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An Enhanced Method of Design and Implementation of IoT-based Underground Cable Fault Identification and Fault Estimation Circuit

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Abstract: - Underground cables serve as vital alternatives to overhead lines in power applications where safety, practicality, or feasibility are concerned. They find extensive use in densely populated urban zones, and industrial settings, and for delivering electricity from elevated posts to consumer premises. Compared to overhead lines, underground cables offer benefits such as reduced voltage drops, lower fault susceptibility, and economical maintenance. However, their manufacturing costs are higher and can vary based on construction and voltage rating. These cables are susceptible to various faults due to underground conditions, wear and tear, and rodent interference. Diagnosing faults is challenging, often requiring the complete extraction of the cable for inspection and repair. This project aims to detect fault locations within underground cable systems from a base station, using an ATmega328 controller to measure distances in kilometers. The prototype employs the fundamental principle of Ohm's law, where current fluctuations correspond to fault lengths. In urban areas, electrical cables are predominantly laid underground instead of overhead lines. Detecting fault locations within these underground cables for timely repairs is a complex task. The proposed solution introduces a prototype with resistors representing cable length in kilometers. Faults are simulated using switches at predetermined intervals to validate accuracy. When a fault occurs, the voltage across series resistors changes and this alteration is processed by an ADC and a programmed PIC IC, which then displays fault location, distance, phase, and time on a 16x2 LCD screen. The system utilizes IoT via the ESP8266 Wi-Fi module to present this information over the Internet.

Keywords: *Underground cables, open circuit fault, short circuit fault, earth fault, fault detection, fault location identification, Internet of Things, PIC controller.*

1. INTRODUCTION

In underground electrical distribution systems, the cables are typically installed within the ground or enclosed in ducts. This construction enhances cable durability and minimizes the occurrence of faults. However, pinpointing and repairing faults in these concealed cables becomes challenging due to their hidden conductors. Locating these faults can be likened to searching for a needle in a haystack. Various methods, coupled with emerging fault detection technologies and electrical tools, have been developed to streamline this task, reducing its time and complexity. It's important to note that there isn't a universally superior method or combination of methods. Instead, a range of techniques is available, each tailored to specific fault types. This diversity ensures both the safety and efficiency of fault detection without compromising cable integrity. Consequently, the subsequent list outlines common electrical supply faults encountered in underground cables.

Underground electricity distribution systems present benefits such as aesthetic appeal and heightened resistance to environmental elements like weather and vandalism. Nevertheless, when faults arise within these systems, determining their precise location becomes intricate due to the concealed nature of the cables beneath the ground. Unlike overhead systems where faults can be more visible, underground faults demand specialized techniques and technologies for accurate detection and resolution.

Several types of electrical supply faults that can occur in underground cables are given as follows.

- Open circuit faults
- Short circuit faults
- Earth faults
- Insulation breakdown
- Cable damage
- Cable joint and insulation failures
- Water ingress

II. PROPOSED HARDWARE MODEL

The fundamental principle of Ohm's law is effectively applied in the development of a fault location tracking system.

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According to Ohm's law, cable resistance is directly proportional to its length under consistent conditions of temperature and cross-sectional area. Therefore, by applying a low DC voltage at the feeder end via a series of resistors in cable lines, the resulting current fluctuates based on the fault's position within the cable. The system development comprises essential components such as a microcontroller, an LCD, a Fault Sensing Circuit Module, an IoT Wi-Fi Module, and a well-structured regulated power supply.

This system is designed to detect short circuits, specifically line-to-ground faults in any phase. In such instances, the voltage across series resistors undergoes alteration, consequently generating an analog signal denoting a voltage drop through the fault-sensing circuit of the system. This analog signal is then directed to the microcontroller's inbuilt ADC, which, upon processing, translates the data into precise digital form.

The resulting information is showcased on a connected LCD screen, displaying both the precise fault location in kilometers from the source station and the corresponding R, Y, and B phases where the fault emerged. Simultaneously, this processed information is also transmitted via an IoT Wi-Fi Module, displaying the same information on a webpage, enhancing accessibility and monitoring. Thus, the system offers a comprehensive solution to detect, process, and communicate fault location data in real time.

The system employs an ATmega328P microcontroller for its operations. The current sensing circuit, constructed using a mix of resistors, interfaces with the ATmega328 microcontroller. The microcontroller's internal ADC is utilized to transform the analog input from the current sensing circuit into digital data. This fault-sensing circuit is created using a set of series resistors coupled with a set of switches positioned adjacent to each resistor. Effective relay control is facilitated through the relay driver. A 16x2 LCD display is seamlessly integrated with the microcontroller to provide an output showcasing fault phase(s) information along with fault location in kilometers.

Block Diagram of proposed Hardware Model

The block diagram of the proposed hardware model is illustrated in Fig. 1.

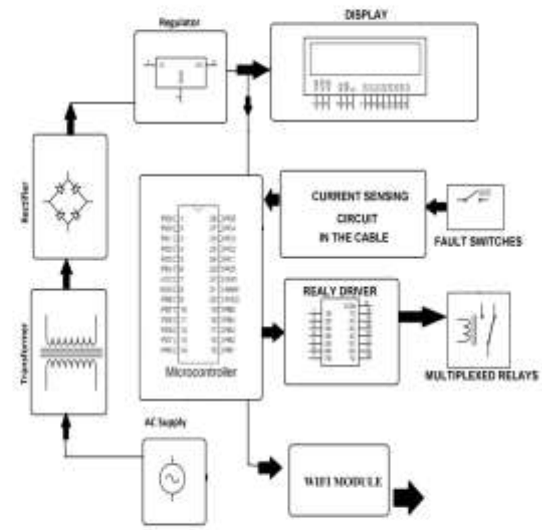

Fig. 1Block Diagram of the proposed model

The procedure commences by stepping down the 230V AC voltage via a transformer. This reduced voltage undergoes a transformation into pulsating direct current via a stable 4-diode bridge rectifier configuration, effectively converting the alternating current from diagonally opposite terminals. Subsequently, the resultant pulsating direct current is directed through a Filter to eliminate any residual alternating current components. To emulate faults, resistors, and switches are strategically employed. The modifications in current resultant from these emulated faults are discerned by monitoring the corresponding voltage drop.

This voltage drop signal is then conveyed to an Analog to Digital Converter (ADC) for conversion into digital format. The resulting digital data is transmitted to the microcontroller, which processes the fault's location and manages the relay driver. This relay driver, in turn, operates the relays responsible for circuit control. Upon fault detection, the relay is triggered, transmitting a trip signal to the circuit breaker and thus isolating the defective segment. An automatic relay, integrated within a control room panel, orchestrates circuit transitions, whether within the same circuit or an alternative one. Furthermore, a Liquid Crystal Display (LCD) connected to the microcontroller furnishes visual feedback, displaying cable statuses or fault locations for the R, B, and Y phases. The system works mainly on the principle of Ohm's Law where a low DC voltage is applied at the feeder end through fault sensing circuit. The system's operation is contingent on the current passing through the fault-sensing circuit module.

The resulting current alteration hinges on the cable's length from the fault location in scenarios of a Single Line to Ground fault, Double Line to Ground fault, or Three Phase to Ground fault. Consequently, the voltage drops across series resistors shift correspondingly, and the fault signal is routed to the microcontroller's internal ADC for digital data conversion. Subsequently, the microcontroller processes this digital data, which is then showcased on the connected LCD. The output indicates fault location in kilometers and phase, adapting to distinct fault conditions. Moreover, this output is replicated on a webpage through the IoT Wi-Fi Module ESP8266 integrated with the system

The system is powered by a 230V AC supply, which is directed to the Adapter Module. This module converts the AC voltage into DC. To eliminate the ripple in the output from the adapter module, a 1000 microfarad electrolytic capacitor is employed. Since a stable 5V voltage is necessary for the system components like the Microcontroller (ATmega328), 16x2 LCD (Liquid Crystal Display), Relay Drivers, Relays, Fault Sensing Circuit Module, and IoT Wi-Fi Module, three 7805 voltage regulators are utilized. These voltage regulators ensure a consistent 5V supply. The first voltage regulator (VR1) delivers the 5V supply to the microcontroller, LCD, and series resistors. The second regulator (VR2) powers the relay driver IC ULN2003A and three relays. The third voltage regulator caters to the IoT ESP8266 Wi-Fi Development Board Module, providing it with a 5V DC supply. The circuit consists of three relays which are driven by a relay driver IC ULN2003A. The relays used here switch off/on the bulb loads R, Y, and B to indicate the fault being occurred in corresponding phases.

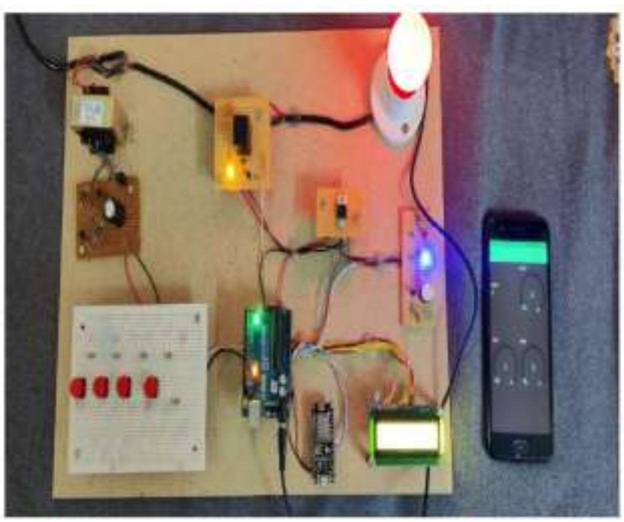

Fig. 2 Hardware model of IoT Based Underground Cable Fault Distance Detection System

The hardware model depicted in Fig. 2 is designed for a single-phase power supply configuration. The power supply is established through a step-down transformer, followed by rectification and regulation. The cable's current sensing circuit gauges the voltage drop magnitude across the resistors, transmitting this information to the microcontroller. By evaluating the voltage, the microcontroller determines the distance of the fault location. the operator to monitor and locate the cable fault.

Fig.3 to Fig.6 show the hardware results for fault locations at 1 Km, 2 Km, 3 Km & 4 Km respectively. The output is also updated onto the IoT cloud using the Blynk Application. By using this application, the operator can monitor and determine the fault location from the base station or any remote area using his/her mobile phone provided the phone is connected to the Internet.

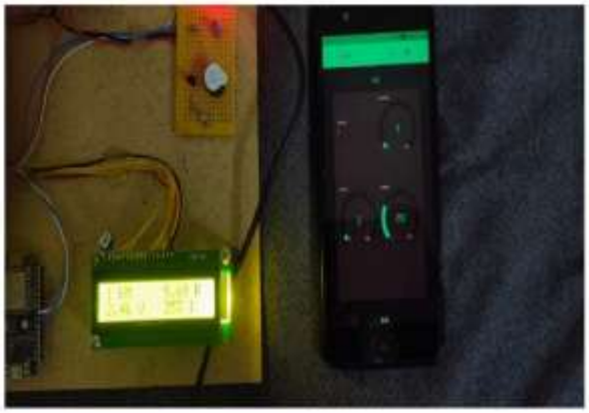

Fig. 3 LCD and IoT displaying the fault at 1Km distance

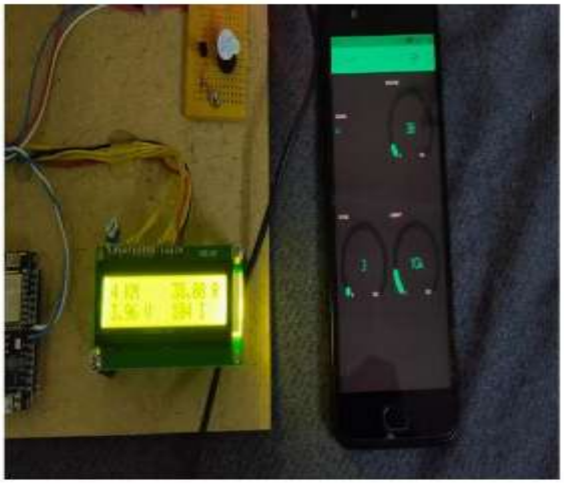

Fig. 4 LCD and IoT displaying the fault at 2Km distance

Fig. 5 LCD and IoT displaying the fault at 3Km distance

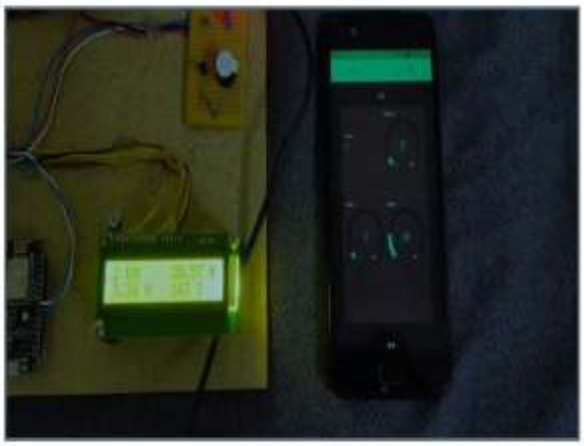

Fig.6 LCD and IoT displaying the fault at 4Km distance

Fig.7 and Fig. 8 are images of the Blynk application displaying the fault distance along with other cable parameters allowing the operator to monitor and locate the cable fault.

Fig. 7 IoT application displaying the fault at 1Km and 2Km distance

III.INTERNET OF THINGS

The integration of IoT in the electrical Power Industry has revolutionized conventional operations. IoT has harnessed wireless technology to connect power industry assets and infrastructure, aiming to reduce power consumption and costs. Its applications span diverse domains including energy systems, residential spaces, industries, cities, logistics, healthcare, agriculture, and more. Over a span of more than 13 decades since 1881, the power grid system has progressively evolved to meet surging energy demands. Power grids now stand as crucial infrastructure components underpinning modern society's functionality. Considering the intricate interplay of power generation and consumption, ensuring an uninterrupted, outage-free power supply is paramount.

These devices can function as data collection units, equipped with various sensors like temperature, humidity, and light sensors. Alternatively, they can operate as data actuation devices, connected to actuators such as relays. In essence, IoT creates an ecosystem where devices with unique capabilities collaboratively contribute to seamless communication, data sharing, and the execution of specific tasks. The utilization of IoT (Internet of Things) for identifying underground cable faults encompasses the integration of sensors, communication devices, and data analytics. This integration facilitates the continuous monitoring, detection, and pinpointing of faults within underground electricity distribution systems. By harnessing IoT technology, the process of fault identification is augmented with real-time data insights and remote monitoring capabilities. This advancement significantly enhances both the efficiency and precision of underground cable fault detection and localization. Deploying a range of sensors along the underground cable's length enables the monitoring of diverse parameters that signal potential faults. These sensors encompass:

- **Temperature Sensors:** Detect abnormal temperature rises, indicative of heat generated by a fault.
- **Acoustic Sensors:** Listen for sounds emitted by partial discharges or arcing at fault points.
- **Vibration Sensors:** Identify mechanical stresses caused by cable movement or physical harm.
- **Current and Voltage Sensors:** Monitor electrical parameters for irregularities that hint at a fault.

- **Gas Sensors:** Detect released gases produced during certain faults.

Sensors gather real-time data pertaining to monitored parameters, wirelessly transmitting this information to a central control system. Communication technologies like cellular networks, Wi-Fi, or protocols such as LoRaWAN facilitate transmission. The central control system or a cloud-based platform processes and analyzes collected data in real time. Advanced analytics algorithms identify patterns, anomalies, and possible fault indicators. Machine learning and AI techniques can amplify fault detection accuracy. Based on analyzed data, the system identifies faults and estimates their locations along the cable route:

- **Temperature Spikes:** Unusual temperature surges signify faults, and sensor positions and temperature change rates aid in estimating locations.
- **Acoustic Signatures:** Specific sound patterns help narrow down potential fault areas.
- **Voltage and Current Changes:** Abnormal shifts in voltage or current levels point to fault presence and approximate location.

IV. CONCLUSION

The implementation of the IoT-based Underground Cable Fault Distance Detection System using a Microcontroller has yielded promising results. The development of a functional prototype has effectively demonstrated the system's ability to detect fault locations with precision within underground cable networks. This achievement not only validates the feasibility of the proposed architecture but also underscores its potential to address future challenges in fault detection. The successful integration of IoT technology and the Microcontroller emphasizes the significance of innovation in enhancing fault detection capabilities, offering a pathway toward more efficient and reliable underground cable network management.

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