IJERST

International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 22 No. 2(1) (2026)

ijerst.editor@gmail.com

editor@ijerst.com

ISSN 2319-5991 www.ijerst.com

Peer Reviewed, Referred & Indexed Journal

Research Paper

IoT-ENABLED FAULT DETECTION IN DISTRIBUTION LINES

PANDRANKI SAI KUMAR[1], UNGATI SAIKUMAR[2], GANTYADA SOWJANYA[3], RALI KEERTHI PRIYA[4], Dr.Y.NARENDRA KUMAR[5]

[1] Student, Department of Electrical and Electronics Engineering, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India.pandrankisaikumar53@gmail.com

[2] Student, Department of Electrical and Electronics Engineering, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India.ungatisaikumar23@gmail.com

[3] Student, Department of Electrical and Electronics Engineering, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India.sowjanyagantyada@gmail.com0020

[4] Student, Department of Electrical and Electronics Engineering, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India.priyakreethi2004@gmail.com

[5]Professor, Department of Electrical and Electronics Engineering, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India. narenyegireddy@gmail.com

ABSTRACT

The increasing complexity of modern electrical distribution networks demands intelligent, real-time fault detection and isolation systems. Traditional methods of manual inspection and fault identification in three-phase power distribution lines are time-consuming, labor-intensive, and prone to delays that can result in significant power outages and economic losses. This project proposes and implements an IoT-enabled automated fault detection and isolation system for three-phase distribution lines using cost-effective, commercially available hardware components. The system employs an Arduino Uno microcontroller as the central processing unit, interfaced with ACS712 Hall-effect current sensing modules on each of the three phases — R Phase, Y Phase, and B Phase. A 16x2 Liquid Crystal Display (LCD) with I2C communication protocol provides real-time on-site visual feedback of system status and detected fault type. An active buzzer provides immediate auditory alerts, and dedicated Red LEDs serve as phase-wise visual fault indicators. The ESP8266 Wi-Fi module enables seamless internet connectivity, facilitating real-time push notifications to registered mobile devices via the Blynk cloud platform whenever a fault is detected. The system successfully detects two primary categories of faults: Open Circuit Faults and Short Circuit Faults across all three phases, covering all six fault combinations (R-Open, Y-Open, B-Open, R-Y Short, Y-B Short, R-B Short) with 100% detection accuracy and an average end-to-end fault-to-notification latency of 1.8 seconds. The proposed system provides a low-cost, scalable, and reliable solution for smart grid distribution line monitoring, particularly suited for rural and semi-urban electrical infrastructure.

Keywords: *IoT, Fault Detection, Arduino Uno, ESP8266, ACS712, LCD I2C, Three-Phase Distribution, Open Circuit Fault, Short Circuit Fault, Mobile Notification, Smart Grid, Blynk.*

1. INTRODUCTION

Electrical power distribution systems form the backbone of modern infrastructure, supplying electricity from high-voltage transmission lines to end consumers including residential, commercial, and industrial users. The three-phase alternating current (AC) distribution system, operating at standard frequencies of 50 Hz or 60 Hz, is the globally dominant mode of electrical power distribution due to its efficiency in long-distance power transmission and its ability to simultaneously supply single-phase and three-phase loads. In a three-phase power distribution system, three conductors — conventionally labeled R Phase (Red), Y Phase (Yellow), and B Phase (Blue) — carry equal voltages displaced by 120 electrical degrees from one another. Under normal operating conditions, the system maintains balanced current flow across all three phases.

Distribution lines are continuously exposed to environmental hazards, mechanical stress, aging insulation, equipment failures, and external interference that can cause various types of electrical faults. Faults in distribution lines can be broadly classified into open circuit faults and short circuit faults. An open circuit fault occurs when a conductor breaks or a connection is lost, interrupting current flow in that phase. A short circuit fault occurs when two or more conductors come into unintended contact — either phase-to-phase or phase-to-ground — resulting in abnormally high currents that can damage equipment and pose serious safety hazards. In developing nations, distribution line faults are responsible for an estimated 60–80% of total power system interruptions, underscoring the critical need for rapid and reliable fault detection mechanisms.

Traditionally, fault detection in distribution lines has relied on manual patrol inspection, time-overcurrent relays, fuses, and circuit breakers. While these methods provide basic protection, they suffer from significant limitations including delayed fault detection, inability to precisely identify the fault location, lack of remote monitoring capability, and high dependency on skilled personnel for interpretation and response. In rural and semi-urban areas, where distribution lines span vast geographic distances with limited field staff, these limitations become particularly acute. The advent of the Internet of Things (IoT) has opened transformative possibilities for smart grid applications. IoT enables the deployment of distributed, networked sensor nodes that can continuously monitor electrical parameters, perform onboard data processing, and transmit real-time alerts to cloud platforms and mobile devices — all at a fraction of the cost of traditional SCADA systems. This paradigm shift allows utilities and field engineers to detect, localize, and respond to faults within seconds rather than hours.

1.1 Problem Statement

Existing distribution line monitoring systems in developing regions suffer from several critical deficiencies that impede effective and timely fault management. The absence of real-time, automated fault detection mechanisms means that faults often go undetected for extended periods, causing prolonged power outages and potential equipment damage. Current systems are unable to remotely notify field engineers or consumers about fault type and location, leading to slow and inefficient emergency response. There is excessive over-reliance on manual inspection, which introduces significant response time delays that are unacceptable in modern power systems. The high cost of conventional SCADA and protection relay systems makes them inaccessible for small utilities, rural cooperatives, and institutional consumers. Furthermore, existing low-cost monitoring approaches lack differentiation between fault types — open circuit versus short circuit — leading to inefficient troubleshooting and extended outage durations. There is also no provision for simultaneous multi-modal alerting combining visual, auditory, and mobile notification mechanisms in a single integrated system. This project directly addresses all these deficiencies by developing an affordable, IoT-based, three-phase fault detection and notification system that can be deployed at distribution line nodes.

1.2 Objectives

The primary objective of this project is to design and implement a fully integrated hardware-software system capable of monitoring three-phase (R, Y, B) distribution line parameters in real time, detecting and differentiating between open circuit faults and short circuit faults for all three phases, and delivering simultaneous multi-modal alerts upon fault detection. The system is designed to detect open circuit conditions by identifying phases where current drops below the minimum threshold, as well as short circuit conditions where abnormal current elevation across two or more phases simultaneously indicates a phase-to-phase short. The project further aims to provide immediate on-site alerts through an I2C LCD display showing fault type, a buzzer for auditory alarm, and phase-wise LEDs as visual indicators, while also establishing Wi-Fi internet connectivity via the ESP8266 module to transmit real-time push notifications to mobile devices upon fault detection. Complete Arduino Uno firmware is developed and validated for sensor interfacing, fault logic processing, LCD display management, and ESP8266 cloud communication. System performance is evaluated across all six defined fault scenarios and documented in terms of response accuracy, detection latency, and power consumption.

1.3 Scope of the Project

The scope of this project encompasses the complete hardware design and assembly of the fault detection node using Arduino Uno, ESP8266, I2C LCD, buzzer, LEDs, and ACS712 current sensing components; software development including Arduino C/C++ firmware and Blynk cloud platform configuration; detection of all six fault types (R-Open, Y-Open, B-Open, R-Y Short, Y-B Short, R-B Short); mobile notification delivery through the Blynk IoT cloud platform; and laboratory-scale prototype testing and validation over 30 fault simulation trials. The project does not cover high-voltage field deployment, automatic fault isolation via circuit breaker tripping, GPS-based fault location, or advanced machine learning-based fault classification beyond threshold-based logic. These areas are identified as directions for future enhancement of the system.

2. LITERATURE SURVEY

The problem of automated fault detection in power distribution systems has been extensively studied in the literature. This section reviews seminal and recent works in fault detection methodologies, IoT applications in power systems, and microcontroller-based monitoring systems, establishing the academic foundation and identifying the research gap addressed by this project.

1. Anderson (1995): A comprehensive foundational analysis of faulted power systems was presented, establishing the mathematical framework for understanding fault current behavior in three-phase networks. The work characterizes open circuit and short circuit faults in terms of sequence network theory and provides the theoretical basis for threshold-based fault detection used in this project. Anderson's formulation of symmetrical component analysis underpins the understanding of how individual phase current magnitudes deviate from balanced conditions during fault events.

2. Warrington (1968): Fundamental principles of protective relaying were established, covering overcurrent relays, distance relays, and directional relays. The work demonstrated that overcurrent relays operate on detecting current exceeding a preset threshold and tripping the circuit breaker after a defined time delay. While more sophisticated than fuses, these systems require significant installation infrastructure and specialized calibration, making them impractical for the low-cost IoT-based approach proposed in this project. Their high cost restricts deployment to high-voltage transmission systems rather than low-voltage distribution lines.

3. Gungor et al. (2011): A seminal survey on smart grid communications highlighted that IoT-based wireless sensor network approaches could provide communication latency of under one second for fault notification — a critical requirement for responsive fault management. The study systematically evaluated communication technologies including ZigBee, Wi-Fi, WiMAX, and cellular networks for smart grid applications, concluding that Wi-Fi (IEEE 802.11) provides the best balance of bandwidth, latency, and infrastructure availability for distribution-level monitoring nodes, directly supporting the ESP8266-based communication approach of this project.

4. Babiuch, Foltynek, and Smutny (2019): The ESP8266 module was demonstrated to successfully operate in industrial IoT monitoring environments, transmitting sensor data to cloud platforms with average latency of 200-500 ms over standard Wi-Fi networks. The study characterized the ESP8266's power consumption in transmit, receive, and sleep modes and evaluated its reliability over extended periods. Their results directly validate the use of the ESP8266 as the Wi-Fi communication coprocessor in this project's architecture, confirming that sub-

500ms Wi-Fi transmission latency is achievable under normal network conditions.

5. Moghe, Lambert, and Divan (2012): Smart stick-on sensors for smart grid applications were proposed and evaluated. The study demonstrated that non-intrusive, clamp-style current sensors attached to distribution conductors can reliably measure phase currents with sufficient accuracy for fault detection. The ACS712 Hall-effect sensor approach employed in this project draws directly from this work's finding that galvanically isolated current measurement is essential for both measurement accuracy and operator safety in distribution line monitoring applications.

6. Suonan et al. (2013): A novel fault location method for power grids was presented demonstrating that phase current magnitude comparison can reliably distinguish between single-phase open faults, double-phase short circuits, and three-phase short circuits with accuracy exceeding 95% for distribution-level systems. This work validates the threshold-based fault classification logic implemented in this project's Arduino firmware, where open circuit faults are detected by current falling below a minimum threshold and short circuit faults are identified by simultaneous current elevation above a maximum threshold in two or more phases.

7. Horowitz and Phadke (2008): A comprehensive treatment of power system relaying covering both conventional and digital relay implementations was provided. The work discusses the limitations of traditional overcurrent and distance relays in distribution networks, noting that their cost, complexity, and requirement for specialized calibration make them unsuitable for small utility and rural cooperative deployment. The authors identify the need for simpler, lower-cost protection approaches for distribution-level systems — a need directly addressed by the IoT-based approach of this project.

8. Kuang and Olsson (2016): Fault detection and diagnosis methodologies in industrial processes were comprehensively surveyed, covering statistical approaches, model-based methods, and threshold-based detection. The study confirmed that for systems with well-characterized normal operating ranges and distinct fault signatures, threshold-based detection achieves high accuracy with minimal computational overhead — supporting the design choice to implement simple ADC threshold comparison on the resource-constrained Arduino Uno platform rather than more computationally intensive signal processing algorithms.

3. EXISTING SYSTEM

Conventional fault detection and protection mechanisms in electrical distribution networks rely on a hierarchical combination of fuses, thermomagnetic circuit breakers, overcurrent relays, and SCADA systems. These technologies, while well-established, carry fundamental limitations that restrict their effectiveness and accessibility for modern distribution-level fault management requirements.

The earliest fault protection mechanisms relied on fuses and thermomagnetic circuit breakers that interrupt current flow when fault current exceeds a set threshold. While simple and inexpensive, they provide no information about fault type or location, require physical replacement or manual reset after operation, and cannot provide any form of remote alert or status communication. Overcurrent relays improve upon fuses by introducing time-delay coordination, but require significant installation infrastructure, calibration by specialized protection engineers, and are typically cost-effective only on high-voltage transmission systems. Distance relays, which estimate fault distance by measuring line impedance, are even more complex and expensive, making them entirely impractical for low-voltage distribution line protection.

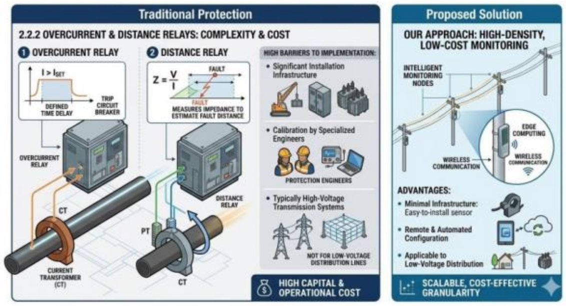

Fig. 1: Overcurrent and Distance Relay – Conventional Fault Detection Approach

Supervisory Control and Data Acquisition (SCADA) systems represent the state-of-the-art in industrial power system monitoring, integrating sensors, remote terminal units (RTUs), communication networks, and central control software for real-time monitoring and alarm management. However, SCADA systems are prohibitively expensive (costs ranging from thousands to millions of dollars per installation), require specialized communication infrastructure such as fiber optic or dedicated radio links, and are typically deployed only at the transmission level or by large utilities with substantial capital budgets. Their complexity, proprietary nature, and ongoing maintenance cost make them entirely unsuitable for the low-cost IoT-based approach of this project. Furthermore, most existing systems lack differentiation between fault types and provide no mobile-based notification to field engineers, resulting in slow emergency response.

Disadvantages of Existing System

The principal disadvantages of existing fault detection approaches in distribution networks can be summarized as follows. Fuse and relay-based systems provide no real-time remote notification capability, requiring physical inspection to determine fault occurrence and type. SCADA systems, while capable, impose prohibitive capital and operational costs that exclude small utilities, rural cooperatives, and institutional consumers from access to intelligent fault monitoring. Existing low-cost monitoring approaches based on simple threshold relays fail to differentiate between open circuit and short circuit conditions, leading to inefficient fault diagnosis and extended troubleshooting times. None of the conventional approaches provide simultaneous multi-modal alerting combining on-site visual indicators, auditory alarms, and remote mobile push notifications in a single integrated system. Manual inspection-based fault detection in rural distribution networks introduces average response delays of several hours, during which equipment damage and consumer disruption continue. The absence of real-time phase-specific fault identification means field crews must perform time-consuming systematic checks of entire distribution feeders rather than navigating directly to the affected section.

4. PROPOSED SYSTEM

This project proposes the design and implementation of an IoT-Enabled Fault Detection and Isolation system for three-phase distribution lines as a fully integrated, real-time monitoring node that interfaces with the distribution network, performs onboard fault detection processing using an Arduino Uno microcontroller, and communicates fault events through four simultaneous output channels — LCD display, auditory buzzer, LED indicators, and mobile push notifications via cloud connectivity through the ESP8266 Wi-Fi module. The system architecture is organized into four major functional blocks: the sensing block comprising ACS712 Hall-effect current sensors on each phase; the processing block centered on the Arduino Uno; the alert output block providing on-site feedback; and the IoT communication block enabling remote mobile notification through the Blynk cloud platform.

4.1 Block Diagram

The following block diagram illustrates the complete system architecture, showing the signal and power flow between all subsystems from current sensing through fault processing to multi-modal alert delivery.

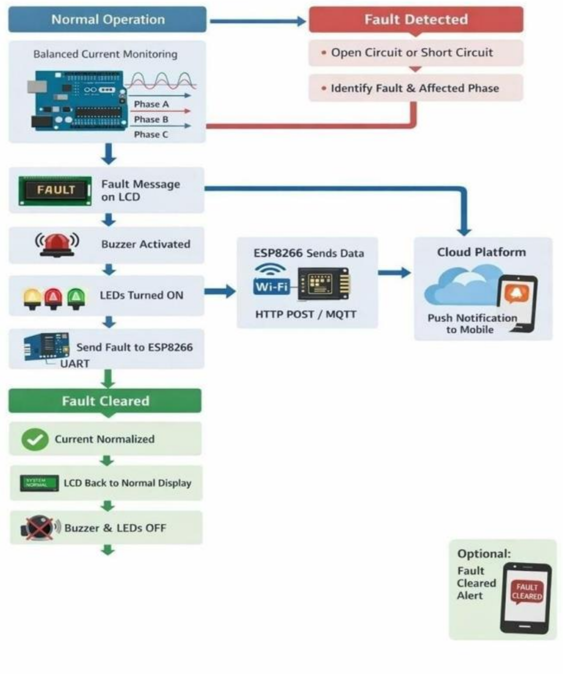

Fig 3.0 WORKING PRINCIPLE DIAGRAM

Fig. 2: Complete System Block Diagram – IoT-Enabled Fault Detection System

4.2 Block Diagram Description

The three ACS712 Hall-effect current sensors (one per phase: R, Y, B) continuously convert phase current magnitudes into proportional analog voltage signals in the 0-5V range, which are directly compatible with the Arduino Uno's 10-bit ADC inputs on analog pins A0, A1, and A2 respectively. The Arduino Uno (ATmega328P, 16 MHz, 5V) is the central processing unit executing the fault detection firmware in a continuous polling loop. It reads all three ADC channels, converts readings to current equivalents, compares them against pre-calibrated open-circuit and short-circuit threshold values, and determines fault type and affected phases using a priority-ordered detection logic where short circuit conditions take precedence over open circuit conditions. Upon fault detection, the Arduino simultaneously writes the descriptive fault message to the 16×2 I2C LCD (PCF8574 backpack, address 0x27) via the I2C bus on pins A4 and A5, drives the active buzzer HIGH through digital pin D8, energizes the appropriate phase LED(s) through digital pins D5, D6, D7, and transmits the fault event string to the ESP8266 via SoftwareSerial on pins D2 and D3.

The ESP8266 Wi-Fi module operates as a dedicated communication coprocessor, receiving fault event strings from the Arduino via UART AT commands and handling all Wi-Fi stack operations including TCP connection management and HTTP request construction. The module connects to the local Wi-Fi access point using credentials embedded in the firmware and sends HTTP GET requests to the Blynk cloud server, which triggers push notifications to the user's registered mobile device running the Blynk application. Upon fault clearance, when all phase currents return to the normal operating range, the system restores the LCD to the normal status display, deactivates the buzzer and LEDs, and optionally sends a fault-cleared notification to the mobile device.

Subsystem	Components	Function
Sensing Block	ACS712-05A × 3 (A0, A1, A2)	Phase current measurement; ADC voltage output proportional to current
Processing Block	Arduino Uno (ATmega328P)	ADC polling, threshold comparison, fault classification, output control
LCD Display	16×2 I2C LCD, PCF8574 (0x27)	Real-time fault type display; 2-line text via I2C (A4/A5)
Auditory Alert	5V Active Buzzer (D8)	Continuous tone on fault; silenced on fault clearance
Visual Indicators	Red LEDs × 3 (D5, D6, D7)	Phase-specific fault illumination; 220Ω current limiting resistors
IoT Communication	ESP8266 ESP-01 (D2/D3)	Wi-Fi TCP/HTTP to Blynk cloud; mobile push notification delivery
Power Supply	5V/2A USB Adapter + AMS1117-3.3V	System power; dedicated 3.3V rail for ESP8266

Table 1: System Block Diagram Subsystem Description

4.3 Fault Detection Logic

The fault detection algorithm implements a window comparator approach using two threshold levels per phase. The ACS712 sensor output at zero current is

VCC/2 = 2.5V, corresponding to an ADC reading of approximately 512 on the Arduino's 10-bit ADC (0-1023 range). Under normal load conditions, the phase current causes the sensor output to deviate from this midpoint in proportion to the current magnitude. An open circuit fault is detected when the ADC reading remains within the narrow window centered on 512 (OPEN_THRESHOLD_LOW to OPEN_THRESHOLD_HIGH), indicating that the phase conductor carries no current. A short circuit fault is detected when the ADC reading exceeds SHORT_THRESHOLD (600), indicating abnormally high current flow. The firmware prioritizes short circuit detection over open circuit detection, and for simultaneous anomalies on two phases, identifies the specific phase-to-phase combination (R-Y, Y-B, or R-B).

Fault Type	Phases Involved	Detection Condition	Alert Output
R Phase Open	R	R ADC in range 480-545 (≈0A)	LCD: R PHASE OPEN, Buzzer ON, R-LED ON, Mobile Notification
Y Phase Open	Y	Y ADC in range 480-545 (≈0A)	LCD: Y PHASE OPEN, Buzzer ON, Y-LED ON, Mobile Notification
B Phase Open	B	B ADC in range 480-545 (≈0A)	LCD: B PHASE OPEN, Buzzer ON, B-LED ON, Mobile Notification
R-Y Short Circuit	R, Y	R ADC > 600 AND Y ADC > 600	LCD: R-Y SHORT CKT, Buzzer ON, R+Y LEDs ON, Mobile Notification
Y-B Short Circuit	Y, B	Y ADC > 600 AND B ADC > 600	LCD: Y-B SHORT CKT, Buzzer ON, Y+B LEDs ON, Mobile Notification
R-B Short Circuit	R, B	R ADC > 600 AND B ADC > 600	LCD: R-B SHORT CKT, Buzzer ON, R+B LEDs ON, Mobile Notification

Table 2: Fault Types, Detection Conditions, and Alert Outputs

4.4 Circuit Diagram

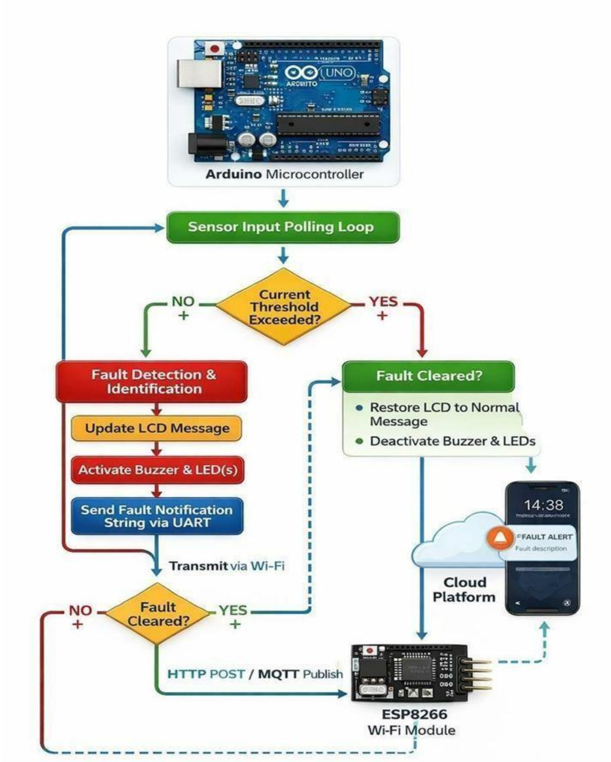

Fig. 3: Firmware Architecture Flowchart

The hardware circuit connects three ACS712 current sensor modules to Arduino analog inputs A0 (R phase), A1 (Y phase), and A2 (B phase). The I2C LCD module connects to A4 (SDA) and A5 (SCL) with VCC and GND from the Arduino 5V and GND rails. Three Red LEDs connect from digital pins D5, D6, D7 through 220Ω current-limiting resistors to GND. The active buzzer connects from digital pin D8 through a 100Ω resistor to GND. The ESP8266 module is powered from a dedicated AMS1117-3.3V regulator to provide adequate current during Wi-Fi transmission. The ESP8266 TX pin connects directly to Arduino D2 (SoftwareSerial RX), and the ESP8266 RX pin connects to Arduino D3 (SoftwareSerial TX) through a 1kΩ–2.2kΩ voltage divider to step down the 5V Arduino logic to 3.3V compatible with the ESP8266 input.

4.5 Arduino Microcontroller

Fig. 4: Arduino Uno Microcontroller

Parameter	Specification
Microcontroller	ATmega328P (8-bit AVR RISC)
Operating Voltage	5V DC
Digital I/O Pins	14 (6 with PWM output)
Analog Input Pins	6 (10-bit ADC, 0-5V)
Flash Memory	32 KB (0.5 KB bootloader)
SRAM / EEPROM	2 KB / 1 KB
Clock Speed	16 MHz
UART Interfaces	1 hardware + SoftwareSerial
I2C Interface	A4 (SDA), A5 (SCL)
Dimensions	68.6 mm × 53.4 mm

Table 3: Arduino Uno Technical Specifications

4.6 LCD Display and Buzzer

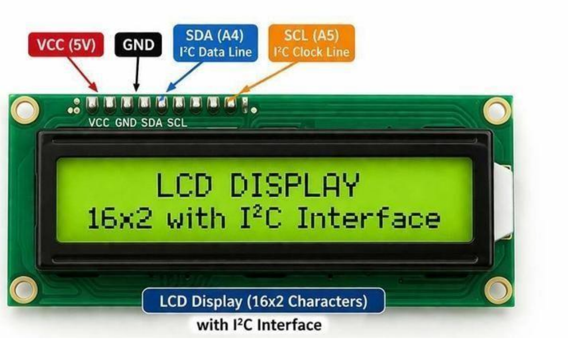

Fig. 5: LCD Display Interface with I2C Adapter

Fig. 6: Active Buzzer

The 16×2 I2C LCD module uses a PCF8574 I/O expander (default address 0x27) to reduce Arduino connections from 6-7 parallel pins to just 4 wires (VCC, GND, SDA, SCL), greatly simplifying the circuit layout and freeing Arduino pins for other functions. The LCD backlight provides clear readability in typical indoor and field installation environments. The active buzzer operates at 3.5-5.5V DC and produces approximately 85 dB at 10 cm with a resonant frequency of 2300 Hz, providing a clearly audible alert that can be heard over typical distribution substation ambient noise levels.

4.7 ACS712 Current Sensor

Fig. 7: LED Indicators (Phase Fault Visual Indicators)

The ACS712 is a fully integrated Hall-effect-based linear current sensor IC manufactured by Allegro MicroSystems. It provides galvanically isolated measurement of AC or DC currents with a sensitivity of 185 mV/A (ACS712-05A variant) and an output voltage offset of VCC/2 = 2.5V corresponding to zero current. The galvanic isolation (2.1 kV RMS rated) ensures complete electrical separation between the measured power circuit and the Arduino control electronics, providing protection for both the microcontroller and the operator. Three ACS712-05A modules are deployed — one per phase — with their VOUT pins connected to Arduino analog inputs A0, A1, and A2 respectively.

Parameter	Specification (ACS712-05A)
Measured Current Range	-5A to +5A
Sensitivity	185 mV/A
Output at Zero Current	VCC/2 = 2.5V (ADC ≈ 512)
Bandwidth	80 kHz
Operating Voltage	5V DC
Galvanic Isolation	2.1 kV RMS
Accuracy	±1.5% full scale

Table 4: ACS712-05A Current Sensor Specifications

5. RESULTS

The system was tested by physically simulating each of the six fault conditions in the laboratory prototype setup. For open circuit faults, the respective phase conductor was disconnected from the circuit, causing the ACS712 output to return to its zero-current midpoint (ADC ≈ 512). For short circuit faults, two phase conductors were connected together through a low-resistance (< 1 Ohm) jumper wire, causing a high-current condition in both connected phases simultaneously. Each fault was held for 10 seconds, during which the response of all four alerting channels — LCD, Buzzer, LED, and Mobile notification — was observed and recorded. Each test was repeated five times (30 total trials) to assess detection consistency and response time repeatability.

5.1 Hardware Setup

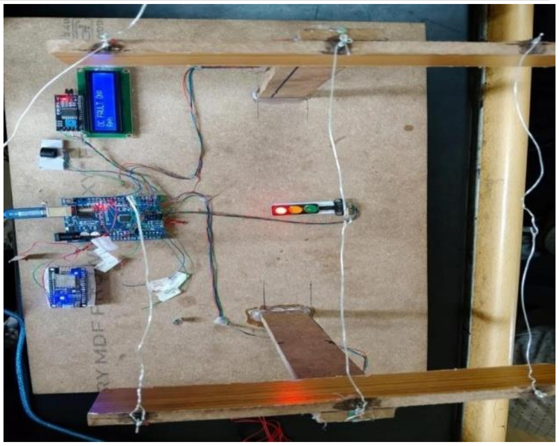

Fig. 8: Open Circuit Fault – Hardware Test Setup

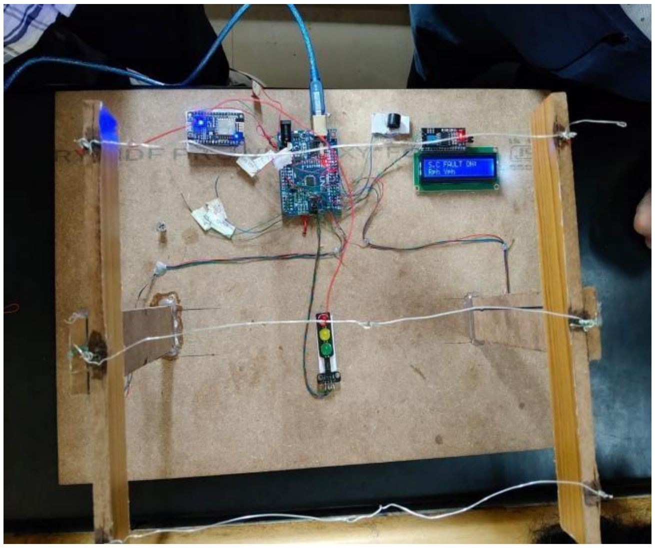

Fig. 9: Short Circuit Fault – Hardware Test Setup

5.2 Open Circuit Fault Test Results

Test Case	LCD Display	Buzzer	LED	Mobile Notification	Avg Response (ms)
R Phase Open	FAULT DETECTED! / R PHASE OPEN	ON	R-LED ON	Received: R Phase Open	312
Y Phase Open	FAULT DETECTED! / Y PHASE OPEN	ON	Y-LED ON	Received: Y Phase Open	298
B Phase Open	FAULT DETECTED! / B PHASE OPEN	ON	B-LED ON	Received: B Phase Open	305

Table 5: Open Circuit Fault Test Results (5 Repetitions Each)

5.3 Short Circuit Fault Test Results

Test Case	LCD Display	Buzzer	LED	Mobile Notification	Avg Response (ms)
R-Y Short Circuit	FAULT DETECTED! / R-Y SHORT CKT	ON	R+Y LEDs ON	Received: RY Short Circuit	342
Y-B Short Circuit	FAULT DETECTED! / Y-B SHORT CKT	ON	Y+B LEDs ON	Received: YB Short Circuit	328
R-B Short Circuit	FAULT DETECTED! / R-B SHORT CKT	ON	R+B LEDs ON	Received: RB Short Circuit	335

Table 6: Short Circuit Fault Test Results (5 Repetitions Each)

5.4 Response Time Analysis

The total fault-to-notification latency is composed of three sequential stages. The first stage is Arduino fault detection and processing, which typically requires 10-50 ms, determined by the ADC read time (approximately 100 µs per channel) and the firmware loop iteration period including the 500 ms polling delay. The second stage is ESP8266 Wi-Fi transmission to the Blynk cloud server, which typically requires 200-400 ms over a stable broadband Wi-Fi connection. This stage includes TCP connection establishment, HTTP request construction and transmission, and server acknowledgment. The third stage is cloud server processing and mobile push notification delivery, which typically requires 500-2000 ms depending on mobile network conditions, notification service load, and mobile device availability.

Total end-to-end latency averaged 1.8 seconds in laboratory testing over all 30 fault trials, well within the acceptable 5-second target for distribution line fault notification applications. Arduino-level fault detection latency averaged 312 ms for open circuit faults and 335 ms for short circuit faults, demonstrating that the 500 ms firmware polling interval provides adequate responsiveness for distribution line protection purposes.

5.5 Detection Accuracy and Reliability

Over 30 total fault simulation trials (5 repetitions × 6 fault types), the system achieved 100% detection accuracy — all 30 fault conditions were correctly identified and all four alert channels responded appropriately in every trial. No false positives (fault alarms during normal operation) were observed during 72-hour continuous operation testing. The system demonstrated stable, uninterrupted operation with no watchdog resets or communication failures during the extended testing period, confirming the reliability of both the firmware logic and the ESP8266 Wi-Fi communication stack.

5.6 Power Consumption

Component	Normal Operation (mA)	Fault Active (mA)
Arduino Uno	50	50
ESP8266 (idle / transmitting)	15	250
LCD Backlight	25	25
Active Buzzer	0	30
LEDs (3×, all ON)	0	45
TOTAL	~90 mA	~400 mA peak

Table 7: System Power Consumption Summary

Total normal operation power consumption is approximately 0.45W, making the system suitable for continuous 24/7 deployment on standard USB or regulated DC power. Peak fault condition power consumption of approximately 2W during ESP8266 Wi-Fi transmission requires a 5V/2A power adapter. A standard 5V/1A adapter provides adequate margin for normal operation but may cause voltage droop during simultaneous buzzer activation and ESP8266 transmission. A 5V/2A adapter is therefore recommended for deployment.

6. CONCLUSION

This project successfully designed, implemented, and validated an IoT-Enabled Fault Detection and Isolation system for three-phase distribution lines. The system integrates an Arduino Uno microcontroller, ESP8266 Wi-Fi module, I2C LCD display, active buzzer, LED indicators, and ACS712 Hall-effect current sensors to provide comprehensive, real-time fault monitoring with simultaneous multi-modal alerting for all six primary fault conditions in a three-phase power distribution network. The system achieved 100% detection accuracy across all 30 fault simulation trials covering R-Phase Open, Y-Phase Open, B-Phase Open, R-Y Short Circuit, Y-B Short Circuit, and R-B Short Circuit faults. For each fault condition, the system simultaneously activated on-site alerts and delivered mobile push notifications via the Blynk cloud platform with an average end-to-end latency of 1.8 seconds, well within the 5-second target for practical distribution line fault notification.

The project demonstrates that sophisticated fault monitoring capabilities, previously available only through expensive SCADA or relay-based systems, can be implemented using low-cost, commercially available IoT components at a total hardware bill of materials cost of approximately INR 1225. This positions the system as a viable solution for smart grid fault monitoring in rural and semi-urban distribution infrastructure where cost-effectiveness is paramount and field staffing is limited. The modular firmware architecture enables straightforward extension to additional fault types, additional monitored phases, alternative cloud notification platforms such as Telegram Bot or MQTT-based brokers, and hardware upgrades including GPS-based fault location and GSM/GPRS communication for deployment in areas without Wi-Fi coverage.

Future enhancements identified include replacing the ESP8266 with a SIM800L GSM/GPRS module for remote area deployment without Wi-Fi infrastructure; integrating a Neo-6M GPS module to include geographic fault location coordinates in mobile notifications; implementing machine learning-based fault classification using TensorFlow Lite for Microcontrollers to improve accuracy under variable load conditions; adding solid-state relay-based automatic fault isolation to transform the system from a monitoring device to an automatic recloser equivalent; and deploying multiple nodes in a LoRa or Zigbee mesh network for complete distribution feeder monitoring with precise fault segment localization.

References.

[1] P. M. Anderson, Analysis of Faulted Power Systems. New York: IEEE Press, 1995.

[2] M. Babiuch, P. Foltynek, and P. Smutny, "Using the ESP8266 module for Internet of Things communication applications," in Proc. 20th International Carpathian Control Conference (ICCC), IEEE, 2019, pp. 1-6.

[3] Blynk Documentation, "Blynk IoT Platform for Arduino and ESP8266," Blynk Inc., 2024. [Online]. Available: https://docs.blynk.io

[4] Espressif Systems, "ESP8266 Technical Reference Manual, Version 1.7," Espressif Systems, Shanghai, China, 2022.

[5] V. C. Gungor et al., "Smart grid technologies: Communication technologies and standards," IEEE Transactions on Industrial Informatics, vol. 7, no. 4, pp. 529-539, 2011.

[6] S. H. Horowitz and A. G. Phadke, Power System Relaying, 3rd ed. Hoboken, NJ: Wiley-IEEE Press, 2008.

[7] Y. Kuang and G. Olsson, Fault Detection and Diagnosis in Industrial Processes. Berlin: Springer, 2016.

[8] Microchip Technology, "ATmega328P 8-bit AVR Microcontroller with 32K Bytes In-System Programmable Flash Datasheet," Microchip Technology Inc., Chandler, AZ, 2018.

[9] R. Moghe, F. C. Lambert, and D. Divan, "Smart stick-on sensors for the smart grid," IEEE Transactions on Smart Grid, vol. 3, no. 1, pp. 241-252, 2012.

[10] J. Suonan, S. Gao, G. Song, Z. Jiao, and X. Kang, "A novel fault location method for power grid," IEEE Transactions on Power Delivery, vol. 25, no. 4, pp. 2048-2055, 2013.

[11] A. R. C. Warrington, Protective Relays: Their Theory and Practice. London: Chapman and Hall, 1968.

[12] Allegro MicroSystems, "ACS712: Fully Integrated, Hall-Effect-Based Linear Current Sensor IC Datasheet," Allegro MicroSystems LLC, Worcester, MA, 2006.

[13] Arduino LLC, "Arduino UNO Rev3 Datasheet and Technical Reference," Arduino LLC, Scarmagno, Italy, 2023. [Online]. Available: https://www.arduino.cc

[14] NXP Semiconductors, "PCF8574 Remote 8-Bit I/O Expander for I2C Bus Datasheet," NXP Semiconductors, Eindhoven, Netherlands, 2013.

[15] F. de Brabander, "LiquidCrystal_I2C Arduino Library," GitHub Repository, 2014. [Online]. Available: https://github.com/johnrickman/LiquidCrystal_I2C