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Underground Cable Fault Detection Using ESP32: A Literature Review

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Abstract: This review looks at IEEE papers published between 2022 and 2026 about finding and pinpointing faults in power cables. It focuses on low-cost systems that use the ESP32 microcontroller. Many recent student-level papers use a resistor network to model the cable and measure the voltage drop across it. They use Ohm's law to calculate the distance to the fault. Then they send alerts through Wi-Fi or GSM to a dashboard. On the hand utility-scale research uses more advanced methods like travelling-wave timing, frequency-domain analysis and machine learning to locate faults on actual cables. The review organizes the existing work into four types: methods, microcontroller-based designs, IoT and ESP32-based systems and AI-based approaches. It compares papers in one table and points out areas where ESP32-based designs can make a difference. These include detecting early-stage faults using cable models doing classification at the edge and testing, in real field conditions.

Keywords: underground cable, fault detection, fault location, ESP32, Internet of Things, Ohm's law method, travelling wave, machine learning

I. INTRODUCTION

Underground cables are now standard in distribution networks. Underground cables are protected from weather. Underground cables take no space. Underground cables carry visual and safety risk than overhead lines. The drawback of cables is that a fault is buried. The fault cannot be. Digging at the wrong spot is slow and expensive. A fast accurate estimate of where the fault's therefore matters as much, as knowing that the fault happened.

The faults most papers consider are:

- Short-circuit (low-resistance) faults: conductor-to-conductor or conductor-to-sheath/ground contact, often after insulation breakdown.
- Open-circuit faults: a broken conductor, so current cannot flow past the fault.
- High-resistance and incipient faults: partial insulation degradation (for example water treeing in XLPE cable) that produces short, self-clearing disturbances before a permanent fault develops [2].

Recent IEEE literature is split into two communities. Many conference papers, those from Indian institutions focus on creating low-cost IoT prototypes. They increasingly use the ESP32 because the ESP32 brings a 12-bit ADC, Wi-Fi and Bluetooth on a single chip. In contrast journal articles and power-systems studies tackle the physics of cables using travelling-wave theory spectral analysis and learning-based classifiers. This review brings both sides together. Asks how an ESP32 system might learn from the second group. The rest of the paper is organised as follows: Section 2 discusses techniques; Section 3 looks, at microcontroller-based detection; Section 4 covers IoT and ESP32 systems; Section 5 explores AI and signal-processing methods. Section 6 presents a comparison table Section 7 highlights research gaps and Section 8 offers conclusions.

II. CLASSICAL FAULT LOCATION TECHNIQUES

Classical methods fall into two groups: bridge (loop) tests that compare resistances, and wave-based methods that time a signal's reflection. A recent systematic review in IEEE Access systematically reviews methods for determining the exact fault location [1].

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• Murray and Varley loop tests: the faulted conductor and a healthy one are joined at the far end to form a Wheatstone-bridge arm. Balancing the bridge gives the resistance ratio, and therefore the distance, to a low-resistance fault. Both tests are simple but need a healthy return conductor and do not work for open-circuit faults.

• Time-domain reflectometry (TDR): a pulse is injected and the echo from the impedance change at the fault is timed. Distance follows from the round-trip time and the cable's propagation velocity. TDR handles open and low-resistance faults, but Liu et al. note its low sensitivity to small or multiple defects [3].

• Frequency-domain and impedance methods: these sweep frequency and analyse input impedance or propagation characteristics. Liu et al. propose using the spectrum of the cable's propagation function with an integral-transform locator. On 50 m, 66 m and 163 m test cables with mechanical and thermal-ageing defects, they report localisation error within 0.21% [3].

• Travelling-wave methods: a fault launches voltage and current waves. Time-stamping their arrival at one or both ends, often GPS-synchronised, gives the distance. Recent IEEE papers pair travelling waves with neural networks [4], [5].

• Field practice on HV cable: utilities combine pre-location (TDR or bridge) with pinpointing on site. Huda et al. apply smart cable fault location equipment to single-phase faults on 150 kV XLPE and oil-filled cables [6].

Optimisation methods have also been applied to the search for the fault point, for example ant colony optimisation for fault tracking [7].

III. MICROCONTROLLER-BASED DETECTION: THE OHM'S LAW METHOD

Nearly every low-cost prototype in the recent IEEE conference literature uses the same principle. The cable is modelled as a chain of series resistors, one per kilometre, and a fault is simulated by switching a point of that chain to ground. A DC source drives current through a known series resistor, and the microcontroller's ADC reads the resulting voltage. Because the resistance up to the fault grows with distance, the measured voltage maps directly to a fault distance.

For a supply voltage V_s, a known series resistor R_s and cable resistance r per km, the voltage at the measurement node for a fault d km away is:

$$V_m = V_s \cdot \frac{r\,d}{R_s + r\,d} \quad\Rightarrow\quad d = \frac{R_s\,V_m}{r\,(V_s - V_m)}$$

In practice firmware compares the ADC reading with a calibrated lookup table, one band per kilometre. Each phase (R, Y, B) is scanned in turn through relays. Short-circuit faults pull the node low, and open-circuit faults are detected by an absent current or an out-of-range reading.

The platforms evolved as follows:

• 8051 and Arduino (ATmega328P): the classic implementation shows the faulted phase and distance on a 16x2 LCD. Recent IEEE examples include distance-locator designs [8] and Arduino systems that add Bluetooth reporting [9] or fault management [10]. Dan-Okwara et al. present an automatic microcontroller-based detection and location system [11].

• GSM and GPS add-ons: an SMS with the fault phase, distance and site coordinates is sent to the maintenance crew [12], [13].

• Low-power MCUs (MSP430 class): this search found no 2022–2026 IEEE paper that pairs the MSP430 with cable fault location. The MSP430s ultra-low-power modes would suit battery or energy-harvesting nodes in cable joints so this is an open niche rather than an established line of work, for MSP430.

The method is inexpensive simple to make and great for learning. Its accuracy depends on the idea that fault resistance's very small and that the cable resistance is the same all along. These things are not true when there is resistance or when a fault is just starting in real cables. Section 7 goes back, to this problem.

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IV. IOT AND ESP32-BASED SYSTEMS

From 2022 onward, IEEE conference papers on this topic shifted from local LCD display to remote IoT monitoring. Fault data is now pushed to a cloud dashboard or mobile app, so the utility learns of a fault without a site visit. Twenty-one of the IEEE papers indexed for this review (2022–2026) carry "IoT" or a named Wi-Fi microcontroller in the title.

Why the ESP32. The ESP32 replaces the Arduino-plus-GSM or Arduino-plus-ESP8266 pair with a single chip. It offers a dual-core processor at up to 240 MHz, integrated Wi-Fi and Bluetooth, a multi-channel 12-bit ADC and enough GPIO to drive relay banks for three phases. It is programmable from the Arduino IDE, which explains its popularity in student projects. Its known weakness is the ADC: readings are non-linear near the supply rails and drift with the reference voltage. This matters directly for an Ohm's-law locator, where the ADC reading is the distance.

How the work has developed:

- 2022–2023, basic IoT alerting. Early papers add IoT connectivity to the resistor-network locator, building on non-IoT detectors such as [14], so that the faulted phase and distance can be viewed remotely [15]–[18]. Devarajan et al. add cloud storage of fault records [16].

- 2024, richer monitoring. Papers frame the system as a monitoring platform for the distribution network rather than a one-off detector [19]–[25]. Jayachandran et al. present an IoT-based smart underground cable fault detector at IEEE ICoCET 2024 [23].

- 2025, multi-type and three-phase. Recent work detects several fault types [27], handles three-phase cables with a distance locator [29], and stresses real-time operation [26], [28], [30], [31].

- 2026, ESP32 with protection. Jegadeesan et al. combine ESP32-driven fault detection with self-isolation of the faulted section of the power distribution network [32]. That moves the system from monitoring towards protection. Other 2026 papers target Industry 4.0 plants [33] and three-phase cable localisation [34].

A representative ESP32 design. Mythry et al. (not IEEE-published, but fully ESP32-based) describe a typical build [41]:

- an ESP32 reading voltage and current on red, yellow and blue resistor-network lines
- opto-isolated relays that disconnect a faulted segment
- an I2C LCD and a NEO-6M GPS module
- e-mail alerts over SMTP carrying the phase, distance and coordinates

Faults are simulated with push buttons at 1, 2 and 4 km. The paper reports no quantitative accuracy and lists cloud integration as future work. This pattern is common across the literature: functional demonstrations are rarely backed by measured location error.

V. AI AND SIGNAL-PROCESSING APPROACHES

The newest IEEE papers, mostly from 2025–2026, attach a learning model to either the IoT data stream or physical-layer signals. The two strands differ in what the model sees.

Learning on IoT sensor data. Here voltage and current readings from the IoT node are used to train a classifier:

- Baskar et al. use a support vector machine to classify electrical faults in underground cable networks from IoT sensor data [35].

- Murugesan et al. combine IoT sensing with machine learning for AI-powered fault detection [36].

- Karthikeyan et al. propose an attention-driven deep-learning framework for IoT-based fault management [37].

These systems mainly improve fault classification: telling short circuit from open circuit and identifying the phase. They still inherit distance accuracy from the underlying measurement.

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Learning on wave and spectral features. This strand works on physical-layer signals and targets location and incipient faults:

- Mashiku et al. model GPS-assisted travelling-wave detection with an artificial neural network [4].
- Chezhian et al. locate incipient faults from travelling waves with an enhanced CNN-LSTM model [5].
- Sahoo et al. use empirical mode decomposition (EMD) to extract features from distribution-cable signals, then classify them with CatBoost [38] and random forest [39]. Both papers target incipient faults, which the Ohm's-law method cannot see.
- Outside IEEE, Fu et al. train an LSTM on shifts in a cable network's resonance frequency to detect and locate faults, validated in MATLAB simulation [40].

The practical lesson for an ESP32 project is that the two strands can meet. Light feature extraction and a small classifier can run on the ESP32 itself. Heavier wave-based models stay in the cloud.

VI. COMPARISON OF REPRESENTATIVE WORKS

The table lists 13 representative IEEE papers, newest first, plus one non-IEEE ESP32 build. Only the TIM 2024 paper [3] reports a measured location error (within 0.21%). None of the IoT prototypes whose details were checked reports one. For several conference papers, the contribution column is taken from the paper's title because the abstract was not retrievable.

TABLE I COMPARISON OF REPRESENTATIVE WORKS

Ref.	Year	Category / Technique	Main contribution
[1]	2026	Review; Survey of location techniques	Systematic review of exact fault-location methods
[32]	2026	IoT + protection; ESP32, relays	ESP32-driven detection with self-isolating distribution
[37]	2026	IoT + AI; Attention-based deep learning	DL framework for IoT-based fault management
[5]	2026	Wave + AI; Travelling wave, CNN-LSTM	Incipient-fault location
[39]	2026	Signal + ML; EMD, random forest	Fault classification in distribution cable
[35]	2025	IoT + ML; IoT sensors, SVM	Electrical fault classification
[38]	2025	Signal + ML; EMD, CatBoost	Incipient-fault identification
[4]	2025	Wave + AI; GPS travelling wave, ANN	Modelled and simulated GPS-assisted location
[27]	2025	IoT; IoT monitoring	Multi-type fault detection
[29]	2025	IoT; 3-phase, distance locator	Three-phase detection with distance display
[13]	2025	Microcontroller + GSM; GSM alerting	SMS-based fault reporting
[3]	2024	Frequency domain; Propagation-function spectrum	Within 0.21% location error on 50–163 m cables
[23]	2024	IoT; IoT fault detector	Smart IoT-based detector
[41]	2025	IoT; ESP32, GPS, SMTP e-mail	Full ESP32 build; no measured accuracy

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VII. RESEARCH GAPS AND PROPOSED DIRECTION

The biggest gap is evidence: ESP32 prototypes are demonstrated, not measured. The gaps below follow from Sections 3–6.

• No quantitative validation. IoT papers show that a fault is flagged at "2 km" but rarely report location error, repeatability or response time. Only the instrumentation-journal work reports an error figure [3].

• Fault resistance is ignored. The Ohm's-law model assumes a bolted (zero-resistance) fault, so any fault resistance appears as extra distance. High-resistance and incipient faults [2], which the signal-processing papers target [38], [39], are invisible to it.

• Uncalibrated ADC. The ESP32's non-linear ADC is used raw in most builds, which directly corrupts the distance estimate.

• Intelligence lives in the cloud. Classification with SVM or deep learning is done off-device [35]–[37]. On-device (edge) classification on the ESP32 is largely unexplored, although it would keep working when connectivity drops.

• Detection without protection. Most systems only report a fault. Automatic isolation of the faulted section appears only recently [32].

• Communication underground. Cable joints and vaults often have poor Wi-Fi or cellular coverage. Long-range low-power links such as LoRa, and low-power MCUs such as the MSP430, are barely studied in the IEEE literature.

Proposed direction for an ESP32 system. A project can close several of these gaps at low cost:

• Calibrate the measurement. Apply ESP-IDF ADC calibration plus a two-point or lookup-table correction against known resistances. Average many samples per reading.

• Model fault resistance. Measure from both cable ends, or take two readings at different source conditions, so that distance and fault resistance can be solved for separately.

• Classify at the edge. Run a small TinyML model on the ESP32 to identify the fault type (short, open, high-resistance) from voltage and current features.

• Isolate automatically. Drive opto-isolated relays to disconnect the faulted segment, following [32].

• Report robustly. Publish to the dashboard over MQTT on Wi-Fi, with LoRa or GSM as a fallback channel.

• Evaluate properly. Report mean absolute location error per kilometre across a sweep of fault resistances, plus detection-to-alert latency. That turns a demonstration into a publishable result.

VIII. CONCLUSION

Recent IEEE literature shows a progression in underground cable fault detection. It started with loop tests and TDR. Then came microcontroller resistor-network locators. After that ESP32-based IoT monitoring took off. Now AI-assisted classification and protection are becoming more common. The ESP32 has become the default platform for low-cost systems. It combines sensing, control and wireless reporting on one chip.. Most ESP32 projects still rely on an idealised Ohm's-law model. They do not show accuracy, in real-world conditions. Journal-level research looks at travelling waves propagation spectra and EMD-based learning. This kind of work handles cable physics and can detect incipient faults. It needs heavier hardware. The strongest contribution an ESP32 project can offer lies in the middle. It should include measurement, fault-resistance-aware location edge classification, automatic isolation and a proper evaluation of location error.



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