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IoT-Based Smart Monitoring and Transmission Line Fault Detection and Localization Using NodeMCU, ACS712 Sensors, GPS and Firebase

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Abstract: Electrical transmission line faults require rapid detection, classification and localization to reduce outage duration and improve service reliability. This paper presents a low-cost IoT-enabled prototype for monitoring a three-phase transmission line model and reporting fault information in real time. Three ACS712 current sensors measure phase currents and a CD4051 analog multiplexer routes the signals to the single ADC input of a NodeMCU ESP8266 controller. A threshold-based firmware algorithm identifies faulted phases, classifies common fault categories such as LG, LL, LLG and LLLG, and estimates the fault distance using a resistor-tap line model representing 2, 4, 6 and 8 km sections. A NEO-6M GPS receiver provides geographic coordinates, while a 16x2 I2C LCD, RGB LEDs, relay module and buzzer provide local indication and alarm functions. The NodeMCU uploads current values, fault type, distance, latitude and longitude to Firebase Realtime Database for remote monitoring. Prototype tests verified end-to-end sensing, display and cloud logging for line-to-line, line-line-ground, three-phase and healthy conditions. The live Firebase snapshot recorded current values of 432, 404 and 430 ADC counts, a 2 km location estimate, and GPS coordinates near 30.39342 N, 78.43390 E. The results demonstrate the feasibility of an IoT-based educational and laboratory prototype, while also showing that additional calibration and repeated trials are needed for robust field-level deployment. ***Keywords: transmission line fault detection; fault localization; Internet of Things; NodeMCU ESP8266; ACS712; Firebase; GPS; smart grid monitoring.***

I. INTRODUCTION

Transmission and distribution lines are exposed to faults caused by insulation failure, conductor contact, lightning, mechanical damage and environmental conditions. Once a fault is detected and isolated, repair time is strongly affected by how quickly the faulted section can be located. Conventional fault-location systems used by utilities include impedance-based and traveling-wave techniques, while educational prototypes often use scaled line models to demonstrate the principles at lower voltage and cost [1]-[3].

The project presented in this paper focuses on a compact hardware prototype that combines embedded sensing, local alarming and cloud-based remote monitoring. Instead of relying only on local fault indicators, the proposed system sends the phase currents, identified fault type, estimated distance and GPS coordinates to Firebase Realtime Database. This makes the prototype useful for laboratory demonstrations of smart grid monitoring, IoT data acquisition and microcontroller-based protection logic.

The main contributions of the work are as follows:

1) A three-phase fault detection prototype using NodeMCU ESP8266, three ACS712 current sensors and a CD4051 analog multiplexer.
2) A firmware-level threshold algorithm for detecting faulted phases and categorizing LG, LL, LLG and LLLG conditions.
3) A resistor-tap localization model that maps the detected abnormal current condition to 2, 4, 6 or 8 km line sections.
4) Integration of LCD, LEDs, relay and buzzer for local visualization and alarm response.
5) Firebase and GPS integration for real-time cloud logging and geographic fault tagging.

II. RELATED WORK AND DESIGN MOTIVATION

Fault location has traditionally been studied using impedance-based algorithms, two-terminal synchronized measurements and traveling-wave methods. The IEEE C37.114 guide outlines techniques and application considerations for AC transmission and distribution line fault location, including one-terminal, two-terminal and traveling-wave approaches [1]. Saha et al. describe the broader theory of fault location on overhead and distribution networks, including signal processing and digital fault locator algorithms [2].

Recent research has also considered laboratory validation, intelligent classification and IoT-assisted monitoring. Roostaee et al. experimentally evaluated impedance-based location schemes for long transmission lines [3], while Adhikari et al. demonstrated online fault detection and classification using fuzzy logic and real-time data acquisition [4]. Pan et al. presented an IoT monitoring system for transmission lines with precise timing and distributed sensing [5]. Compared with these advanced systems, the present prototype emphasizes low-cost hardware, simple threshold logic and cloud visualization suitable for an embedded systems project.

III. PROPOSED SYSTEM ARCHITECTURE

The proposed system is organized into five functional layers: a scaled three-phase line model, current sensing, embedded processing, local output and cloud/IoT storage. The line model uses aluminium sheet contacts to represent fault points and 10 ohm resistors to emulate discrete 2 km sections. The ACS712 sensors observe phase-current behavior, the CD4051 multiplexer allows the ESP8266 to read three analog channels through one ADC pin, and the NodeMCU performs fault classification and communication.

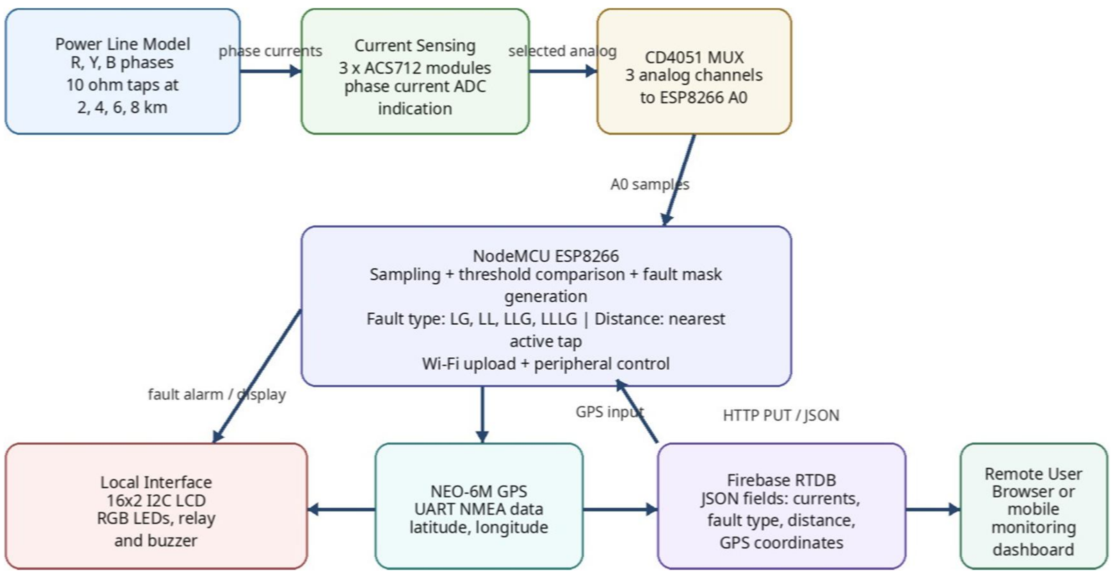

Figure 1. Block diagram of the proposed IoT-based fault detection and localization architecture.

A. Hardware Components

Table 1 Table 1. Major hardware and software elements used in the prototype

Component	Specification/Role	Function in the Prototype
NodeMCU ESP8266	Wi-Fi microcontroller	Reads multiplexed sensor data, executes fault logic and uploads JSON records to Firebase.
ACS712 current sensors	30 A Hall-effect modules	Measure the current condition of R, Y and B phases.
CD4051 multiplexer	8-channel analog MUX	Routes the three sensor outputs to the single A0 input of the ESP8266.
NEO-6M GPS	UART GPS receiver	Provides latitude and longitude for fault-event tagging.
I2C LCD 16x2	PCF8574 backpack	Displays fault type and distance locally.
RGB LEDs and buzzer	Visual and audible indicators	Indicate phase involvement and alarm during a fault.
Relay module	3-channel relay interface	Provides isolation/control action for the faulted phase segment in the prototype.
Resistor-tap line model	10 ohm sections	Represents 2, 4, 6 and 8 km locations for laboratory fault simulation.
Firebase RTDB	Cloud JSON database	Stores current values, fault type, distance and coordinates for remote access.

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IV. METHODOLOGY

A. Current Acquisition and Thresholding

During each sampling cycle, the NodeMCU selects one ACS712 sensor channel through the CD4051, reads the analog value at A0, and repeats the process for the three phases. In the laboratory setup, healthy phase readings were observed near 410 to 450 ADC counts, while a faulted phase was interpreted using a threshold below approximately 200 counts. The practical threshold is a calibration parameter and should be tuned after sensor zero-offset measurement, supply stabilization and repeated no-fault/fault observations. For phase i in {R, Y, B}, the binary fault flag is defined as $m_i = 1$ when $C_i < T$, and $m_i = 0$ otherwise, where C_i is the measured ADC count and T is the selected threshold. The firmware forms a phase mask from m_R, m_Y and m_B, then assigns the fault label and activates the corresponding LCD, LED, relay and buzzer states.

B. Fault Classification Logic

Table 2 Table 2. Fault-classification mapping implemented by the prototype firmware

Code	Fault Type	Decision Condition	Local Indication	Firebase Tag
LG	Line-to-ground	One phase below threshold with ground involvement	Single phase LED	lg
LL	Line-to-line	Two phases below threshold	Two phase LEDs	ltl
LLG	Line-line-to-ground	Two phase fault plus ground condition; prototype result used all-phase low pattern	All LEDs in test	llg
LLLG	Three-phase fault	Three phases below threshold; labelled as three-phase condition in firmware	All LEDs	lllg
Healthy	No fault	All phases in normal range	All LEDs off	none

C. Distance Localization

Fault localization is implemented using a resistor-network representation of the line. Taps are placed at 2, 4, 6 and 8 km and a fault is introduced by connecting the appropriate aluminium contact points. When the measured current pattern deviates from the calibrated healthy range at a tap, the firmware assigns the nearest corresponding line section as the fault distance. This discrete localization model is intended for laboratory demonstration; a field system would require line impedance parameters, synchronized measurements or traveling-wave information for continuous distance estimation.

D. Cloud Data Structure

After detecting a fault, the NodeMCU transmits a JSON record to Firebase Realtime Database through Wi-Fi. The event record contains current1, current2, current3, faulttype, distance, latitude and longitude. This structure enables both immediate monitoring and later analysis of fault history.

{"current1": 432, "current2": 404, "current3": 430, "faulttype": "ltl", "distance": 2, "latitude": 30.39342, "longitude": 78.43390 }

V. EXPERIMENTAL SETUP

The prototype was tested by manually introducing faults at the aluminium-sheet junction points of the scaled transmission line. Each test case activated the appropriate line contact, and the output was observed through the LCD, phase LEDs, buzzer and Firebase console. The result images show the LCD reporting a line-to-line fault state and the Firebase database recording measured phase currents, a distance estimate and GPS values.

Figure 2. Prototype LCD and phase indicator observations during fault simulation Table 3 showing cloud-recorded current values, fault tag, distance and GPS coordinates.

Field	Value
current1	432
current2 404	404
current3 430	430
distance 2	2
faulttype	"ll"
latitude	30.39342
longitude	78.4339

VI. RESULTS AND ANALYSIS

The experimental observations are summarized in Table 4. Normal readings were approximately 410 to 450 ADC counts, and a faulted phase was identified when the reading dropped below the selected threshold. The cloud snapshot verified that the system successfully pushed data to Firebase with a distance value of 2 km and GPS coordinates around 30.39342 N, 78.43390 E.

Table 4 Experimental observations from simulated fault tests and live Firebase upload

Test	Simulated Condition	C1	C2	C3	Distance (km)	Firebase Tag	Observation
1	R-ground (LG) at 2 km	432	404	430	2	ltl	Logged as LTL; needs calibration.
2	R-Y (LL) at 2 km	<200	<200	430	2	ltl	LL at 2 km.
3	R-Y-ground (LLG) at 4 km	<200	<200	<200	4	llg	LLG at 4 km.
4	Three-phase (LLLG) at 6 km	<200	<200	<200	6	lllg	3-phase at 6 km.
5	Healthy system	430	430	430	-	none	Healthy state.
6	Live Firebase push	432	404	430	2	ltl	Cloud/GPS verified.

The tests show that the system can acquire phase currents, identify abnormal current conditions, estimate a discrete distance, update the LCD and LEDs, and push the event to Firebase. The LL, LLG, three-phase and healthy cases matched the expected qualitative behavior. The R-ground test, however, was observed with current values that remained close to the healthy band and was logged as ltl in Firebase. This mismatch suggests that the firmware threshold and decision rules should be refined before the system is used for more rigorous validation. Possible improvements include sensor calibration, RMS current computation, averaging or filtering, separate ground-sensing logic, and repeated trials at each distance tap.

VII. DISCUSSION

The main advantage of the proposed prototype is the combination of low-cost sensing and IoT reporting. The ESP8266 provides sufficient processing and Wi-Fi connectivity for simple threshold-based fault classification, and the ACS712 modules allow isolated current sensing for the scaled laboratory circuit [6], [7]. The CD4051 reduces analog-input requirements by multiplexing the three sensor channels into one ADC input [8]. Firebase Realtime Database is suitable for this project because it stores JSON data and synchronizes updates with connected clients in real time [10].

At the same time, the prototype should be interpreted as an educational model rather than a direct field-ready protection device. Real transmission lines involve distributed parameters, high voltages, transient components, load variation, fault resistance and safety requirements that are not represented by the resistor-tap model. Future work should replace fixed threshold decisions with calibrated RMS or phasor-based measurements, add isolation and protection for higher-voltage testing, and collect larger datasets to quantify classification accuracy statistically.

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VIII. CONCLUSION

An IoT-based smart monitoring and transmission line fault detection prototype was designed and evaluated using NodeMCU ESP8266, ACS712 current sensors, a CD4051 multiplexer, NEO-6M GPS and Firebase Realtime Database. The system detects abnormal phase-current patterns, classifies common fault types, estimates discrete tap distance, provides local LCD/LED/buzzer indication and uploads structured fault records to the cloud. Experimental observations confirm the feasibility of end-to-end sensing and cloud reporting for a scaled laboratory model. The observed LG/LTL ambiguity highlights the need for improved calibration and decision logic. With additional signal processing, repeated testing and higher-voltage isolation design, the prototype can be extended toward a more reliable smart-grid monitoring platform.

IX. FUTURE SCOPE

1) Use RMS or phasor-based current extraction instead of single ADC thresholds to reduce noise sensitivity.
2) Collect a larger labelled dataset and apply machine learning to improve classification of LG, LL, LLG and LLLG events.
3) Add GSM/SMS or LoRa communication for locations where Wi-Fi is unavailable.
4) Develop a web or Android dashboard with a map view of GPS-tagged faults.
5) Integrate isolated voltage/current sensing and protection circuitry for safer high-voltage laboratory testing.
6) Add SCADA-compatible data exchange for industrial monitoring demonstrations.

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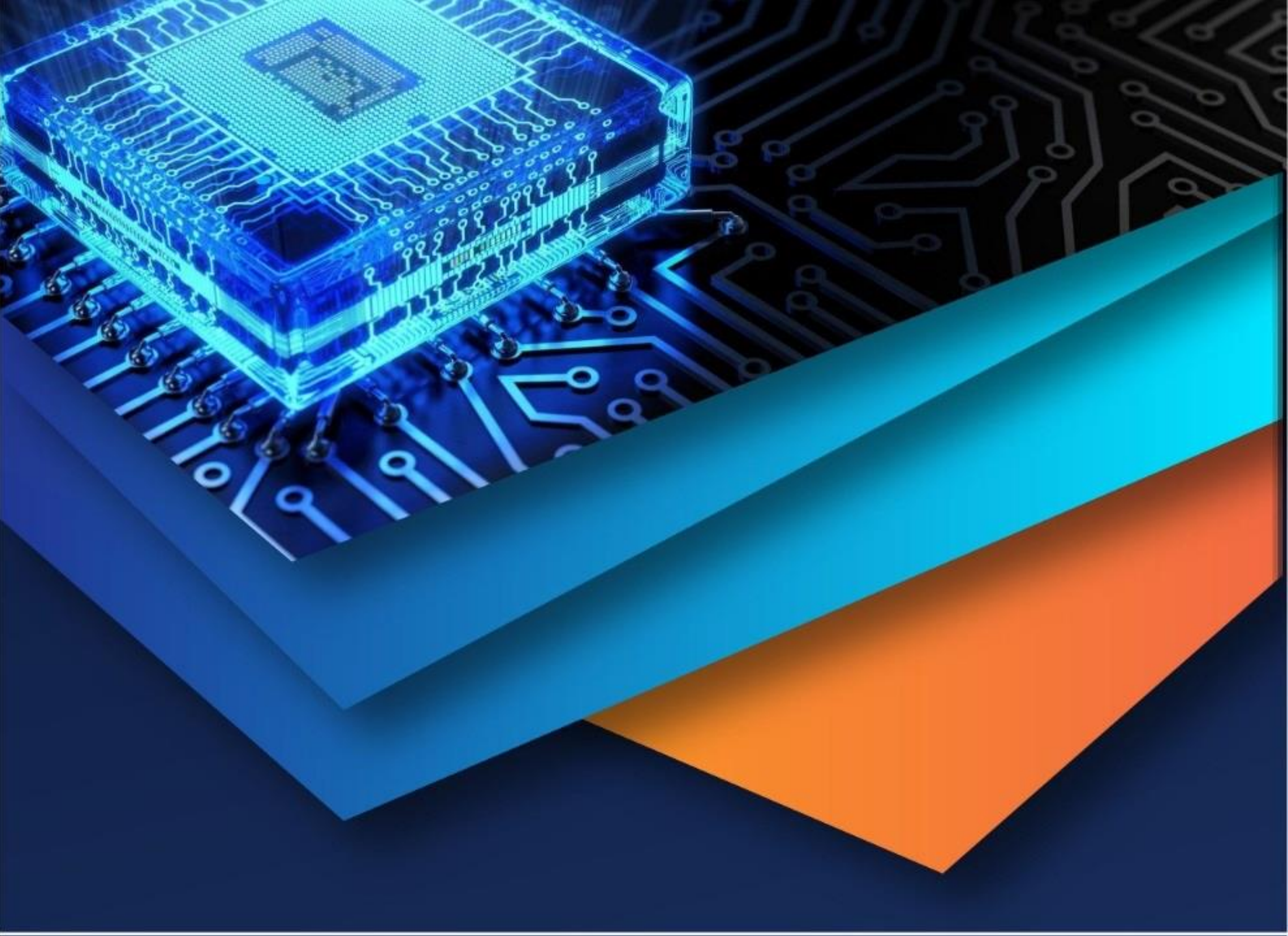
Appendix A: Firmware-Level Workflow

1) Initialize LCD, GPIO pins, Wi-Fi, Firebase client and GPS serial input.
2) Select ACS712 channel R through CD4051 and read A0; repeat for Y and B.
3) Compare C1, C2 and C3 with the calibrated threshold T.
4) Generate the phase fault mask and assign fault type: none, LG, LL, LLG or LLLG.
5) Estimate the fault distance from the active 2/4/6/8 km tap.
6) Update LCD text, phase LEDs, relay state and buzzer alarm.
7) Parse GPS latitude and longitude from NEO-6M NMEA data.
8) Upload JSON data to Firebase Realtime Database.



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