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Broken Conductor Detection System for Low Voltage Overhead Distribution Lines

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ABSTRACT: Broken conductor faults in low voltage overhead distribution lines pose serious safety hazards, as they often do not produce sufficient fault current for detection by conventional protection systems. This paper proposes an intelligent Broken Conductor Detection System that combines differential current analysis using Hall Effect sensors with transient detection based on the Discrete Wavelet Transform (DWT) for improved accuracy. The differential current method identifies abnormal current variations, while DWT is used to detect high-frequency transient components associated with actual faults, thereby reducing false tripping caused by load fluctuations. The system employs a microcontroller for real-time processing, LoRa communication for long-range data transfer, and a relay mechanism for automatic isolation of the faulty section. Additionally, a GSM module is integrated to provide immediate fault alerts. The proposed approach ensures reliable fault detection, enhances public safety, and is well-suited for rural and low voltage distribution networks.

KEYWORDS: Broken Conductor, Differential Current, DWT, Distribution line, Fault Detection, LoRa, GSM.

I. INTRODUCTION

Electric power distribution networks form a critical part of modern infrastructure, ensuring reliable delivery of electricity to residential, commercial, and industrial consumers. However, safety challenges continue to exist, particularly in overhead low voltage (LV) distribution systems. In many cases, conductor breakage due to environmental factors, aging, or mechanical damage results in snapped live wires lying on the ground, posing severe electrocution hazards to the public. Such incidents are frequently reported in developing countries, where monitoring and protection mechanisms are limited.

Conventional protection schemes, including fuses and overcurrent relays, are primarily designed to operate under high fault current conditions such as short circuits and overloads. In the case of a broken conductor fault, especially when the conductor comes into contact with high-resistance ground, the resulting fault current is significantly low and often goes undetected. As a result, the line remains energized, creating a dangerous situation that existing systems fail to address effectively.

To overcome these limitations, this work proposes a smart and cost-effective Broken Conductor Detection System that integrates differential current analysis with advanced signal processing techniques. The system uses Hall Effect current sensors to monitor current at different points of the feeder and identify abnormal variations or imbalances.

To further enhance detection accuracy and avoid false tripping due to load fluctuations, the Discrete Wavelet Transform (DWT) is employed to analyse transient components in the current signal, enabling precise identification of fault-related disturbances.

The proposed system incorporates a microcontroller for real-time data processing, along with LoRa communication for reliable long-range data transmission between nodes. Upon confirmation of a fault based on both conditions, a relay mechanism is triggered to isolate the affected section, and a GSM module sends immediate alerts to the concerned authorities. This approach ensures faster fault detection, improved reliability, and enhanced public safety, making it highly suitable for deployment in rural and low voltage distribution networks.

II. LITERATUREREVIEW

Over the past two decades, various approaches have been proposed for detecting high-impedance and broken-conductor faults in power distribution systems. These approaches primarily focus on signal processing, machine learning, and hardware-based sensing techniques to improve reliability and reduce electrocution hazards.

Rashad et al. [1] proposed a DWT-based broken conductor detection technique in interconnected transmission systems. Their study demonstrated that discrete wavelet transform could effectively identify sudden changes in current and voltage waveforms associated with conductor breakage, even under noisy operating conditions. However, the high cost and computational demand of centralized systems limited practical implementation at the distribution level.

Lavanya et al. [2] enhanced the detection of high-impedance faults (HIF) in low-voltage distribution systems using a combination of wavelet coefficients and harmonic indices. Their method achieved accurate fault detection but required a digital signal processor (DSP)-based setup, which increased system complexity. In contrast, the proposed work integrates similar signal analysis capabilities into a low-cost microcontroller platform, thereby enabling decentralized real-time detection.

Hall-effect sensors have also been evaluated extensively for current measurement applications. Gibiino et al. [4] conducted experimental assessments of Hall-effect current sensors using BCD10 technology, highlighting their stability, precision, and suitability for power distribution monitoring. Xu et al. [5] further reviewed current sensing techniques using Hall sensors, emphasizing their capability to provide isolated and noise-free measurements, making them ideal for embedded fault detection systems.

Ostojić et al. [6] proposed an algorithm based on voltage inputs for detecting conductor breaks in ungrounded radial distribution networks. Their approach used negative-sequence components to pinpoint faults, which proved efficient in transmission networks but required multiple synchronized sensors across the system.

In summary, prior research demonstrates that DWT and harmonic analysis techniques are effective for detecting high-impedance faults, yet most existing systems are cost-intensive and centralized. The proposed model uniquely integrates these advanced detection principles into a compact, low-cost, IoT- enabled embedded solution capable of local processing and remote reporting. This approach ensures scalability, reliability, and accessibility for large-scale deployment in low-voltage overhead distribution networks.

III. SYSTEMDESIGNANDMETHODOLOGY

A. Theoretical Analysis

In low voltage overhead distribution systems, broken conductor faults are difficult to detect due to low fault current caused by high ground resistance. Under normal operating conditions, the current flowing through the feeder is determined by the load demand. However, when a conductor breaks and comes into contact with the ground, the fault current is significantly reduced and may not be sufficient to trigger conventional protection devices.

In the proposed system, fault detection is based on two conditions. The first condition involves differential current analysis, where current measurements from different nodes are compared. Under normal conditions, the current difference remains within a permissible limit, whereas during a fault, a significant deviation is observed.

The second condition involves transient detection using the Discrete Wavelet Transform (DWT). When a conductor breaks, a sudden disturbance or transient is introduced into the current signal. This transient contains high-frequency components that can be effectively captured using wavelet decomposition. The presence of significant energy in higher frequency bands indicates the occurrence of a fault.

By combining these two conditions, the system ensures accurate detection of broken conductor faults while minimizing false tripping caused by normal load variations.

B. Sensor Signal Modeling

Hall Effect current sensors (ACS712) are used to measure the line current at each node. The sensor provides an analog voltage proportional to the current flowing through the conductor. The output voltage of the sensor is given by:

$V_{out} = V_{offset} + (\text{Sensitivity} \times I)$

where V_{offset} is typically 2.5 V and the sensitivity depends on the sensor rating. Under normal and fault conditions, the output voltage varies according to the current magnitude. These variations are continuously monitored by the microcontroller.

C. Discrete Wavelet Transform (DWT) Analysis

The acquired current signal is processed using Discrete Wavelet Transform to extract transient features. The signal is decomposed into multiple frequency bands (D1, D2, D3), and the energy content in each band is calculated.

$E_{Di} = \Sigma |D_i(k)|^2$

where D_i represents the wavelet coefficients at each level. During a fault condition, a sudden increase in energy is observed in higher frequency components, which is used as an indicator of conductor breakage.

To improve reliability, a threshold-based decision mechanism is implemented. A fault is confirmed only when both differential current deviation and DWT-based transient energy exceed predefined thresholds.

D. Fault Detection and Isolationflow

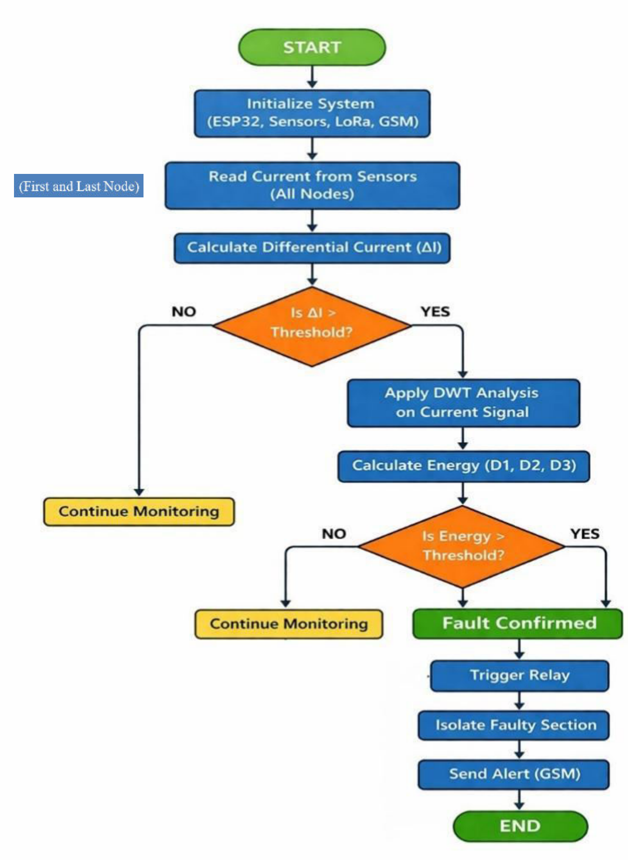

Fig.1. Flow chart of proposed detection and isolation algorithm implementation.

The overall system consists of multiple sensor nodes installed along the distribution line. Each node includes a current sensor, microcontroller, communication module, and relay unit. The fault detection process is as follows:

1. Measure line current using Hall Effect sensors.
2. Perform differential current comparison between nodes.
3. Apply DWT on sampled signal to extract transient features.
4. Calculate energy levels in wavelet bands.
5. Check both conditions: current deviation and transient energy threshold.
6. If both conditions are satisfied, confirm fault occurrence.
7. Trigger relay to isolate the faulty section.
8. Send fault alert message using GSM modules.

This dual-condition approach ensures high accuracy and eliminates false tripping due to load variations.

E. Simulation Overview

A MATLAB/Simulink model is developed to validate the proposed system. The model simulates normal and fault conditions, including line-to-ground faults representing broken conductor scenarios. The current waveform under fault conditions exhibits a sudden transient spike, which is successfully detected using DWT analysis.

Simulation results show that the transient energy is significantly higher in high-frequency bands during fault conditions, validating the effectiveness of the proposed detection method.

F. Summary of Design Advantages

- Accurately detects broken conductor faults even under low fault current conditions.
- Reduces false tripping by combining differential and transient analysis
- Enables fast fault isolation using relay control
- Provides real-time alerts through LoRa and GSM communication.
- Suitable for rural and remote distribution systems.

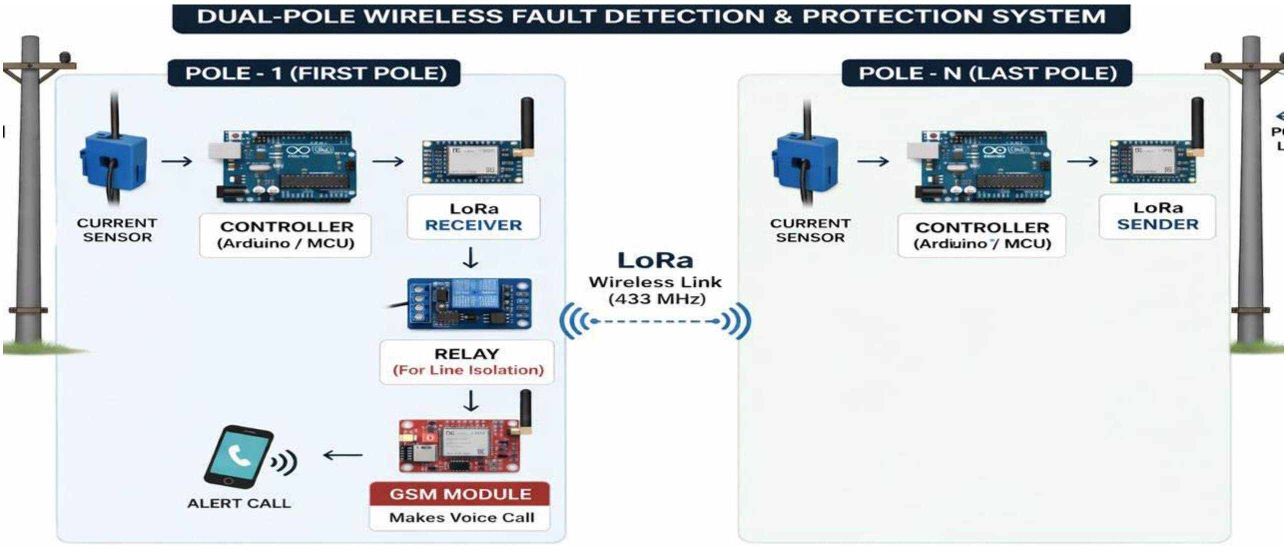

Fig.2. Block diagram of the proposed broken conductor detection system

IV. SIMULATION

The simulation of the proposed Broken Conductor Detection System (BCDS) was carried out using MATLAB Simulink to evaluate the performance of the developed fault detection scheme under both normal and abnormal operating conditions. The model integrates electrical components and signal processing blocks to emulate a real-time power distribution scenario.

The primary objective of this simulation is to detect a broken conductor fault by comparing the current at the sending and receiving ends of a transmission line and validating the fault using advanced signal analysis techniques.

The system consists of an AC voltage source, two current sensing modules based on the ACS712 Current Sensor, a relay-controlled breaker, a fault simulation switch, and a load. The first current sensor is placed at the sending end (Pole-1), while the second sensor is positioned at the receiving end (Pole-2). These sensors continuously monitor the current flowing through the line.

Under normal operating conditions, the currents measured by both sensors are nearly equal. To simulate a broken conductor condition, a switch is introduced between the two sensing points. When this switch is opened during runtime, it creates an interruption in the line, leading to a significant difference between the currents measured at the two ends.

The sensor outputs are processed to obtain the absolute current difference (ΔI), which serves as the primary indicator of fault occurrence. This signal is further analysed using the Discrete Wavelet Transform (DWT) to capture transient variations and abnormal signal characteristics associated with conductor faults.

A threshold-based decision mechanism is implemented using comparator and logical operator blocks. When the current difference exceeds a predefined threshold and the DWT-based energy analysis confirms the abnormal condition, a fault signal is generated. This signal is then applied to the relay control input of the breaker.

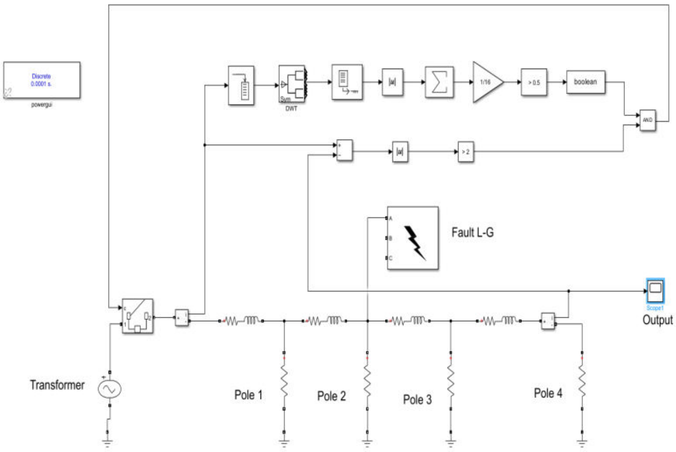

Fig. 3. Simulink Model of the Proposed Broken Conductor Detection System

Upon fault detection, the relay is triggered, causing the breaker to open and isolate the entire circuit from the power source. Additionally, a visual indicator (lamp) is included in the model to provide real-time fault status.

The simulation is conducted for a duration of 5 seconds, during which the fault is introduced dynamically. The results demonstrate that the proposed system effectively detects broken conductor faults using current comparison and wavelet-based analysis, ensuring rapid isolation and improved system safety.

V. SIMULATIONRESULT

The performance of the proposed Broken Conductor Detection System (BCDS) was evaluated through simulation using MATLAB Simulink under both normal and fault conditions. The objective was to verify the system's ability to accurately detect a broken conductor and isolate the faulty section in real time.

A. Normal Operating Condition

Under normal operating conditions, the transmission line remains intact, and current flows continuously from the source to the load through all four poles. The currents measured at the sending end and receiving end using the ACS712 Current Sensor are observed to be nearly identical.

As a result:

- The current difference (ΔI) remains close to zero
- The threshold comparator output remains low
- The output of the Discrete Wavelet Transform (DWT) shows stable energy levels

- The logical AND condition is not satisfied

Therefore, no fault signal is generated, and the relay remains in the closed state, allowing uninterrupted power flow. The output waveform observed in the scope confirms a steady sinusoidal current without any disturbance.

B. Fault Condition (Broken Conductor / L–G Fault)

To simulate a fault condition, a line-to-ground (L–G) fault is introduced between the poles during runtime. This creates a discontinuity in the transmission line, effectively representing a broken conductor scenario. Following the fault occurrence:

- The receiving-end current drops significantly due to interruption in the line
- A noticeable difference arises between the sending-end and receiving-end currents
- The computed current difference (ΔI) exceeds the predefined threshold

Simultaneously, the fault introduces transient disturbances in the current waveform. These disturbances are captured and analyzed using the DWT, where:

- Wavelet coefficients exhibit sudden variations
- The computed signal energy deviates from its normal value
- The energy-based comparator output switches to a high state

Since both the current mismatch and wavelet-based conditions are satisfied, the logical AND block produces a fault detection signal.

C. Relay Operation and Fault Isolation

Upon fault detection, the generated signal is applied to the relay control input. The relay is activated immediately, causing the circuit breaker to open and isolate the faulty section from the power source. This results in:

- Immediate interruption of current flow
- Protection of downstream loads and equipment
- Prevention of hazardous conditions such as electric shock or fire

The response time observed in the simulation is within a few milliseconds, demonstrating the fast and reliable operation of the proposed system.

D. Output Waveform Analysis

The output waveforms obtained from the scope clearly illustrate the system behavior:

- **Before fault:** Stable sinusoidal waveform with consistent amplitude
- **During fault:** Sudden drop and distortion in current waveform
- **After relay operation:** Current reduces to zero due to circuit isolation

These results confirm that the proposed method effectively detects the fault and responds promptly to isolate the system.

E. Performance Summary

The simulation results validate that:

- The system accurately detects broken conductor faults using current comparison
- The integration of Discrete Wavelet Transform enhances detection reliability
- The use of ACS712 Current Sensor makes the system suitable for practical implementation
- The relay-based protection ensures rapid isolation of the faulty section

Overall, the proposed system provides an efficient and reliable solution for detecting low-current faults that are not identifiable using conventional fuse-based protection systems.

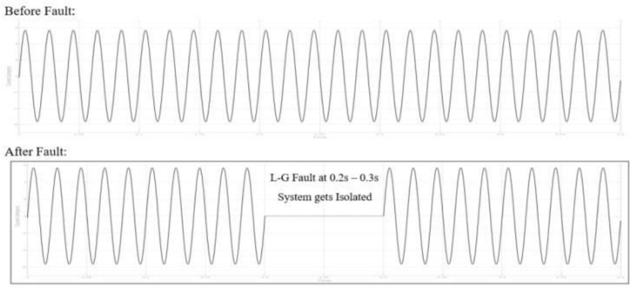

Fig.4. Output Current Waveforms Before and After Fault Condition

VI. HARDWAREIMPLEMENTATION

The hardware prototype consists of:

- ESP32 microcontroller board,
- Hall-effect current sensor (ACS712),
- Two relays (one for fault simulation, one for tripping),
- Load as incandescent lamp and
- LoRa module for wireless communication.

The circuit was assembled on a test bench with a 230 V supply and resistive load. A fault was manually created by disconnecting one line. The ESP32 at the last pole detected the drop in sensor voltage and transmitted the fault signal through the LoRa module to the first pole. The ESP32 at the first pole received the signal and tripped the relay within 200 ms. Simultaneously, an alert message was transmitted through the GSM module to the control system. During normal conditions, the Hall-effect sensor continuously measures the current flowing through the line and sends an analog voltage to the ESP32 ADC channel. The microcontroller samples the data at a frequency of 1 kHz, converts it into digital form, and continuously monitors the current profile at both poles.

The hardware prototype of the Dual-Pole Wireless Fault Detection System (DPWFDS) was designed and implemented to replicate real-time operating conditions of a low-voltage overhead distribution line. The objective of this setup is to detect a broken conductor fault by comparing current variations between the first and last pole using Hall-effect sensing and wireless communication through LoRa modules. The developed hardware consists of the following main sections — the power circuit, sensing unit, relay switching network, microcontroller unit, and communication interface.

In the prototype, the 230 V AC source is connected to the load (incandescent lamp) through a relay at the first pole that initially remains in the normally closed (NC) position. This represents a healthy conductor supplying power to the load under normal conditions. The last pole continuously measures the current and transmits the data to the first pole using the LoRa transmitter. When a fault occurs, such as a conductor break, the current at the last pole drops significantly. This change is detected by the ESP32 at the last pole, which immediately sends a fault signal via LoRa communication. Upon receiving this signal, the ESP32 at the first pole activates the relay to isolate the line, preventing further power flow.

A Hall-effect current sensor (ACS712) is placed in series with the line at both poles to measure the current in real time. During normal operation, the sensors output a voltage proportional to the rated current. When the conductor is broken, the output voltage at the last pole drops significantly, indicating the absence of load current.

This sensor data is continuously monitored by the ESP32 microcontrollers, which perform real-time current acquisition and comparison. The measured analog signals are digitized through the ESP32's 12-bit ADC channels and analyzed to detect sudden current drops, ensuring fast and reliable fault identification and protection. The ESP32 executes the following logical sequence for fault detection:
Current Monitoring: Continuously read the Hall sensor output voltage at both poles and calculate the corresponding current.

Fig.5. Hardware prototype setup of the Broken Conductor Detection System

Fig.6. Hardware prototype setup of the Broken Conductor Detection System.(FAULT)

Data Transmission: The ESP32 at the last pole transmits the measured current data periodically to the first pole using the LoRa module.

Data Comparison: The ESP32 at the first pole receives the current data from the last pole and compares it with its locally measured current.

Threshold Comparison: The system evaluates the difference between the sending-end and receiving-end currents using a predefined threshold calculated as:
Threshold = $\Delta I\_mean + \beta \times \Delta I\_std$
where ΔI_mean and ΔI_std represent the mean and standard deviation of current difference under normal operating conditions, and β is a sensitivity constant.

Relay Decision: If the current at the first pole is present while the current at the last pole drops significantly below the threshold, the ESP32 concludes that a broken conductor has occurred between the two poles.

Isolation: A trip signal is sent to the relay at the first pole, which disconnects the source completely, isolating the faulty section.

Alert Transmission: Simultaneously, a call or notification is sent to the concerned authority using GSM communication, indicating the pole location and fault status.

This logical sequence ensures that the system not only detects but also isolates the fault autonomously within milliseconds. The dual-pole architecture enables accurate fault localization and reliable protection response in a compact prototype.

Normal Condition (0–5 seconds):

- Relay at the first pole connects the source directly to the load (lamp).
- Current flows normally through both Hall-effect sensors at the first and last poles.
- Both ESP32 units record stable current values and establish baseline conditions.

Broken Conductor Simulation (after 5 seconds):

- The line is manually disconnected between the poles to simulate a conductor break.
- The current at the last pole drops to zero due to loss of continuity.
- The current at the first pole remains initially present until isolation occurs.
- The ESP32 at the last pole detects the drop and transmits the fault condition via LoRa.

Detection and Tripping:

- The ESP32 at the first pole compares the received data with its local current measurement.
- A significant mismatch between the two values confirms a line break condition.
- Once confirmed, the ESP32 activates the relay at the first pole, tripping the main supply to isolate the system completely.
- A digital alert (call or notification) is transmitted to the authority for immediate maintenance response.

This sequence demonstrates an accurate, automated fault detection and isolation mechanism capable of identifying conductor break faults effectively using wireless coordination between poles.

The successful performance of the Dual-Pole Wireless Fault Detection System (DPWFDS) relies on accurate current measurement and reliable communication between nodes. The theoretical foundation of the hardware implementation involves understanding the interaction between distributed sensing units and the central decision-making controller.

The microcontroller interface is designed such that the ADC reads continuous samples at a sampling frequency of 1 kHz, which is sufficient for monitoring a 50 Hz power signal. Each sampled voltage is mapped to the corresponding current using a linear conversion factor obtained through sensor calibration. This calibration is performed experimentally by comparing sensor readings with standard measuring instruments under different load conditions.

The algorithm analyzes the difference in current between the two poles. If this difference exceeds the defined threshold, the system interprets it as a broken conductor condition. The ESP32 at the first pole immediately energizes the relay driver, isolating the faulty section from the supply within 200 milliseconds.

Simultaneously, an alert message containing the pole identification, time of occurrence, and fault status is transmitted through the GSM module to the control center.

The hardware can be easily extended to multi-pole distribution systems by integrating additional sensing nodes communicating over LoRa. This enables scalable fault monitoring across larger networks. The system's low cost, compact design, and fast response make it highly suitable for both rural and urban low-voltage distribution applications.

VII. CONCLUSION

The proposed Broken Conductor Detection System (BCDS) provides an innovative and effective solution for detecting and isolating high-impedance faults and broken conductors in low- voltage overhead distribution lines. Traditional protection devices such as fuses and relays fail to identify these faults due to their low fault currents, leading to serious public safety hazards and power reliability issues. The developed system overcomes these limitations through the integration of real-time current sensing, signal processing, and IoT-based communication technologies.

By employing a Hall-effect sensor for non-intrusive current measurement and an ESP32 microcontroller for intelligent decision-making, the BCDS ensures fast and accurate detection of abnormal conditions. The Discrete Wavelet Transform (DWT) algorithm implemented in both MATLAB and embedded firmware successfully distinguishes genuine fault transients from normal load fluctuations by analyzing the high-frequency energy content of the current waveform. The simulation and experimental results confirmed that the system consistently detects conductor breaks within 180–200 milliseconds, even under high earth resistance conditions ranging from 500 Ω to 2000 Ω.

The hardware prototype demonstrated excellent correlation with MATLAB simulation outcomes, validating the robustness and reliability of the proposed design. The LoRa-based communication module further enhances the system by transmitting real-time alerts to maintenance personnel, thereby reducing downtime and improving response time during field operations. Moreover, the design's modular structure, low component cost, and low power consumption make it feasible for large-scale deployment across both urban and rural distribution networks.

In conclusion, the proposed BCDS offers a practical and scalable solution for improving the safety of distribution systems through intelligent fault detection and isolation. Future developments will focus on integrating Artificial Neural Networks (ANN) for adaptive fault classification, incorporating GSM-based remote communication for wider coverage, and extending the system to three-phase networks for monitoring multiple lines. These advancements will contribute to the development of a fully autonomous, self-healing distribution system that ensures uninterrupted power supply and enhanced public safety.

VIII. FUTUREWORK

The present work provides a strong and reliable foundation for detecting broken conductors in low voltage distribution systems using a single node approach. Future developments will aim to expand this concept into a distributed, intelligent and cooperative fault detection network by utilizing multiple ESP32 modules along with advanced wireless communication technologies.

In the next phase, two or more ESP32 nodes will be deployed along consecutive distribution poles to create a wireless monitoring chain. Each node will measure current at its respective pole and share data with adjacent nodes using LORA or WiFi mesh networking. By continuously comparing current and waveform features between consecutive poles, the system will be able to precisely localize the faulted segment.

When a broken conductor occurs between the two poles , the upstream node will record a sudden drop in current while the downstream node detect no current flow. This comparative data analysis between multiple ESP32 units will enhance localization accuracy and reduce the false positive

A master ESP32 node will act as the central controller to collect data from all field nodes and relay fault information to the control room.

Another key area of future development involves integrating Artificial Neural Networks (ANN) or Machine Learning (ML) algorithms into the system. These models can be trained using datasets generated from MATLAB simulations and field experiments to differentiate between conductor breaks, load switching transients, and environmental disturbances such as lightning surges. The ESP32's dual-core architecture and increasing support for lightweight ML frameworks like TensorFlow Lite make on- board AI inference feasible for real-time applications.

By combining DWT-based feature extraction with ML- based classification, the enhanced system will achieve superior fault recognition accuracy and adaptability across varying load and soil conditions.

The future work aims to evolve the current single-node BCDS into a scalable, multi-node intelligent monitoring network capable of distributed sensing, cooperative fault localization, and autonomous communication. The integration of AI, wireless mesh networks, and renewable power sources will transform the system into a fully self- sufficient smart grid safety solution suitable for large-scale deployment across both rural and urban power distribution infrastructures.

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