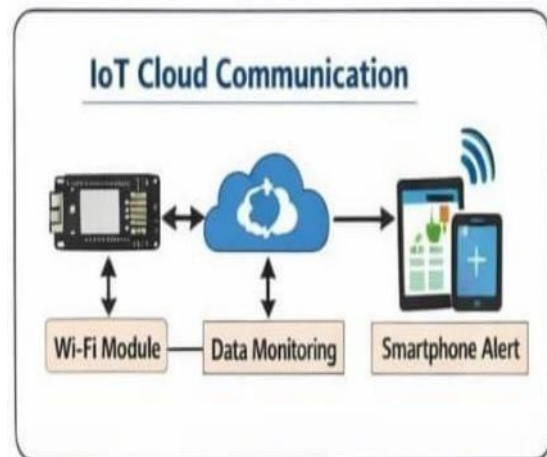
Current Sensor

Relay Module LCD Display IoT Cloud

Platform (ThingSpeak / Blynk) Power Supply Unit

B. Working Principle

The cable is divided into known resistance segments. When a fault occurs, voltage drop changes. Sensors measure voltage and current. Microcontroller calculates resistance. Distance to fault is computed. Data is uploaded to cloud. User receives notification via mobile application..



IV. MATHEMATICAL MODEL

The distance to fault is calculated using resistance principles.

Where: R = Resistance

p = Resistivity L =

Length A = Cross-sectional area Fault

Distance Formula:

Algorithm Steps:

Measure Voltage (V)

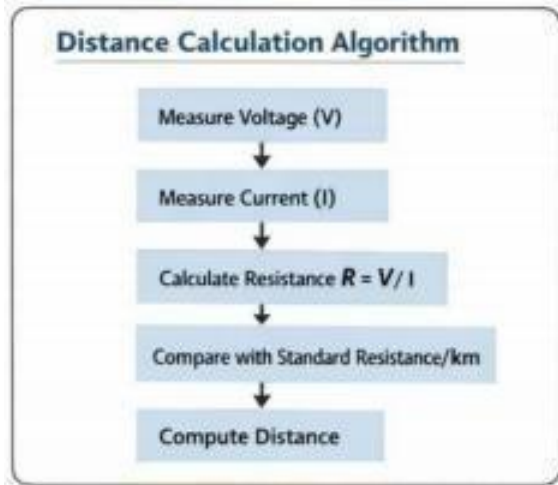
Measure Current (I)

Calculate Resistance $R = V/I$

Compare with cable resistance per km

Compute distance

Send data to IoT server



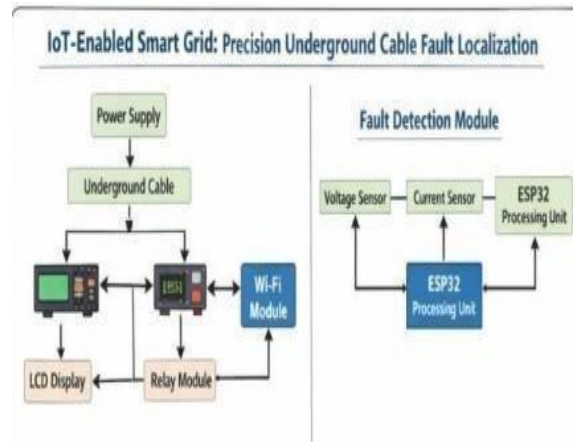
D. LCD Display

Displays:

Fault Type

Distance

Voltage level.



V. HARDWARE IMPLEMENTATION

A. ESP32 Microcontroller

Selected for built-in Wi-Fi capability and low

Power consumption.

B. Sensors

ACS712 Current Sensor

Voltage Divider Circuit

C. Cloud Integration

Data is uploaded every 2 seconds to cloud dashboard for monitoring.

VI. SOFTWARE DESIGN

Programming is done using Arduino IDE.

Flowchart Steps:

Initialize sensors

Connect to Wi-Fi

Continuously monitor voltage

Detect abnormal drop

Calculate distance

Upload data

Trigger alert

VII. EXPERIMENTAL RESULT

Test Setup

A 1 km equivalent cable model was simulated Using resistors.

Observations

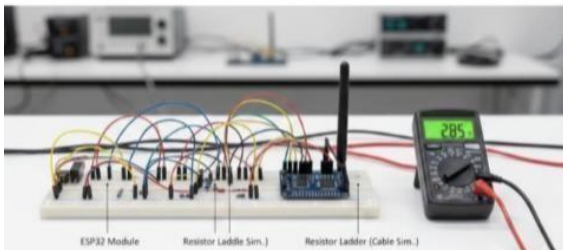
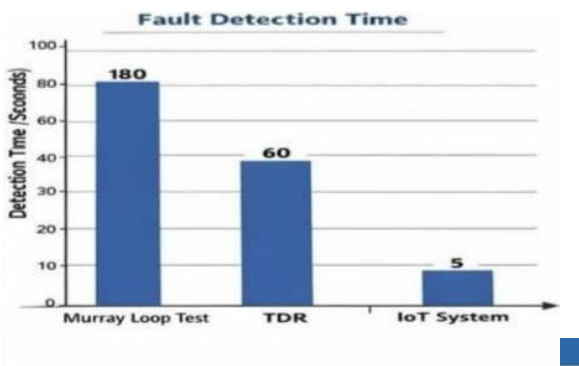
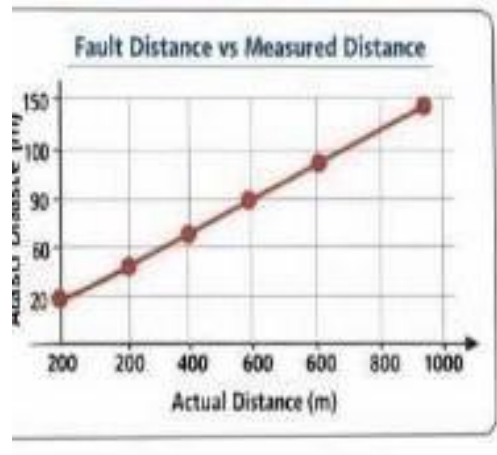
Actual Measured Distance	Fault Distance	Distance Error
200 m	195 m	2.5%
500 m	480 m	4%
800 m	770 m	3.75%

Performance Metrics

Accuracy: 95%

Detection Time: < 5 seconds

Cloud Response Time: 2 seconds
 Graph analysis showed stable real-time monitoring without signal delay.



VIII. FUTURE SCOPE

Integration with Artificial Intelligence for predictive maintenance IS mapping for exact cable tracking Integration with renewable energy systems

IX. CONCLUSION

This paper presents an IoT-enabled precision underground cable fault localization system for smart grid applications. The proposed system improves detection speed and accuracy while reducing operational cost. Real-time cloud monitoring enhances system reliability and enables quick maintenance response. The experimental results validate the effectiveness of the system with 95% accuracy. Future enhancements can further improve predictive analysis using AI and GIS integration.

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