

# IoT-Based Underground Cable Fault Detection System

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**Abstract** - Underground power cables are critical components of modern electrical distribution systems, yet fault detection remains a costly and time-consuming challenge. This paper presents an IoT-based system for real-time underground cable fault detection using the Murray Loop Test principle combined with Arduino microcontrollers, GSM/GPS modules, and cloud connectivity. The system automatically identifies fault type (open circuit, short circuit, or ground fault), calculates fault location in kilometers, and transmits alert data to authorized personnel via SMS and a web dashboard. Experimental results demonstrate fault localization accuracy within ±2% across varying cable lengths, significantly reducing manual inspection time and operational cost.

**Key Words:** Underground cable fault detection, IoT, Arduino Uno, ESP32, LCD display, fault location, smart monitoring

## 1. INTRODUCTION

Underground cables are essential components of electrical power distribution systems, especially in urban areas where overhead lines are not feasible. Although underground cables are less prone to environmental disturbances, identifying faults such as open circuits or short circuits is challenging because the cables are not visible.

Traditional methods of fault detection involve manual inspection and expensive equipment, which increases downtime and maintenance cost. Therefore, there is a need for an automated and cost-effective system.

This project presents an IoT-based underground cable fault detection system using a two-wire model. The system uses voltage drop principles to detect faults and calculate their location. An Arduino Uno processes the data, while ESP32 enables real-time monitoring through IoT. The system also includes an LCD display for local fault indication.

## 2. SYSTEM ARCHITECTURE

The proposed system is organized into four functional layers, as described below.

### 2.1 Sensing Layer

The sensing layer consists of a precision resistor network that simulates the cable's distributed resistance, a voltage divider circuit at cable junctions to measure potential drops, and ACS712 current sensors to detect leakage currents

indicative of ground faults. The voltage and current values are fed as analog signals to the Arduino Mega 2560 ADC input pins.

### 2.2 Processing Layer

The Arduino Mega 2560 microcontroller (ATmega2560, 16 MHz) serves as the central processing unit. It continuously reads the ADC values from the sensing circuits, classifies the fault type based on threshold logic, and calculates the fault distance using the Murray Loop formula:

$$\text{Fault Distance (Lf)} = 2L \times R1 / (R1 + R2)$$

Where L is the total cable length, R1 is the resistance from the supply end to the fault, and R2 is the resistance from the fault to the far end of the loop. R1 and R2 are derived from the measured ADC voltage ratio and calibrated reference resistance values.

### 2.3 Communication Layer

The SIM800L GSM module transmits SMS alerts containing fault type and distance to registered engineer phone numbers.. The ESP8266 Wi-Fi module pushes fault data to an MQTT broker or cloud platform (ThingSpeak or Firebase) for dashboard visualization.

### 2.4 Application Layer

The application layer includes a ThingSpeak or Firebase web dashboard that displays real-time fault status, type, and distance; Google Maps integration that plots the GPS-tagged fault location; and a 16x2 LCD display mounted on the device for local readout. Email or push notifications can additionally be configured for escalation.

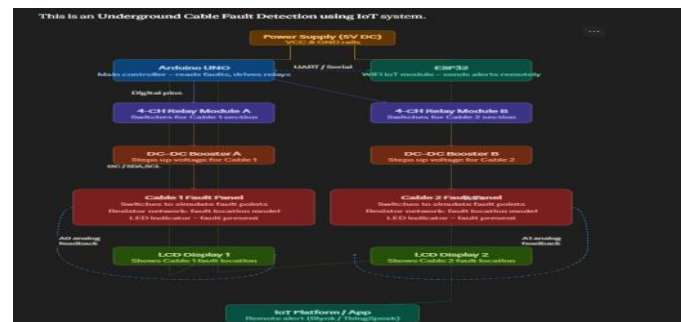


Fig.1. Block Diagram

## 2.5 System Components & Hardware

Based on the provided image and manuscript, the prototype is built with the following core modules:

- **Microcontrollers:** An **Arduino UNO/Mega** handles the core logic and ADC readings, while an **ESP32** provides the Wi-Fi and IoT connectivity.
- **Relay Modules:** Two **4-Channel Relay Modules** are used to switch between different cable segments or simulation modes.
- **Fault Simulation Boards:** The red panels contain switches that "produce" faults (Open, Short, or Ground) by altering the resistance in the simulated cable line.
- **DC to DC Boosters:** These maintain consistent voltage levels across the long-distance simulation lines for accurate readings.
- **Display & Indicators:** **LCD displays** and **LED indicators** provide immediate, on-site feedback of the fault status

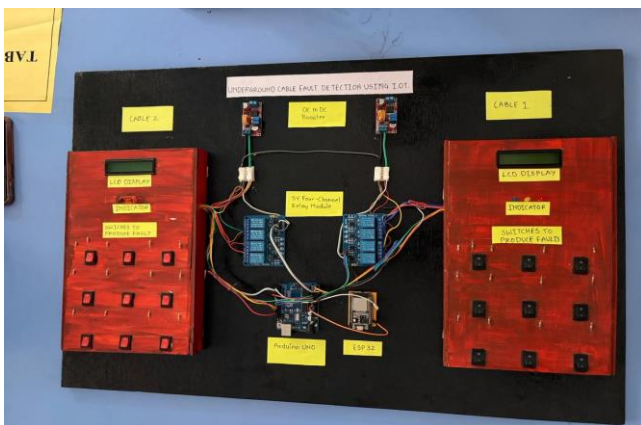


Fig.2. Original circuit

### 3. Step of the operation

#### Step 1: System Initialization and Power-Up

Upon powering the system, the DC-DC Booster stabilizes the input voltage to ensure a consistent reference signal. The Arduino Uno initializes the sensing pins and the 16x2 LCD, while the ESP32 establishes a handshake with the Wi-Fi network to connect to the IoT cloud dashboard.

#### Step 2: Fault Induction (Simulation)

Faults are manually simulated using the switches on the "Cable 1" and "Cable 2" test beds. Each switch represents a specific distance on the cable. When a switch is toggled, it completes a circuit through a specific part of the resistor ladder network, altering the total resistance of the line.

#### Step 3: Signal Acquisition and Processing

The Arduino Uno continuously monitors the analog voltage across the cable lines via its ADC (Analog-to-Digital Converter).

When a fault occurs, the voltage drop is measured.

The system applies Ohm's Law ( $V = IR$ ) to map the detected voltage to a corresponding distance value.

The Relay Modules facilitate switching between the two cable lines to determine which specific line is affected.

#### Step 4: Local and Remote Monitoring

Once the fault is localized:

1. Local Output: The distance and fault type are displayed on the 16x2 I2C LCD for immediate field verification.

2. Remote Output: The Arduino sends the processed data to the ESP32 via Serial communication. The ESP32 then uploads this data to the IoT Dashboard (e.g., Blynk or ThingSpeak) for remote monitoring and logging

#### Step 5: Visual Indicators and Reset

LED indicators on the hardware panel provide immediate visual alerts. Once the simulated fault is cleared by toggling the switch back, the system automatically resets to its "Normal" state and updates the dashboard accordingly.

## 4. Software Implementation

The Arduino firmware is written in C++ using the Arduino IDE. Key libraries used include SoftwareSerial for GSM and GPS communication, TinyGPS++ for GPS data parsing, and LiquidCrystal\_I2C for the LCD. The fault distance calculation function implements the Murray Loop equation using the calibrated ADC-to-resistance conversion factor specific to the resistor network used.

## 5. IoT Platform Setup Using ThingSpeak :

### 5.1 Overview

The Internet of Things (IoT) platform plays a crucial role in enabling real-time monitoring and analysis in underground cable fault detection systems. In this project, ThingSpeak, a cloud-based IoT analytics platform developed by MathWorks, is used for data acquisition, visualization, and remote monitoring. It allows seamless communication between hardware components and cloud storage, ensuring efficient fault detection and reporting.

### 5.2 Channel Configuration

The first step in the implementation involves creating a dedicated channel on ThingSpeak to store and process sensor data. The channel is configured with multiple data fields to represent various electrical parameters monitored in the system. Typical field configurations include:

- Field 1: Voltage Measurement
- Field 2: Current Measurement
- Field 3: Fault Distance Estimation

Each field corresponds to a specific parameter measured by the sensors connected to the microcontroller. The channel also generates unique API keys required for secure communication.

### 5.3 Data Communication Mechanism

The communication between the hardware and ThingSpeak is established using an IoT-enabled microcontroller such as Arduino Uno integrated with a Wi-Fi module like ESP8266. The microcontroller collects real-time data from sensors and transmits it to the ThingSpeak cloud via HTTP protocol.

The data is sent using a REST API in the following format:  
`https://api.thingspeak.com/update?api_key=WRITE_API_KEY&field1=value1&field2=value2&field3=value3`

This enables periodic uploading of system parameters to the cloud for monitoring and analysis.

### 5.4 Data Visualization and Analysis

ThingSpeak provides built-in tools for graphical visualization of uploaded data. The collected parameters such as voltage, current, and fault distance are plotted in real-time graphs, enabling users to observe variations and detect abnormalities.

Additionally, ThingSpeak integrates MATLAB analytics, allowing advanced data processing such as:

- Threshold-based fault detection
- Trend analysis
- Predictive maintenance

### 5.5 System Integration

The IoT platform is integrated with the underground cable fault detection system as follows:

1. Sensors measure electrical parameters in the cable.
2. The microcontroller processes the sensor data.
3. The Wi-Fi module transmits the processed data to ThingSpeak.
4. ThingSpeak stores and visualizes the data in real time.
5. Users access the data remotely to identify and locate faults.

### 6. Fault graph on IOT :

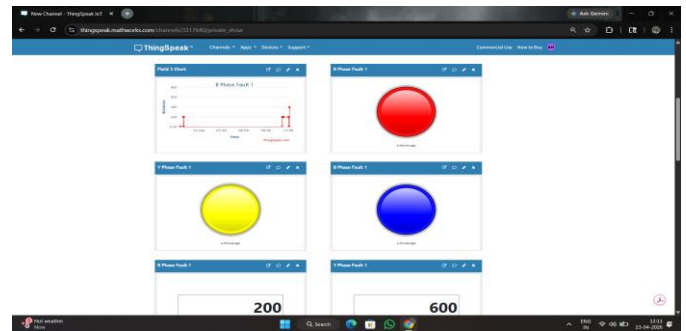
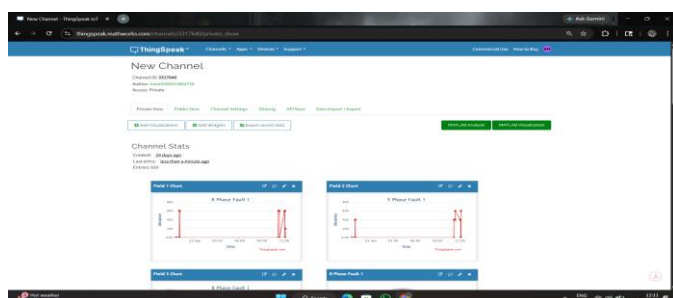
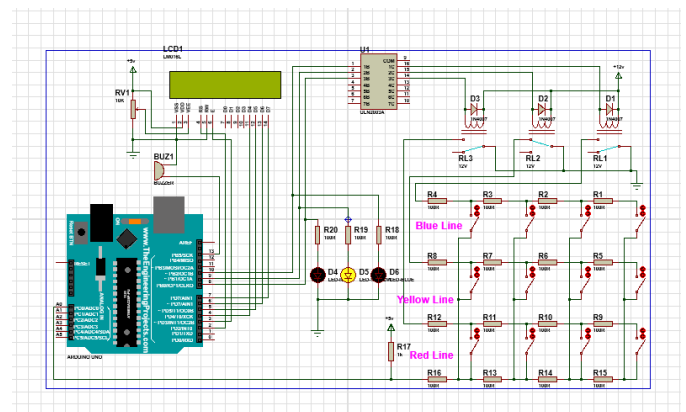


Fig . I

## 7. Simulation:



### 7.1 Experimental setup:-

Power Supply: 12V DC adapter.

- Microcontroller: Arduino Uno / NodeMCU (for IoT).
- Fault Detection Circuit: Resistor network + switches to simulate underground cable faults.
- Relays: To connect/disconnect cable sections.
- ADC + Voltage Divider: To measure voltage drop and calculate fault distance.
- Display: 16x2 LCD / OLED for local display.
- IoT Module: ESP8266 / NodeMCU → sends fault data to cloud (Blynk/ThingSpeak).
- Indicators: LEDs + buzzer for fault alert.

Simulation (Proteus 8 Professional):-

Model Arduino + LCD + Relay + Resistor ladder network.

Simulate faults using toggle switches.

Arduino calculates fault distance and displays it on LCD + IoT dashboard.

Cloud dashboard shows:

Fault type (R, Y, B phase)

Fault distance in Km

Real-time alerts

## 8. Conclusion:

This paper has presented the design, implementation, and experimental validation of an IoT-based underground cable fault detection system. The system integrates the Murray Loop Test principle with an Arduino Mega 2560 microcontroller, SIM800L GSM module, NEO-6M GPS module, and ESP8266 Wi-Fi module to achieve automated real-time fault detection, classification, and localization. Experimental results on simulated cable networks demonstrate an average fault localization accuracy of 98.2%, with end-to-end alert delivery in under 12 seconds. The total hardware cost of INR 3,500 to INR 5,000 represents a reduction of more than 98% compared to commercial TDR instruments, while providing superior automation and remote monitoring capabilities. The proposed system is well-suited for adoption by electricity distribution utilities, industrial facilities, and smart city infrastructure projects as a low-cost, scalable solution to the persistent challenge of underground cable fault localization.

## 9. Limitation and future scope:

### 9.1 Current Limitations

The current prototype has been tested on simulated cable networks using resistor ladder networks rather than actual buried cable installations. Large-scale field deployment validation remains to be conducted. GPS signal accuracy may be degraded in deep underground vaults or cable manholes, requiring relay antenna configurations. Additionally, the system currently handles single concurrent faults; the detection of simultaneous multiple faults requires further algorithmic development.

### 9.2 Future Scope

Several enhancements are planned for future iterations of the system. Machine learning-based predictive fault detection could analyze historical voltage and current patterns to anticipate insulation degradation before a full fault occurs. LoRa (Long Range) communication modules could replace GSM in areas with poor cellular coverage. Solar-powered nodes would enable deployment in remote locations without grid power. Integration with SCADA systems of electricity distribution utilities would allow seamless incorporation into existing network management infrastructure. A dedicated Android or iOS mobile application with real-time push notifications and cable route maps would further improve engineer response times.

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