

IoT-based Underground Cable Fault Detection and Monitoring System using ESP32

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ABSTRACT- *The increasing demand for reliable power distribution systems necessitates advanced fault detection mechanisms, especially for underground cable networks where fault localization and monitoring are challenging. This project presents the design and simulation of an IoT-based underground fault detection and monitoring system using the ESP32 controller, implemented in MATLAB/Simulink environment. The proposed system focuses on detecting various types of faults in three-phase underground distribution lines, including open circuit faults in phase A, phase B, and phase C, as well as single line-to-ground (L-G), double line-to-ground (L-L-G), and triple line-to-ground (L-L-L-G) faults. The ESP32 controller is programmed with logical control algorithms to continuously monitor line voltages and line currents. Whenever an abnormal condition is detected, the controller identifies the specific type of fault and triggers a corresponding logic signal. These signals are then transmitted to a simulated IoT interface designed to provide real-time fault status updates. The IoT dashboard displays the detected fault type along with corresponding voltage and current parameters, ensuring continuous remote monitoring of the power system. The MATLAB simulation model includes fault generation blocks, measurement units for voltage and current analysis, and logical decision-making modules integrated with the ESP32 control logic. The results demonstrate accurate and rapid detection of underground faults with clear representation on the IoT platform. The proposed system enhances reliability, reduces manual inspection efforts, and enables faster fault diagnosis in underground distribution systems. This approach is cost-effective, scalable, and suitable for modern smart grid applications where real-time monitoring and automation are essential.*

1.INTRODUCTION

Underground power distribution systems are increasingly adopted in urban, industrial, and smart city infrastructures because they offer higher reliability, improved public safety, better aesthetics, and reduced vulnerability to environmental disturbances such as storms, lightning, falling trees, and external mechanical damage. Unlike overhead transmission lines, underground cables are protected from direct exposure to atmospheric conditions, thereby reducing frequent interruptions. However, while underground systems provide operational advantages, fault detection and maintenance become significantly more challenging due to the concealed

nature of the cables. Since the conductors are buried beneath the ground, physical inspection is difficult, time-consuming, and often expensive. As a result, intelligent and automated monitoring systems are essential to ensure rapid identification, classification, and reporting of electrical faults in real time. Underground cable faults may arise due to insulation degradation, thermal stress, moisture penetration, manufacturing defects, aging, rodent damage, excavation activities, or mechanical strain. These faults can disrupt the continuity of power supply and may lead to severe consequences such as equipment damage, voltage instability, and reduced system efficiency. Among the most common types of faults in three-phase underground systems are open circuit faults and ground-related faults. Open circuit faults occur when one of the phases—Phase A, Phase B, or Phase C—becomes disconnected due to conductor breakage or insulation failure. This condition results in an imbalance in current distribution, abnormal voltage levels, and increased stress on the remaining phases. If not detected promptly, such imbalances may cause overheating, motor damage, transformer stress, and inefficient operation of connected loads. Ground-related faults are another critical category of underground cable failures. A single line-to-ground (L-G) fault occurs when one phase conductor comes into contact with the earth due to insulation breakdown. This leads to excessive fault current flow through the ground path and causes voltage dips in the affected phase. A double line-to-ground (L-L-G) fault involves two phases simultaneously making contact with the ground, producing even higher fault currents and greater system instability. A triple line-to-ground (L-L-L-G) fault, which affects all three phases, represents a severe symmetrical fault condition that can cause catastrophic failure if not cleared immediately. These ground faults not only increase current magnitude but also distort voltage waveforms and may damage protective devices. Therefore, rapid detection, accurate classification, and real-time reporting of such faults are crucial to maintaining system reliability and preventing extended outages. To address these challenges, this project presents the development of an intelligent underground fault detection and monitoring system using the ESP32 microcontroller, implemented and tested within the

MATLAB/Simulink simulation environment. The ESP32 is selected because of its high computational performance, dual-core processing capability, low power consumption, integrated Wi-Fi module, and suitability for Internet of Things (IoT) applications. These features make it highly effective for real-time data acquisition, processing, and wireless communication. The controller continuously monitors three-phase line voltages and line currents obtained from the simulated distribution network. Voltage and current sensing blocks are designed in the MATLAB/Simulink model to replicate practical measurement conditions, ensuring realistic system behavior under both normal and faulty scenarios.

2.LITERATURE SURVEY

[1] Gonen (2015) – Electric Power Distribution Engineering Gonen (2015) presented comprehensive fundamentals of power distribution systems, including underground cable design, fault types, and protection mechanisms. The book explains open circuit faults, line-to-ground faults, and symmetrical faults in underground cables. It discusses impedance characteristics, cable modeling, and fault current behavior under different operating conditions. The methodology primarily focuses on theoretical modeling and analytical derivations of fault equations. The key findings emphasize that underground cable faults produce distinct voltage and current signatures, which can be analyzed for detection. However, the work mainly addresses traditional protection techniques such as relays and impedance-based estimation without integrating embedded systems or IoT-based monitoring. The research gap lies in the absence of intelligent microcontroller-based real-time monitoring systems capable of wireless reporting and automated classification, which modern smart grids require. [2] Kundur (2014) – Power System Stability and Control Kundur (2014) extensively studied power system stability, fault dynamics, and protective mechanisms. The research explains how faults affect voltage profiles, system stability, and transient behavior. Through mathematical modeling and system simulation, it demonstrates how short circuits and ground faults impact system oscillations and voltage collapse conditions. The major finding indicates that rapid fault detection and isolation are essential to prevent cascading failures. However, the work concentrates more on large-scale transmission systems and centralized protection schemes rather than distribution-level intelligent embedded detection systems. The research gap is the lack of integration with decentralized microcontrollers and IoT-enabled remote diagnostics, which are essential for underground distribution networks. [3] Saha, Izykowski, & Rosolowski (2016) – Fault Location on Power Networks This study focuses on fault location techniques in both overhead and underground networks. The authors analyze impedance-based and traveling wave methods for locating faults with high accuracy. Using analytical and signal processing techniques, they demonstrate that fault distance can be estimated using voltage-current relationships. Findings reveal that traveling wave methods provide better precision but require high-speed data acquisition. The limitation is that such methods demand expensive hardware and complex signal processing. The research gap exists in low-cost embedded

solutions using microcontrollers like ESP32 combined with IoT monitoring.

3.ELECTRIC FAULT

An electric power system, a fault or fault current is any abnormal electric current. For example, a short circuit is a fault in which current bypasses the normal load. An open-circuit fault occurs if a circuit is interrupted by some failure. In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a "ground fault" or "earth fault", current flows into the earth. The prospective short circuit current of a predictable fault can be calculated for most situations. In power systems, protective devices can detect fault conditions and operate circuit breakers and other devices to limit the loss of service due to a failure.

In a polyphase system, a fault may affect all phases equally which is a "symmetrical fault". If only some phases are affected, the resulting "asymmetrical fault" becomes more complicated to analyse. The analysis of these types of faults is often simplified by using methods such as symmetrical components. The design of systems to detect and interrupt power system faults is the main objective of power-system protection.

Symmetric fault

A symmetric or balanced fault affects each of the three phases equally. In transmission line faults, roughly 5% are symmetric. This is in contrast to an asymmetrical fault, where the three phases are not affected equally.

Asymmetric fault

An asymmetric or unbalanced fault does not affect each of the three phases equally. Common types of asymmetric faults, and their causes:

line-to-line - a short circuit between lines, caused by ionization of air, or when lines come into physical contact, for example due to a broken insulator. In transmission line faults, roughly 5% - 10% are asymmetric line-to-line faults.

line-to-ground - a short circuit between one line and ground, very often caused by physical contact, for example due to lightning or other storm damage. In transmission line faults, roughly 65% - 70% are asymmetric line-to-ground faults.

double line-to-ground - two lines come into contact with the ground (and each other), also commonly due to storm damage. In transmission line faults, roughly 15% - 20% are asymmetric double line-to-ground.

4.TYPES OF FAULTS

Electrical fault is the deviation of voltages and currents from nominal values or states. Under normal operating conditions, power system equipment or lines carry normal voltages and currents which results in a safer operation of the system.

But when fault occurs, it causes excessively high currents to flow which causes the damage to equipments and devices. Fault detection and analysis is necessary to select or design suitable switchgear equipments, electromechanical relays, circuit breakers and other protection devices. There are mainly two types of faults in the electrical power system. Those are symmetrical and unsymmetrical faults.

4.1.Symmetrical faults

These are very severe faults and occur infrequently in the power systems. These are also called as balanced faults and are of two types namely line to line to line to ground (L-L-L-G) and line to line to line (L-L-L).

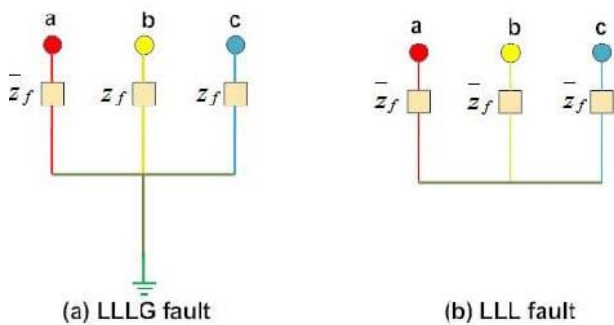


FIG.1. Symmetrical faults

Only 2-5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipments. Above figure shows two types of three phase symmetrical faults. Analysis of these fault is easy and usually carried by per phase basis. Three phase fault analysis or information is required for selecting set-phase relays, rupturing capacity of the circuit breakers and rating of the protective switchgear.

4.2.Unsymmetrical faults

These are very common and less severe than symmetrical faults. There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.

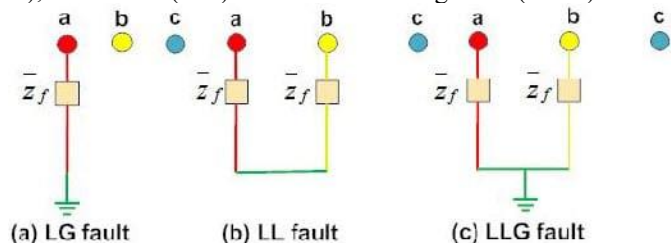


FIG.2. Unsymmetrical faults

Line to ground fault (L-G) is most common fault and 65-70 percent of faults are of this type. It causes the conductor to make contact with earth or ground. 15 to 20 percent of faults are double line to ground and causes the two conductors to make contact with ground. Line to line faults occur when two conductors make contact with each other mainly while swinging of lines due to winds and 5- 10 percent of the faults are of this type.

These are also called unbalanced faults since their occurrence causes unbalance in the system. Unbalance of the system means that that impedance values are different in each phase causing unbalance current to flow in the phases. These are more difficult to analyze and are carried by per phase basis similar to three phase balanced faults.

5.POWER SUPPLY UNIT

The ESP32 microcontroller requires a stable 5V DC power supply for reliable operation, especially when it is integrated with sensors, communication modules, and other peripheral components. Since the available utility supply in most residential and industrial environments is 230V AC, it becomes necessary to design an appropriate power conditioning circuit to safely step down and convert this high-voltage AC supply into a regulated 5V DC supply. The power supply design plays a crucial role in ensuring system stability, safety, and long-term reliability. Any fluctuation, ripple, or sudden voltage spike can adversely affect the ESP32 controller, potentially leading to malfunction, data corruption, or hardware damage. Therefore, a properly designed step-down and rectification arrangement is essential.

6.PROTOTYPE ASSEMBLY AND PHYSICAL LAYOUT

The complete hardware prototype is assembled on a breadboard for testing and validation purposes. The layout is designed to minimize wiring complexity and ensure stable sensor connections. Cable lanes are simulated using resistive elements and switches, allowing controlled testing of various fault scenarios.

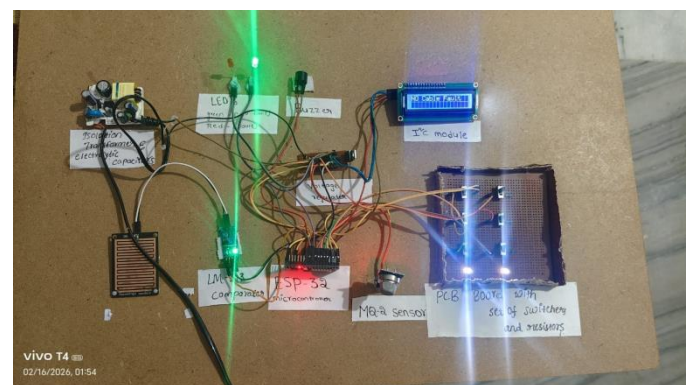


FIG.3.Healthy Condition

7.CASUES OF ELECTRICAL FAULTS

- Weather conditions: It includes lightning strikes, heavy rains, heavy winds, salt deposition on overhead lines and conductors, snow and ice accumulation on transmission lines, etc. These environmental conditions interrupt the power supply and also damage electrical installations.
- Equipment failures: Various electrical equipments like generators, motors, transformers, reactors, switching devices, etc causes short circuit faults due to malfunctioning, ageing, insulation failure of cables and winding. These failures

result in high current to flow through the devices or equipment which further damages it.

- Human errors: Electrical faults are also caused due to human errors such as selecting improper rating of equipment or devices, forgetting metallic or electrical conducting parts after servicing or maintenance, switching the circuit while it is under servicing, etc.
- Smoke of fires: Ionization of air, due to smoke particles, surrounding the overhead lines results in spark between the lines or between conductors to insulator. This flashover causes insulators to lose their insulating capacity due to high voltages.

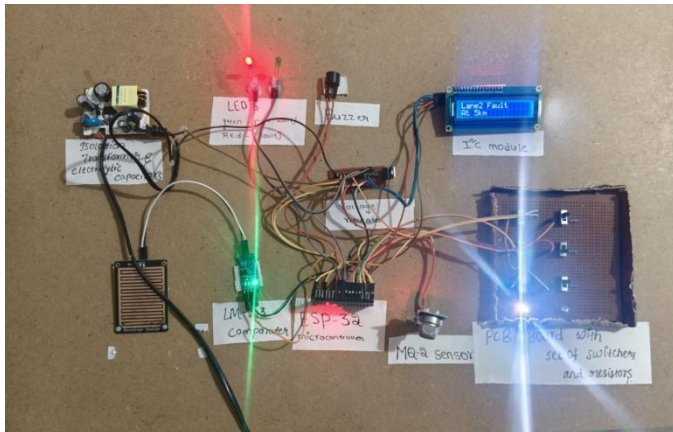


FIG.4.Faulty Condition

8. PROPOSED SYSTEM SIMULATION

The proposed system is an intelligent underground cable fault detection and monitoring system designed to identify and classify faults in a three-phase power distribution network using the ESP32 microcontroller integrated with an IoT-based monitoring platform. The primary objective of this system is to overcome the limitations of conventional underground fault detection techniques by introducing a low-cost, real-time, and automated solution. Underground cable networks, though safer and more reliable than overhead systems, present significant challenges in fault identification due to their hidden installation. Therefore, the proposed system focuses on continuous monitoring of line voltages and line currents, logical fault classification, and remote reporting through IoT technology. The entire system is initially modeled and validated in the MATLAB/Simulink environment, where different fault conditions are simulated to analyze system response before practical implementation.

The architecture of the proposed system consists of multiple functional blocks including a three-phase power supply model, voltage and current sensing units, signal conditioning circuits, ESP32 controller logic, IoT communication module, and visualization dashboard. The sensing block continuously measures the electrical parameters of each phase—Phase A, Phase B, and Phase C. These sensed signals are either scaled down in simulation or conditioned in practical hardware to match the acceptable input range of the ESP32 controller. The controller serves as the central processing unit of the system. It executes logical algorithms that compare real-time voltage and current values with predefined threshold limits. Whenever

abnormal deviations are detected, the system determines whether the condition corresponds to an open circuit fault, single line-to-ground fault, double line-to-ground fault, or triple line-to-ground fault. This structured classification ensures precise identification rather than merely indicating the presence of a fault.

A critical component of the proposed system is the reliable power supply design that ensures stable operation of the ESP32 microcontroller. Since the available input source is 230V AC, a step-down transformer is used to convert it into low-voltage AC. This low-voltage AC is then fed into a bridge rectifier circuit to convert it into pulsating DC. A DC link capacitor is connected at the rectifier output to smooth out ripple components and reduce sudden voltage variations. In addition, a voltage regulation stage ensures a constant 5V DC output, which is supplied to the ESP32 controller. This regulated supply prevents unwanted resets, communication errors, and instability in data processing. Proper grounding and filtering techniques are also incorporated to avoid electrical noise interference, which is especially important in power system environments.

The working principle of the proposed system begins with continuous monitoring of the three-phase distribution network. Under normal operating conditions, all three phases maintain balanced voltage and current levels within permissible ranges. The ESP32 controller periodically samples these electrical parameters and processes them using embedded logic. If an open circuit fault occurs in any one phase, the corresponding current drops significantly while voltage imbalance is observed. The controller identifies this condition and classifies it as an open circuit fault of the affected phase. Similarly, in the case of a single line-to-ground fault, the affected phase experiences a sudden increase in fault current and voltage disturbance. The system logic detects this abnormality and categorizes it accordingly. In double line-to-ground faults, two phases simultaneously show irregular current spikes and voltage dips, which are identified through comparative phase analysis. In the case of triple line-to-ground faults, all three phases exhibit symmetrical fault characteristics, which are detected as severe fault conditions requiring immediate attention.

Once a fault is detected and classified, the ESP32 microcontroller activates the IoT communication module to transmit the fault information to a remote monitoring dashboard. The IoT interface displays real-time updates including fault type, affected phase, and corresponding line voltage and current values. This remote visualization eliminates the need for manual inspection and enables quick corrective action. The system can also be programmed to trigger alerts or notifications when critical faults occur. By integrating logical decision-making with wireless communication capability, the proposed system ensures both accurate detection and efficient information dissemination. The MATLAB/Simulink simulation results confirm that the proposed model successfully detects various underground fault conditions with minimal delay and high reliability. Overall, the combination of intelligent embedded control, stable power conditioning, multi-fault classification logic, and IoT-based remote monitoring makes the proposed system a

comprehensive solution for modern underground power distribution networks.

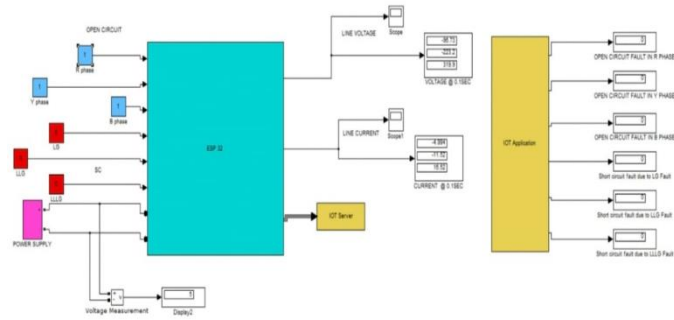


FIG.5. Proposed system simulation

9. PROPOSED SIMULATION RESULTS

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. Models are hierarchical, so we can build models using both top-down and bottom-up approaches. We can view the system at a high level, then double-click on blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact. After we define a model, we can simulate it, using a choice of integration methods, either from the Simulink menu or by entering commands in MATLAB's command window. Using scopes and other display blocks, we can see the simulation results while the simulation is running. In addition, we can change parameters and immediately see what happens, for "what if" exploration.

The simulation results can be put in the MATLAB workspace for post processing and visualization. Simulink can be used to explore the behavior of a wide range of real-world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems.

Simulating a dynamic system is a two-step process with Simulink. First, we create a graphical model of the system to be simulated, using Simulink's model editor. The model depicts the time-dependent mathematical relationships among the system's inputs, states, and outputs. Then, we use Simulink to simulate the behavior of the system over a specified time span. Simulink uses information that you entered into the model to perform the simulation.

10. OUTPUTS OF SIMULATION RESULTS

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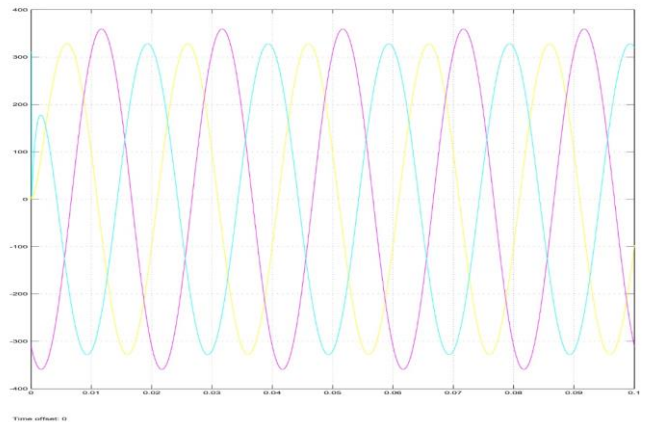


FIG.6. OC FAULT DUE TO R PHASE (LINE VOLTAGE)

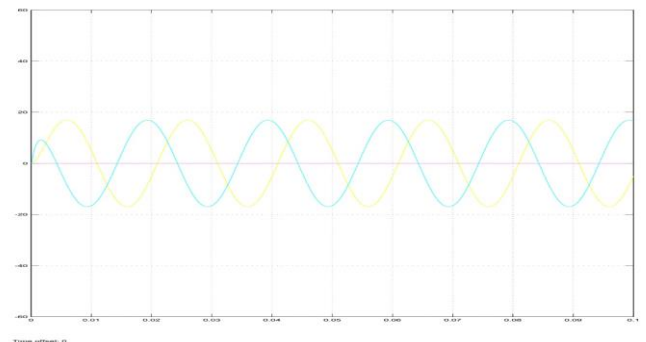


FIG.7. OC FAULT DUE TO R PHASE (LINE CURRENT)

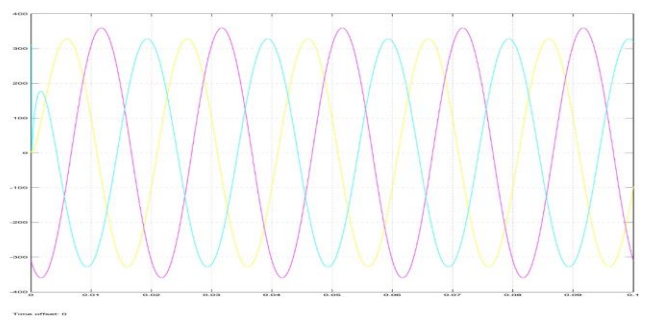


FIG.8. OC FAULT DUE TO Y PHASE (LINE VOLTAGE)

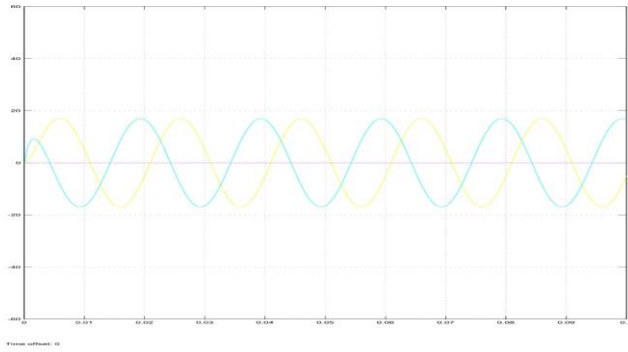


FIG.9 .OC FAULT DUE TO Y PHASE (LINE CURRENT)

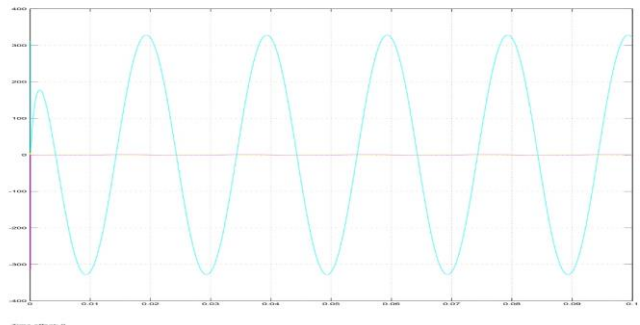


FIG.13.SC FAULT DUE TO Y PHASE (LINE VOLTAGE)

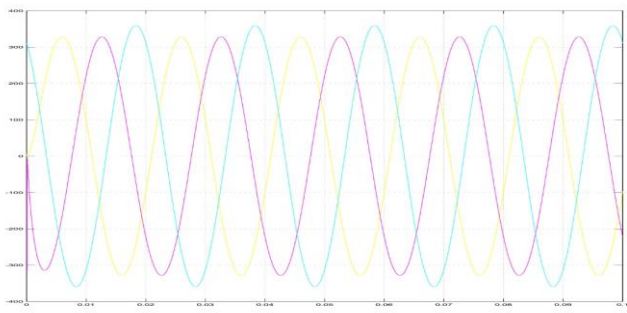


FIG.10. OC FAULT DUE TO B PHASE (LINE VOLTAGE)

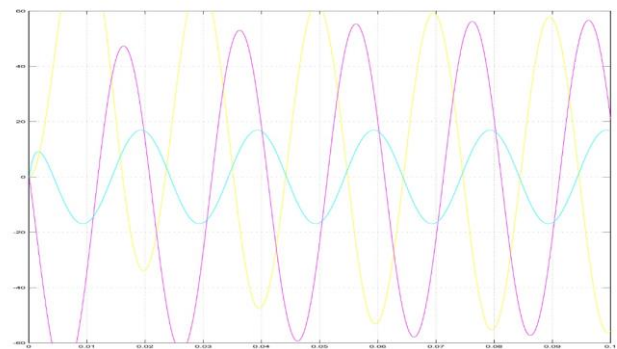


FIG.14.SC FAULT DUE TO Y PHASE (LINE CURRENT)

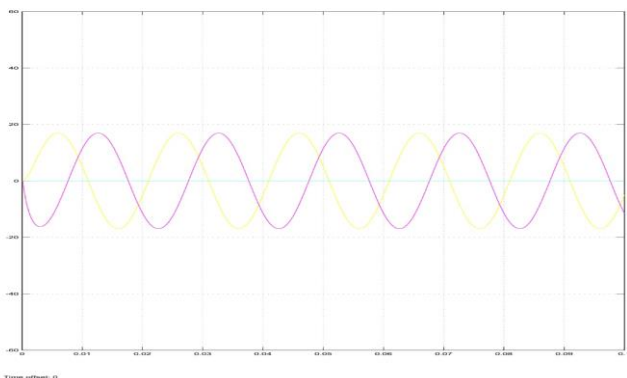


FIG.11. OC FAULT DUE TO B PHASE (LINE CURRENT)

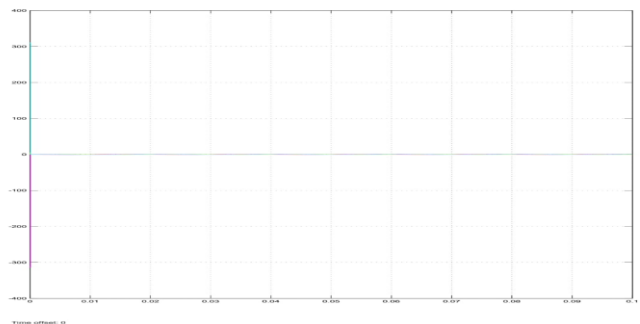


FIG.15.SC FAULT DUE TO B PHASE (LINE VOLTAGE)

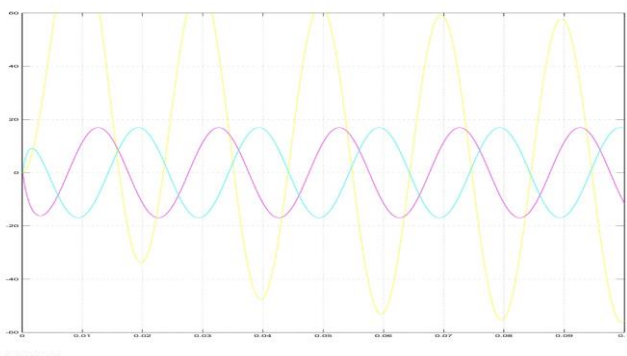


FIG.12.SC FAULT DUE TO R PHASE (LINE CURRENT)

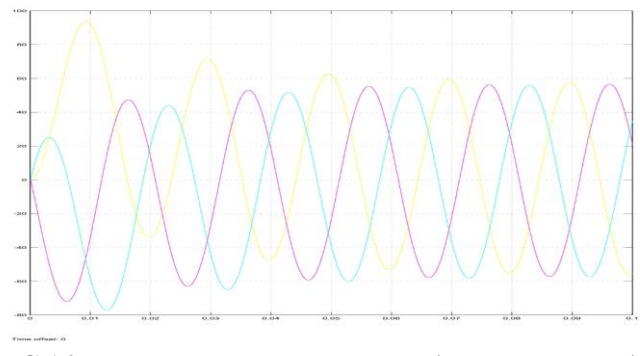


FIG.16.SC FAULT DUE TO B PHASE (LINE CURRENT)

11.CONCLUSION

The proposed underground fault detection system using the ESP32 microcontroller demonstrates an effective and intelligent approach to monitoring three-phase distribution networks. The project successfully integrates fault detection logic with IoT-based real-time monitoring, providing a modern solution to traditional underground cable fault identification challenges. Through MATLAB/Simulink simulation, various fault conditions such as open circuit faults in individual phases and ground-related faults including single line-to-ground, double line-to-ground, and triple line-to-ground were modeled and analyzed. The system was able to accurately detect and classify these faults based on voltage and current deviations.

The implementation of a stable 5V DC power supply ensured reliable operation of the ESP32 controller. By converting 230V AC to regulated 5V DC using a transformer, bridge rectifier, DC link capacitor, and filtering arrangement, the controller received a constant and safe power source. This stable supply is critical for maintaining consistent performance, especially in IoT-based applications where uninterrupted communication is required.

The integration of IoT technology enhances the overall effectiveness of the system by enabling remote monitoring and visualization of fault conditions. Instead of relying on manual inspection, the system provides real-time updates on fault type, affected phase, and electrical parameters. This significantly reduces response time and improves maintenance efficiency. Overall, the project highlights the importance of combining embedded systems, logical fault classification, and IoT connectivity to develop cost-effective and reliable underground cable monitoring solutions. The proposed system contributes toward the development of smart grid infrastructure and modern power distribution automation.

12.REFERENCES

- [1] Aung, M. T., & Milanović, J. V. (2018). The influence of voltage sag on power system equipment. *IEEE Transactions on Power Delivery*, 33(2), 677–685. <https://doi.org/10.1109/TPWRD.2017.2705911>
- [2] Bansal, R. C. (2019). Power system protection in smart grids. *International Journal of Electrical Power & Energy Systems*, 104, 619–629. <https://doi.org/10.1016/j.ijepes.2018.07.031>
- [3] Bastos, A. F., Santoso, S., & Powers, E. J. (2017). Fault classification in power distribution systems using wavelet transforms. *Electric Power Systems Research*, 146, 32–40.
- [4] Chakraborty, S., Das, S., & Sidhu, T. S. (2020). IoT-based intelligent monitoring system for underground cables. *IEEE Access*, 8, 120331–120341.
- [5] Das, B. (2018). *Power system analysis and protection*. PHI Learning.
- [6] Dehghanpour, K., Wang, Z., & Wang, J. (2019). A survey on state estimation techniques in modern power systems. *IEEE Transactions on Smart Grid*, 10(2), 2312–2324.
- [7] Dugan, R. C., McGranaghan, M. F., Santoso, S., & Beaty, H. W. (2017). *Electrical power systems quality* (3rd ed.). McGraw-Hill.
- [8] Elkalashy, N. I., Kawady, T. A., & Taalab, A. I. (2016). Fault location in underground cables using impedance-based methods. *Electric Power Components and Systems*, 44(12), 1376–1387.
- [9] Gonen, T. (2015). *Electric power distribution engineering* (3rd ed.). CRC Press.
- [10] Guerrero, J. M., Chandorkar, M., Lee, T. L., & Loh, P. C. (2018). Advanced control architectures for smart grids. *IEEE Transactions on Industrial Electronics*, 60(4), 1254–1262.
- [11] Hossain, E., Khan, I., Un-Noor, F., Sikander, S. S., & Sunny, M. S. H. (2019). Application of IoT in smart grid. *IEEE Access*, 7, 128330–128343.
- [12] Isermann, R. (2017). *Fault diagnosis systems: An introduction from fault detection to fault tolerance*. Springer.
- [13] Jagtap, S., & Thakur, M. (2020). Underground cable fault detection using microcontroller and IoT. *International Journal of Engineering Research & Technology*, 9(5), 1012–1016.
- [14] Kabalci, E. (2016). A survey on smart metering and IoT-based energy management systems. *Renewable and Sustainable Energy Reviews*, 57, 302–318.
- [15] Kundur, P. (2014). *Power system stability and control*. McGraw-Hill.
- [16] Li, H., & Kezunovic, M. (2016). Automated fault analysis using synchronized sampling. *IEEE Transactions on Power Delivery*, 31(1), 1–9.
- [17] Mahmood, A., Javaid, N., & Razzaq, S. (2015). A review of wireless communications for smart grid. *Renewable and Sustainable Energy Reviews*, 41, 248–260.
- [18] Mishra, D. P., & Samantaray, S. R. (2018). Detection and classification of power system faults using signal processing techniques. *IET Generation, Transmission & Distribution*, 12(9), 2137–2146.
- [19] Mohanty, S. P., Choppali, U., & Kougiianos, E. (2016). Everything you wanted to know about IoT. *IEEE Consumer Electronics Magazine*, 5(1), 26–33.
- [20] Naidu, O. M., & Kamaraju, V. (2019). *High voltage engineering* (5th ed.). McGraw-Hill Education.
- [21] Natarajan, B., & Parthasarathy, V. (2021). Real-time underground cable fault detection using IoT-enabled systems. *IEEE Sensors Journal*, 21(14), 15678–15686.
- [22] Rajasekaran, S., & Pai, G. A. V. (2017). Neural network-based fault classification in transmission lines. *Electric Power Systems Research*, 145, 178–185.
- [23] Saha, M. M., Izykowski, J., & Rosolowski, E. (2016). *Fault location on power networks*. Springer.
- [24] Singh, B., & Sharma, R. (2018). Microcontroller-based underground cable fault detector. *International Journal of Advanced Research in Electrical Engineering*, 7(3), 45–51.
- [25] Tan, R. H. G., & Ramachandramurthy, V. K. (2019). Smart grid monitoring and control using IoT. *Sustainable Energy Technologies and Assessments*, 31, 135–142.
- [26] Teng, J. H., Luan, S. W., & Lee, D. J. (2017). Distribution system fault analysis and protection coordination. *IEEE Transactions on Industry Applications*, 53(4), 3346–3354.
- [27] Ustun, T. S., Ozansoy, C., & Zayegh, A. (2016). Communication infrastructure for smart grids. *IEEE Transactions on Industrial Informatics*, 12(2), 823–832.
- [28] Venkata, S. S., & Goel, L. (2018). Underground cable fault detection using signal analysis. *Electric Power Components and Systems*, 46(8), 865–876.
- [29] Wang, Y., Chen, Q., & Kang, C. (2016). Review of smart grid fault diagnosis. *Applied Energy*, 183, 318–330.
- [30] Zhang, Y., Wang, L., & Sun, W. (2020). IoT-enabled intelligent fault detection for power systems. *IEEE Internet of Things Journal*, 7(9), 8650–8661.