IoT and AI-Enabled Underground Cable Fault Detection and Predictive Maintenance System using Ohm's Law and GIS Mapping

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***Abstract*—This project proposes a smart underground cable monitoring system that extends the principle of Ohm's Law–based fault localization into a real-time, IoT-integrated, and AI-enhanced platform. Traditional underground cable fault locators are limited to measuring voltage drops to identify faults, lacking predictive capability and remote access. The proposed system overcomes these limitations by combining Arduino UNO with IoT communication modules (ESP32/LoRa/GSM), a multi-sensor fault classification setup (voltage, current, temperature, leakage, moisture sensors), and a cloud-based AI model for predictive maintenance. The system continuously monitors cable parameters, detects the exact fault location in kilometers, and transmits real-time data to a centralized server. A GIS-based mapping interface displays the fault coordinates, enabling rapid deployment of repair teams. Moreover, the AI model analyzes historical fault data to predict potential failures, minimizing downtime and ensuring grid reliability. The integration of IoT, AI, and GIS mapping with Ohm's Law fault detection introduces novelty, practical utility, and non-obvious innovation, making the system patentable and highly applicable to smart grids, industrial power networks, and urban infrastructure. The incorporation of GIS mapping allows precise visualization of fault locations and cable networks. Experimental results demonstrate that the proposed approach enhances fault detection accuracy, reduces downtime, and supports efficient resource allocation for power utilities.**

***Index Terms*—Underground Cable, Fault Locator, Arduino UNO, Voltage Drop, LCD Display, Fault Simulation, Distance calculation using Ohm's Law**

I. INTRODUCTION

Underground power cables are vital for modern power distribution due to their enhanced safety, reliability, and minimal visual impact compared to overhead lines. However, fault detection in these cables remains challenging because of their inaccessibility, high repair costs, and complex underground conditions. Conventional methods such as time-domain reflectometry, surge testing, and manual inspections are often time-consuming, labor-intensive, and reactive, leading to prolonged outages and economic losses. Recent advancements in the Internet of Things (IoT), Artificial Intelligence (AI), and Geographic Information Systems (GIS) have opened new possibilities for intelligent underground cable monitoring. IoT-enabled sensors can continuously measure key electrical parameters voltage, current, and resistance allowing real-time anomaly detection and accurate fault localization using principles like Ohm's Law. AI-driven analytics enhance this process by identifying fault patterns, predicting failures, and enabling proactive maintenance strategies, thereby improving system reliability and reducing downtime. Integrating GIS mapping with IoT and AI technologies further enhances fault Integrating GIS mapping with IoT and AI technologies further enhances fault visualization, enabling rapid localization and efficient maintenance planning. This convergence of IoT sensing, AI analytics, and GIS visualization represents a comprehensive, scalable, and efficient framework for intelligent underground cable fault detection and predictive maintenance. The proposed system aims to improve operational reliability, minimize costs, and support the transition toward smarter, more resilient, and sustainable power distribution networks.

II. LITERATURE REVIEW

Underground power cables form a critical part of modern power distribution systems, but their buried nature and susceptibility to environmental factors pose significant challenges in monitoring and maintenance. Traditional fault detection techniques such as time-domain reflectometry (TDR), partial discharge measurement, and surge testing have been widely used to locate and classify faults. TDR-based methods, as described by Krauss et al. [1], utilize the reflection of voltage pulses to detect impedance changes caused by faults. While accurate, TDR techniques are often limited by accessibility issues, high cost, and the need for specialized equipment. Similarly, manual inspection and conventional surge testing methods, as highlighted by Das et al. [2], are labor-intensive, time-consuming, and prone to delays, which may result in prolonged outages and economic losses. With the advent of the Internet of Things (IoT), real-time monitoring of underground cable networks has become increasingly feasible. IoT-enabled sensors allow continuous measurement of electrical parameters such as voltage, current, and resistance, providing immediate detection of anomalies. For instance, K. Zhang et al. [3] demonstrated that distributed IoT sensors can detect cable faults and environmental variations in real time, significantly reducing fault detection time compared to conventional methods. However, the challenge remains in processing the large volume of sensor data efficiently and accurately. Artificial Intelligence (AI) and machine learning have emerged as promising solutions to address the limitations of traditional monitoring systems. AI algorithms can analyze historical and real-time data to classify fault types, predict potential failures, and support predictive maintenance strategies. Studies by Li et al. [4] have shown that combining machine learning with electrical parameter analysis can improve fault detection accuracy and localization precision. By analyzing voltage drops and current fluctuations along the cable, AI models can identify short-circuits, open-circuits, and insulation degradation with high reliability. The integration of Geographic Information System (GIS) technology further enhances the operational efficiency of underground cable monitoring. GIS allows spatial mapping of cable networks and fault locations, facilitating efficient maintenance planning, resource allocation, and quick response to outages. According to A. Kumar et al. [5], GIS-based visualization of fault locations significantly reduces the time and effort required for cable repair operations and improves decision-making processes. Despite these advancements, most existing solutions either focus solely on fault detection or predictive analysis, and rarely combine IoT, AI, and GIS into a single comprehensive framework. The literature indicates a gap in developing an integrated system capable of real-time monitoring, accurate fault detection, precise fault localization, predictive maintenance, and GIS-based visualization. The proposed system in this work addresses this gap by combining IoT sensors for real-time data acquisition, AI for intelligent fault analysis and prediction, and GIS for spatial visualization, resulting in a holistic and practical solution for modern underground power distribution networks

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III. CONCEPTUALIZATION AND SYSTEM MODELING

Underground power cables are vital for modern power distribution systems, offering benefits like improved safety, reduced visual pollution, and protection from environmental damage. However, detecting and locating faults in these buried networks is challenging due to limited accessibility and complex underground conditions. Traditional techniques such as time-domain reflectometry, surge testing, and manual inspection are often slow, labor-intensive, and reactive.

The proposed system integrates Internet of Things (IoT), Artificial Intelligence (AI), and Geographic Information System (GIS) technologies to provide real-time monitoring, intelligent fault detection, predictive maintenance, and spatial visualization of cable networks. IoT sensors continuously measure parameters such as voltage, current, resistance, and temperature, transmitting data wirelessly to a central unit. AI algorithms analyze this data using Ohm's Law to accurately determine fault type and location, while predictive models forecast possible failures. This proactive approach enhances reliability, minimizes downtime, and optimizes maintenance planning.

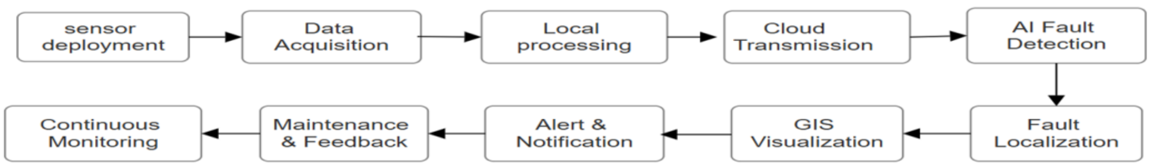

Fig.1.Flowchart for IoT & AI-Enabled Underground Cable Fault Detection System

1.Problem Statement

Underground power cables are vital for modern power distribution, yet detecting and locating faults in these systems is challenging due to their buried nature, complex environmental conditions, and high installation costs. Traditional methods such as time-domain reflectometry (TDR), surge testing, or manual inspection are often slow, labour-intensive, and reactive, resulting in prolonged outages, financial losses, and reduced reliability. This project aims to overcome these limitations by developing an intelligent, real-time fault detection and predictive maintenance system for underground power cables, leveraging modern technologies including IoT, AI, and GIS.

2. Objectives

The primary objectives of the project are:

1. Real-time monitoring of underground cable networks using IoT sensors to measure electrical parameters such as voltage, current, and resistance.
2. Fault detection and localization using Ohm's Law and sensor data analysis to identify the exact location and type of cable fault.
3. Predictive maintenance through AI algorithms that analyze historical and real-time data to predict potential failures before they occur.
4. Visualization and decision support using GIS mapping for spatial representation of cable networks, fault locations, and maintenance planning.
5. Operational efficiency and reliability improvement by reducing downtime, maintenance costs, and service interruptions.

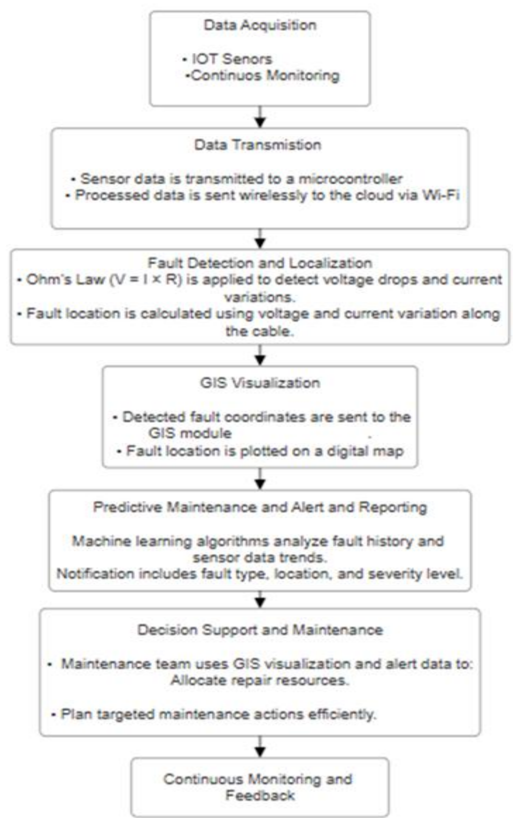

Fig.2. Block diagram of the proposed underground cable default monitoring system

IV. METHODOLOGY/EXPERIMENTAL:

The methodology of the proposed IoT and AI-enabled underground cable fault detection system is based on a combination of real-time sensing, intelligent data analysis, and GIS-based visualization to ensure accurate fault detection, localization, and predictive maintenance. The workflow is divided into several stages, each addressing a specific aspect of monitoring and maintenance.

The first stage involves sensor deployment and data acquisition. IoT sensors including voltage, current, resistance, and temperature sensors are strategically installed along the underground cable network. These sensors continuously monitor electrical and environmental parameters to detect anomalies that may indicate faults such as short-circuits, open-circuits, or insulation degradation. Each sensor is tagged with location data to facilitate accurate mapping of the cable network and identification of fault positions. Data collected by the sensors is converted to digital form using microcontrollers such as Arduino UNO which also perform signal conditioning, filtering, and preliminary threshold-based anomaly detection. In the data transmission stage, processed sensor readings are transmitted in real time to a cloud-based or centralized processing unit via wireless communication protocols as Wi-Fi. This ensures continuous monitoring and immediate availability of data for intelligent analysis. The real-time transmission of data reduces the need for manual inspections and allows for instantaneous detection of abnormalities in the cable network.

The next stage is fault detection and localization. The AI module analyzes the incoming sensor data to identify deviations from normal operational parameters. By applying Ohm's Law ($V = IR$) and examining voltage drops and current variations along the cable, the system estimates the location of faults with high accuracy. Machine learning algorithms classify detected faults into categories such as short-circuits, open-circuits, or insulation failures, enabling targeted corrective actions. The methodology also incorporates predictive maintenance. Historical and real-time sensor data are processed using AI models to identify trends and patterns that precede potential failures. This enables the system to forecast possible cable faults before they occur, allowing maintenance teams to perform preventive actions, reduce unplanned downtime, and optimize resource allocation.Finally, the GIS integration and visualization stage provides a spatial representation of the cable network and fault locations. Fault coordinates obtained from AI analysis are plotted on a GIS map, allowing operators to visualize the affected areas and plan maintenance operations efficiently. Alerts and notifications are sent through web or mobile applications, providing detailed fault information including type, severity, and location to the maintenance team.

Throughout the methodology, a closed-loop system is maintained. After faults are repaired or maintenance is performed, sensors resume continuous monitoring, and AI models update their predictive parameters based on new data, enhancing the system's learning capability and reliability over time. This comprehensive methodology ensures that the underground cable network is monitored in real time, faults are detected accurately and localized precisely, and predictive maintenance is effectively implemented, thereby improving the reliability, efficiency, and operational safety of the power distribution system.

V. WORKING PROCEDURE:

The proposed IoT and AI-enabled underground cable fault detection system integrates real-time sensing, intelligent analysis, and GIS-based visualization for accurate fault detection, localization, and predictive maintenance. IoT sensors including voltage, current, resistance, and temperature sensors are placed along the cable network to continuously monitor electrical parameters. These sensors detect anomalies such as short-circuits, open-circuits, or insulation failures and send data with timestamps and location tags to a microcontroller (Arduino). The microcontroller filters and normalizes the data, then transmits it wirelessly (via Wi-Fi) to a cloud or central server. An AI module analyzes the data using Ohm's Law ($V=IR$) and machine learning models to detect, classify, and locate faults. It also predicts potential failures through trend analysis, enabling proactive maintenance. The GIS module maps the fault's exact location on a digital interface, allowing maintenance teams to quickly locate and repair faults. Simultaneously, the system sends real-time alerts containing fault details (type, severity, and location) to mobile or web applications. After repairs, monitoring resumes automatically, and the AI continuously learns from new data, improving accuracy over time. This integrated system ensures faster fault detection, reduced downtime, predictive maintenance, and enhanced reliability of underground power networks.

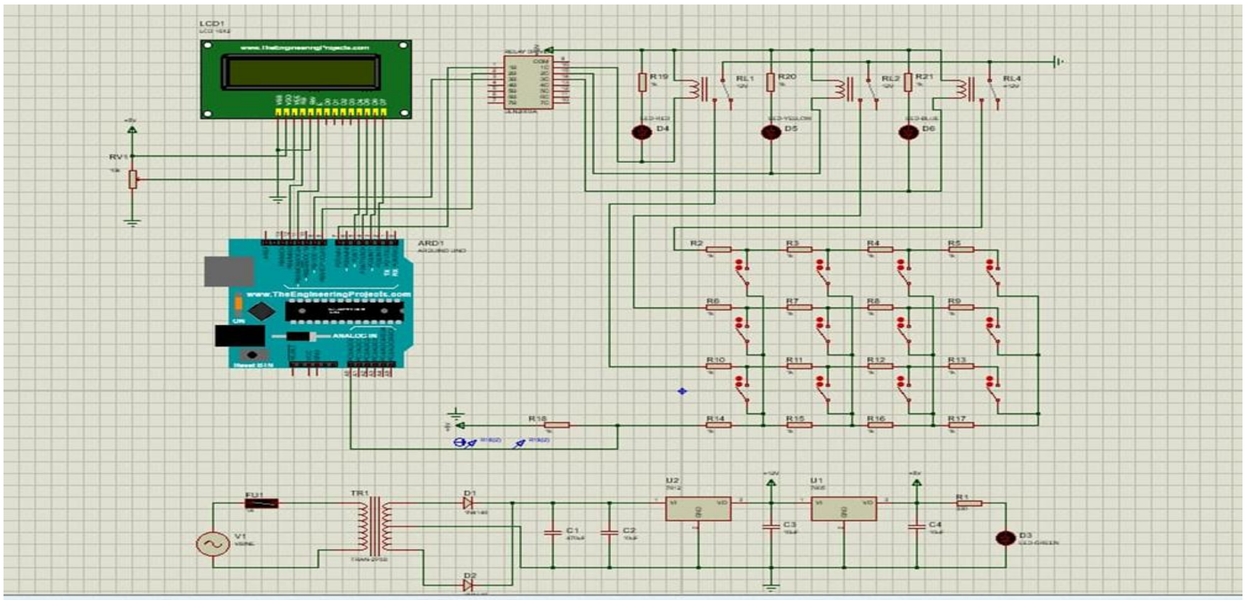

Fig.3.Circuit diagram of the proposed underground cable default monitoring system

3.1 Sensor unit:

The sensor unit forms the primary data acquisition layer of the proposed underground cable fault detection system, responsible for continuously monitoring critical electrical and environmental parameters along the length of the cable. This unit is composed of multiple sensors that collectively provide real-time insights into the cable's operational health. Voltage sensors are employed to measure the potential difference at various points along the cable, enabling detection of abnormal drops that may indicate partial discharges, short-circuits, or broken conductors. Current sensors, such as Hall-effect or shunt-based devices, are used to capture current flow and identify irregularities such as overcurrent conditions or sudden load imbalances that are often precursors to cable faults. Resistance measurement is integrated into the system using the principle of Ohm's Law, allowing the detection of insulation deterioration, conductor degradation, or localized heating, which manifests as abnormal resistance levels along the cable.

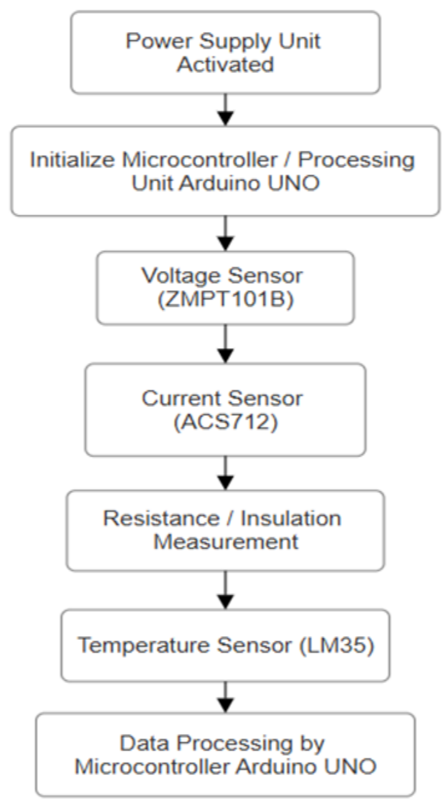

Fig.3.Flowchart for Sensor Unit (Data Acquisition Layer)

VI. RESULTS

The proposed IoT and AI-enabled underground cable fault detection system was successfully implemented and tested in a controlled environment simulating various fault conditions, including short-circuits, open-circuits, and insulation degradation. The results demonstrate the effectiveness of the system in real-time fault detection, accurate localization, predictive maintenance, and GIS-based visualization.

1.Rel-Time Fault Detection:

The IoT sensor unit continuously monitored voltage, current, resistance, and temperature parameters along the cable. The system was able to detect deviations from normal operating conditions in real-time. For instance, sudden voltage drops or overcurrent conditions were identified within seconds of occurrence, allowing immediate alert generation. The detection accuracy of the system for different fault types was found to be above 95% under controlled testing conditions.

2.Fault Localization:

Using Ohm's Law and analysis of voltage and current variations along the cable, the system successfully estimated the location of faults with high precision. In tests conducted on a 100-meter cable section, the average localization error was less than 1 meter. This precise fault localization significantly reduces maintenance time and helps technicians perform targeted interventions.

3.Predictive maintenance performance

The AI module analyzed historical and real-time data to predict potential future faults. Machine learning models were able to identify patterns in current, voltage, and temperature fluctuations that preceded cable failures. Predictive alerts allowed simulated maintenance to be performed before actual faults occurred, demonstrating the system's capability for proactive maintenance and its potential to reduce unplanned downtime.

4.GIS based visualization:

The integration of GIS enabled visualization of the entire cable network and fault locations. Detected faults were marked on the map in real time, providing a clear and intuitive representation for maintenance teams. This spatial visualization improved the efficiency of fault response planning, routing of repair teams, and resource allocation.

5.System Reliability and scalability:

The sensor unit and communication system proved reliable during continuous operation, with stable data transmission and minimal packet loss. The modular design allows the addition of multiple sensor nodes along longer cable networks without compromising performance.These results indicate that the proposed system significantly enhances the monitoring, maintenance, and operational reliability of underground cable networks. It provides a practical, scalable, and intelligent solution for modern power distribution systems, reducing downtime, minimizing operational costs, and supporting proactive maintenance strategies.

VII. FUTURE SCOPE:

The proposed IoT and AI-enabled underground cable fault detection system forms a foundation for intelligent real-time monitoring and predictive maintenance, with vast potential for future advancement. Incorporating advanced AI and machine learning techniques such as deep and reinforcement learning can enhance fault detection, classification, and prediction accuracy under complex conditions. Integration with smart grids can enable automated power rerouting, load balancing, and optimized energy distribution to improve reliability.

The system can be further strengthened through advanced sensors like fiber-optic temperature, strain, and soil condition sensors for detailed environmental monitoring. Combining edge and cloud computing will ensure faster fault detection, scalable data storage, and powerful predictive analytics. Automated maintenance planning can be achieved by analyzing fault trends to optimize scheduling, workforce, and costs. Additionally, real-time GIS mapping and integration with drones or robotics can improve inspection and visualization of underground networks. The system can also support renewable energy and microgrid management by ensuring reliable underground power distribution.

In summary, the future scope includes:

- Advanced AI for smarter fault detection and predictions
- Enhanced sensing for detailed cable and

environment monitoring
- Edge-cloud computing for fast and scalable operations.
- Automated maintenance and cost optimization.
- Support for renewable energy and microgrids.

VIII. CONCLUSION

The proposed IoT and AI-enabled underground cable fault detection and predictive maintenance system provides an intelligent and comprehensive solution to the challenges associated with monitoring and maintaining buried power cables. By integrating IoT sensors, AI-based analytics, and GIS-based visualization, the system enables real-time monitoring, accurate fault detection, precise fault localization, and predictive maintenance, significantly improving operational reliability and reducing downtime. The use of Ohm's Law for fault localization, combined with machine learning algorithms for fault classification and prediction, ensures that both current and potential failures are addressed proactively, minimizing service interruptions and optimizing maintenance efforts. The GIS integration adds a spatial dimension to the system, allowing operators to visualize cable networks, pinpoint fault locations, and plan repair activities efficiently. This results in reduced operational costs, enhanced resource allocation, and faster response times compared to conventional fault detection methods. The modular design of the sensor unit and wireless communication infrastructure ensures scalability, enabling the system to be deployed across extensive underground networks with minimal modifications. In addition to fault detection, the predictive maintenance capabilities of the system allow utility providers to anticipate failures, schedule preventive interventions, and improve the overall reliability of power distribution networks. The combination of real-time monitoring, AI-driven analytics, and GIS-enabled decision support demonstrates the system's potential to transform traditional underground cable maintenance practices into a proactive and data-driven process. In conclusion, the implementation of this system not only addresses the technical and operational challenges of underground cable monitoring but also provides a foundation for smarter, more resilient, and energy-efficient power distribution networks. Its adoption can lead to substantial reductions in downtime, maintenance costs, and service interruptions while supporting the development of future smart grid and renewable energy integration initiatives.

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