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# IoT BASED UNDERGROUND CABLE FAULT DISTANCE DETECTION SYSTEM

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**Abstract** Underground cables are commonly used for power transmission in scenarios where overhead lines are not feasible, such as in highly populated urban settings, industrial sites, or for connecting power from utility poles to buildings. These cables offer several benefits over their overhead counterparts, including reduced voltage drops, fewer faults, and lower maintenance costs, though they are more costly to produce and install. Costs can varybased on the materials used and the required voltage capacity. Despite their robustness, underground cables are susceptible to various faults due to environmental factors, deterioration, and damage from animals. Locating and diagnosing these faults can be challenging as it often requires excavating the cable for inspection and repair.

This project aims to pinpoint fault locations in underground cables from a base station using an ATmega328 microcontroller, measured in kilometers. The method involves a straightforward application of Ohm's Law, where changes in current indicate the fault's location along the cable. This system is especially useful in urban environments where cables are buried, and faults are harder to locate without significant disruption.

The developed prototype simulates a cable networkusing resistors to represent different lengths and switches to introduce faults at specific intervals to test the system's accuracy. When a fault occurs, it alters the voltage across the resistors. This change is converted into digital data by an ADC and processed by a programmed PIC microcontroller, which then displays the fault's location, phase, and timing on a 16X2 LCD screen. Additionally, the system incorporates IoT technology, utilizing an ESP8266 Wi-Fi module to transmit fault data online, enhancing the monitoringand response capabilities.

## Introduction

In the 21st century, there has been a significantincrease in the number of consumers relying on electricalenergy, prompting rapid advancements in the electric power infrastructure. To meet this demand, there has been an expansion in electrical transmission lines and the integration of new sources of energy, including renewables like solar power. Electricity distribution occurs through two primary methods: overhead lines and underground cables. Particularly in urban and densely populated areas where overhead lines pose challenges and risks, underground cables are preferred for their reliability in power transmission. These cables offer numerous benefits over overheadlines, as detailed in section 1.2 of the original document. Recent advancements in technology and mass production have further expanded the use of underground cables, especially in high- voltage applications of the

Underground cables may contain one or three cores, depending on their intended use. For instance, three- corecables, typically made of tinned copper or aluminum and designed to be flexible, are used for three-phase electrical service.

1.1 Construction of Underground Cable:

Different parts of power cables are shown in Figure 1. The power cable consists primarily of the following components.

- The conductor
- The insulating segment
- Bedding
- Beading/Armouring
- The outer casing or sheath

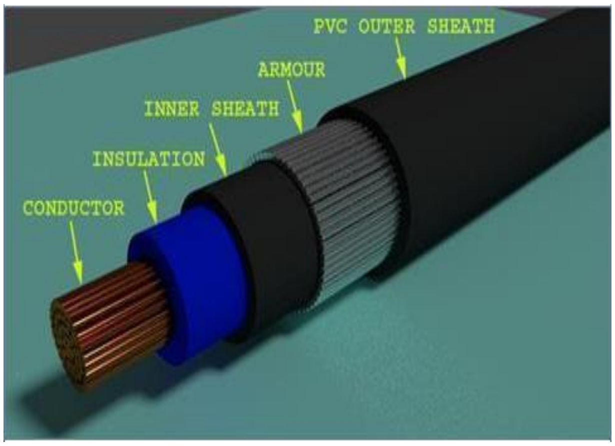
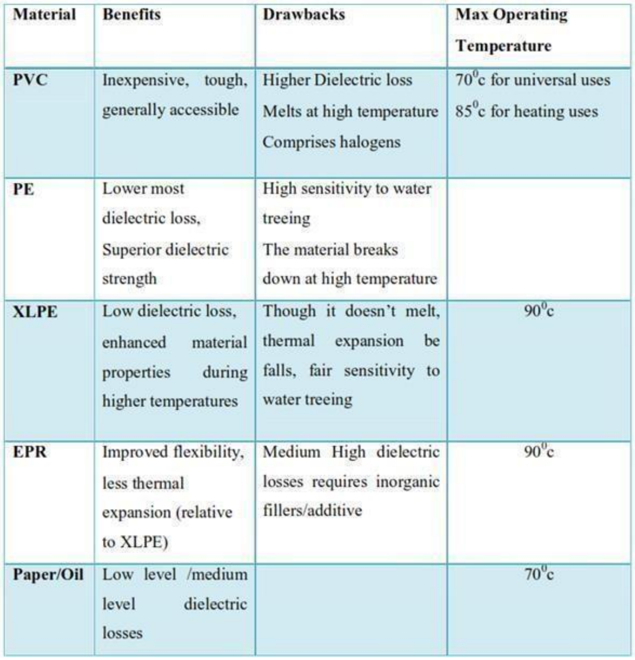


Figure 1 Parts of underground cable

The insulation required to be provided is mainly based on the temperature. The insulation is made available on the conductor part of a cable mainly by PVC, XLPE Rubber as shown in table Table 1 Type of material and their corresponding temperatures

| Insulating Material | Max. Operating Temperature |
|---|---|
| Polyvinyl chloride (PVC) of Type A | 750c |
| Polyvinyl chloride (PVC) of Type B | 850c |
| Polyvinyl chloride (PVC) of Type C | 850c |
| XLPE | 900c |
| EPRIE-1 made of rubber | 900c |
| RUBBER EPR IE-1, IE-2, IE-3, IE-5 made of Silicon | 1200c |



| Material | Benefits | Drawbacks | Max Operating Temperature |
|---|---|---|---|
| PVC | Inexpensive, tough, generally accessible | Higher Dielectric loss<br>Melts at high temperature<br>Comprises halogens | $70^{0}$c for universal uses<br>$85^{0}$c for heating uses |
| PE | Lower most dielectric loss,<br>Superior dielectric strength | High sensitivity to water treeing<br>The material breaks down at high temperature | |
| XLPE | Low dielectric loss, enhanced material properties during higher temperatures | Though it doesn't melt, thermal expansion be falls, fair sensitivity to water treeing | $90^{0}$c |
| EPR | Improved flexibility, less thermal expansion (relative to XLPE) | Medium High dielectric losses requires inorganic fillers/additive | $90^{0}$c |
| Paper/Oil | Low level /medium level dielectric losses | | $70^{0}$c |

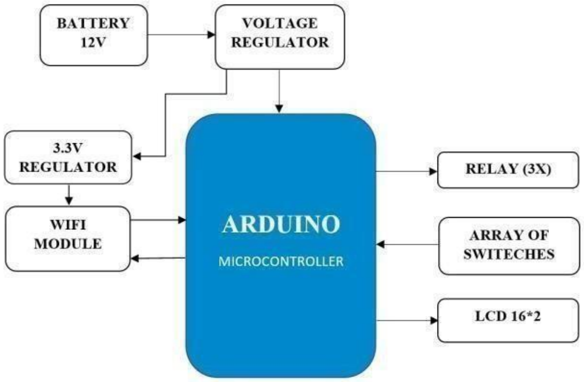
## Aims and Objectives of the Project

Diagnosing and repairing faults in underground cables can be cumbersome and typically involves excavating the cable for thorough inspection. This project focuses on identifying the exact locations of faults in underground cables from a central base station, with distances measured in kilometers using an ATmega328P controller. The system displays critical information such as fault distance, phase, and timing on a 16X2 LCD that interfaces with the microcontroller. Additionally, IoT technology is employed through the ESP8266 Wi-Fi module, enabling remote viewing of this information online.

The primary goal of this system is to facilitate rapid repairs and restore the power supply efficiently, thereby enhancing overall system performance while reducing operational costs and time spent locating faults in the field. By pinpointing the precise location of the fault, the system minimizes the need for extensive field inspections and potential disruptions, leading to a more streamlined maintenance process.

## Designed System

The system employs Arduino-based technology to compute the distance of faults in both underground and overhead transmission cables from the base station. By integrating smart fault detection and location capabilities, it accurately identifies the precise location of faults, allowing for a swift response from technical crews. This rapid response time is crucial in preventing damage to transformers and other electrical equipment, thereby averting potential disasters. For underground cable fault detection, a switching unit is deployed along the cable line, enabling easy localization of faults. Additionally, the system enhances the identification of short circuit faults within underground cables, providing specific phase information for targeted troubleshooting. When faults occur, the microcontroller triggers the display unit to showcase the exact fault location on a dedicated website via IoT connectivity. Furthermore, inbuilt protective mechanisms automatically shut off respective loads upon fault detection, mitigating the risk of further damage



## Components

**1. Switching Units:** Switching units are vital for an IoT underground cable fault detection system as they are responsible for selectively connecting and disconnecting circuits within the network. These switches could be mechanical relays or solid-state devices that respond to commands from the microcontroller. They must be capable of handling the high voltages and currents typically associated with underground cables without degrading over time due to electrical stress or mechanical wear. Their performance is critical since inaccurate switching could lead to false readings or fail to isolate a fault, causing further system damage or prolonged downtime.

**2. Arduino Uno:** The Arduino Uno serves as the central processing unit for this project. Its simplicity, robustness, and open-source nature make it an excellent choice for prototyping and small-scale production. The Uno can gather data from sensors, process that data with the help of its ATmega328 microcontroller, and control other hardware components like the relays and LCD monitor. It's also compatible with a wide range of modules and shields for additional functionality, like connectivity or advanced sensor integration.

At the core of the Arduino's architecture is a microcontroller, typically from the Atmel AVR family (e.g., ATmega328, ATmega2560), although newer models have adopted ARM-based processors. The choice of microcontroller dictates the board's capabilities, including the number of input/output (I/O) pins, memory (both Flash, for program storage, and SRAM, for variables), and peripherals like timers, serial communication interfaces, and analog-to-digital converters (ADCs). The microcontroller operates at the heart of the Arduino board, interfacing with a variety of peripherals that extend its capabilities. For instance, digital I/O pins can be used for reading digital sensors, driving LEDs, or communicating with other digital devices. Analog inputs, facilitated by the onboard ADCs, allow the Arduino to interface with analog sensors or other analog signals, expanding its applicability in various domains. Furthermore, communication interfaces such as SPI, I2C, and UART are integral to the Arduino's architecture, enabling the board to communicate with other microcontrollers, computers, or various peripherals (e.g., sensors, displays). This versatility is a cornerstone of the Arduino ecosystem, allowing for a wide range of applications from simple hobbyist projects to complex industrial systems.

Setting up the Arduino involves both hardware setup and software configuration. The initial step is to select an appropriate Arduino board that meets the project's requirements. Following the selection, the physical setup involves connecting the board to a computer via USB, which provides both power and a communication channel for programming. The software setup entails installing the Arduino IDE, available for Windows, macOS, and Linux. The IDE is a user-friendly interface that allows developers to write, compile, and upload programs (sketches) to the Arduino board. It includes a code editor, a console for viewing output, and access to a library manager for adding external libraries to projects. Before uploading a sketch tothe board, the appropriate board model and communication port must be selected within the IDE. Once configured, sketches are compiled into machine language and uploaded to the microcontroller. The Arduino IDE utilizes avrdude, a utility for interacting with AVR microcontrollers, to transfer the compiled code to the board.

The utilization of Arduino boards in projects follows a cyclic process of writing code, compiling, uploading, and testing. The Arduino programming language, based on C/C++, abstracts complex hardware operations into simple, high-level functions, making it accessible to beginners while retaining the power needed for advanced users. A typical Arduino sketch consists of two main functions: `setup()` and `loop()`. The `setup()` function is called once when the program starts and is used to initialize settings, such as pin modes or serial communication parameters. The `loop()` function continuously executes, allowing the board to respond to changing inputs or to control outputs in real-time. For debugging, the Serial library is instrumental, enabling data communication over the USB connection to the computer. This feature allows developers to send debugging information back to the Arduino IDE's serial monitor, facilitating troubleshooting and development.

The Arduino platform has emerged as a cornerstone in the field of electronics and embedded system development, attributed to its straightforward architecture, ease of setup, and versatile usage. By providing an accessible entry point to microcontroller-based projects, Arduino has fostered a culture of innovation and creativity among a diverse audience. Its open-source model not only encourages learning and experimentation but also contributes to the ever-expanding repository of knowledge and resources available to developers worldwide. Through its continued evolution, the Arduino ecosystem promises to remain at the forefront of educational and hobbyist electronics, contributing significantly to the field of embedded systems.

**3. NodeMCU:** NodeMCU is a low-cost open-source IoT platform. It typically includes an ESP8266 Wi-Fi module, which allows the device to connect to the internet. In an underground cable fault detection system, the NodeMCU can be used for sending real-time data to a cloud server, enabling remote monitoring and control capabilities. Its inclusion in the setup underscores the IoT aspect of the project, bringing online connectivity to the embedded system.

**4. Relays:** Relays in this project are electromechanical or solid-state switches that allow the low-power Arduino Uno to control high-power circuits. A relay module can isolate the microcontroller from potentially harmful high-voltage interactions, thus protecting the electronics. In a fault detection scenario, the relay would be used to cut off power to a faulty section or to route testing signals to different cable segments.

**5. LCD Monitor:** An LCD monitor provides a human-readable display interface for the system, showing status updates, readings from sensors, and fault location information. For a user operating the system, the LCD would display essential diagnostics and system messages, allowing for easy interaction and monitoring. The LCD must be chosen to be clear and readable in a variety of lighting conditions, especially if the system is to be used outdoors or in brightly lit industrial environments.

**6. Voltage Regulator:** Voltage regulators ensure that all components receive a stable and appropriate voltage level, which is crucial for the reliable operation of the system. Fluctuations in power could cause erratic behavior or damage sensitive electronics. In this application, the voltage regulator must step down and regulate the power from the source to levels suitable for the microcontroller, sensors, and other logic-level components.

**7. Power Source:** The power source provides energy to all electronic components. It must be capable of delivering a steady and uninterrupted supply of electricity, with enough capacity to handle the system's demands. The choice of power source—whether it's battery-powered for portability or connected to the mains for continuous operation—will depend on the deployment scenario of the fault detection system

## Software Required

**1. Arduino IDE:** The Arduino Integrated Development Environment (IDE) is the primary tool for writing, compiling, and uploading the code to the Arduino microcontroller. It supports C and C++ languages, providing a user-friendly interface that simplifies the programming process. For this project, the IDE is used to program the Arduino Uno with the logic required to control hardware components, process sensor data, and handle communication protocols.

**2. Embedded C:** Embedded C is a set of language extensions for the C programming language by the C Standards committee to address commonality issues that exist between C extensions for different embedded systems. It plays a fundamental role in programming microcontrollers for tasks like reading sensor inputs, controlling output devices, and managing the timing and logic operations required for fault detection and system response.

**3. Ubidots Explorer:** Ubidots Explorer is a cloud service that provides tools for capturing and visualizing data from IoT devices. By connecting the NodeMCU to Ubidots, you can create a dashboard that displays real-time data, generates alerts, and stores historical information for analysis. In the context of underground cable fault detection, Ubidots can help operators quickly identify and locate faults, and also review performance over time to predict and prevent future issues.

### 2.1 System Design

Embedded systems, due to their portable nature and power constraints, prioritize efficient power usage to prolong battery life and minimize heat generation. To meet these requirements, a power supply unit is essential to provide the necessary voltage for proper circuit operation. This unit typically comprises a transformer, rectifier, filter, and regulator. Initially, an alternating current (AC) voltage of around 230 volts RMS is supplied to the transformer, which steps down the voltage to the desired AC level. Subsequently, a diode rectifier converts the AC voltage into full-wave rectified voltage, which is then filtered dc complexity while ensuring optimal performance in driving the display.

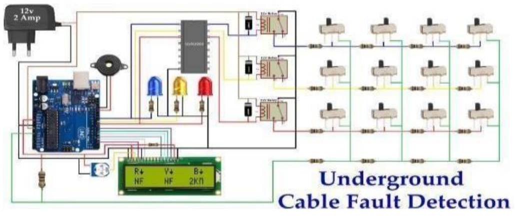


Figure 3 Schematics diagram

The resulting DC voltage may still exhibit some ripple or AC voltage variation. To mitigate this, a regulator circuit is employed to provide a DC output with significantly reduced ripple voltage and a stable voltage level even when the input or load conditions fluctuate. This ensures consistent and reliable power delivery to the embedded system's components, optimizing performance while adhering to strict power constraints.

In our project, we utilize several key components to ensure the efficient and reliable operation of our electronic circuits. One crucial element is the transformer, which facilitates the transformation of electric power from one circuit to another while maintaining the same frequency. Specifically, we employ a step-down transformer to reduce the voltage from 230 volts AC to 12 volts AC, providing a suitable supply for our electronic circuits.

Additionally, we implement a bridge rectifier for full-wave rectification, a process that enhances the direct current (DC) level obtained from a sinusoidal input. The bridge rectifier configuration ensures that both positive and negative cycles of the input signal are utilized effectively, resulting in a smoother DC output across the load. To further refine the DC voltage and minimize ripples, we incorporate a capacitive filter circuit, which effectively filters out high-frequency components and delivers a stable DC voltage to the load.

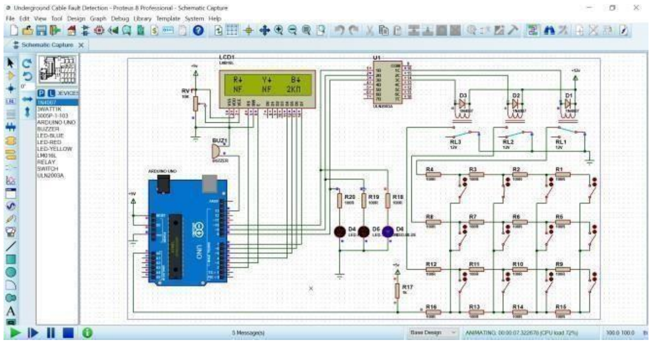


Figure 4 circuit diagram

Furthermore, the controller integrated circuit (IC) in our system features two 8-bit registers: an instruction register (IR) and a data register (DR). The IR stores instruction codes and address information, while the DR temporarily holds data to be written to or read from display data RAM (DD RAM) or character generator RAM (CG RAM). This arrangement allows for seamless data transfer and control between the microprocessor unit (MPU) and the display components. With the dot-matrix liquid crystal display controller and driver LSI, our system can efficiently display alphanumeric characters, Japanese kana characters, and symbols on a dot-matrix liquid crystal display. By integrating essential functions such as display RAM, character generator, and liquid crystal driver into a single chip, our system achieves minimal In our system, after the voltage has been filtered through the capacitor, it undergoes further refinement and stabilization through regulation. A voltage regulator plays a crucial role in maintaining a constant output voltage regardless of fluctuations in the supply voltage, variations in load, or changes in temperature. For this purpose, we utilize a fixed voltage regulator, specifically the LM7805 IC. The LM7805 is a reliable regulator capable of providing a regulated +5V output, ideal for powering microcontrollers and other sensitive electronic components.

The LM7805 regulator offers several key features that contribute to its effectiveness and reliability in our system. It can handle output currents of up to 1A, making it suitable for powering a variety of electronic devices. Moreover, it provides a range of output voltages, including 5V, 6V, 8V, 9V, 10V, 12V, 15V, 18V, and 24V, offering flexibility for different applications. Additionally, the LM7805 incorporates built-in protections such as thermal overload protection and short-circuit protection, safeguarding the regulator and downstream components from potential damage due to excessive heat or electrical faults. Furthermore, it features output transistor safe operating area protection, enhancing its durability and longevity in demanding operating conditions. Overall, the LM7805 regulator ensures stable and reliable power delivery, essential for the proper functioning of our embedded system.

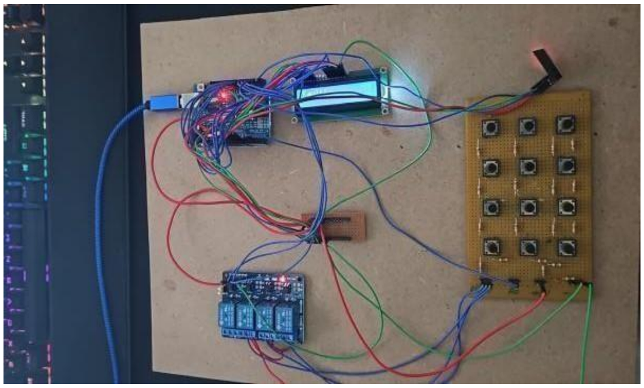


Figure 5 IoT fault detection system

## Results and Discussion

The hardware setup for the fault detection system is illustrated in Figure 6. In this setup, individual switches are connected in zones to detect faults within the underground cable. When a fault occurs, it is sensed by the relay, which then transfers this information to the Arduino Nano. The Arduino Nano processes this data and displays the distance of the fault on a 16x2 LCD display. Additionally, the fault information is transmitted from the Arduino Nano to the NodeMCU, which sends the data to the cloud for monitoring and alerts. Ubidots, a Software as a Service (SaaS) platform, is utilized for monitoring the data and generating alerts, as depicted in. In Case 1, where there are no faults present in the underground cables, the display unit will indicate that the line is normal. This indicates that the system is capable ofaccurately detecting and differentiating between normal operatingconditions and faults within the cable infrastructure.In Case 2, if there is a short circuit fault detected n

withinany of the three lines within the range of 150 km, the system willpromptlyalert the user and displaythe specific fault. Additionally,the respective phase relay associated with the faulty line will be deactivated, which will be indicated by an LED. For instance, if the fault is identified in line B at a distance of 150 km, the user will receive an alert indicating the distance and the affected line. detecting faults in underground cables, thereby minimizing downtime and enhancing reliability. Through extensive experimentation and analysis, the system's effectiveness in accurately pinpointing fault locations within the cable network has been demonstrated. The implementation of relay units, Arduino Nano, and Node MCU enables real-time monitoring and alerts, ensuring prompt responseto any detected faults.

In Case 3, if short circuit faults are detected simultaneously in all three lines within different kilometer ranges, the system will again alert the user and display all the detected faults. Moreover, all three phase relays corresponding to the faulty lines will be deactivated, each indicated by an LED. For example, if faults are detected in line A at 100 km, line B at 50 km, and line C at 150 km, the display unit will show all three faults accordingly, and the user will receive alerts for each fault detected.

Figure 6 illustrates the graphical representation of the detected faults, providing a visual overview of the fault occurrences. Meanwhile, Figure 7 presents the measured current rating values, offering insights into the electrical behavior of the system.

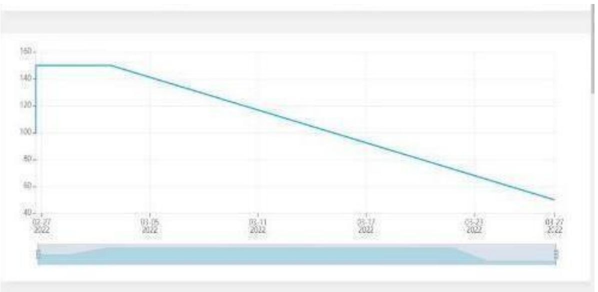


Figure 6 Fault detection plot

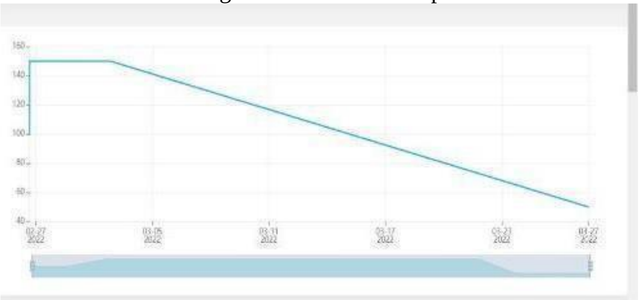


Figure 7 Current value plot

# Conclusions

The study on " IoT-based Fault Detection of Underground Cables through Node MCU" represents a significant advancement in the field of electrical infrastructure maintenance and safety. By integrating IoT technology with Node MCU, the system demonstrates remarkable efficiency in

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