



A Low-Cost Multi-Parameter Framework for Intelligent Earthing Condition Monitoring and Preventive Maintenance

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ABSTRACT

Earthing is a fundamental safety measure in electrical installations, as it provides a low-impedance path for fault current and facilitates the proper operation of protective devices. However, the condition of an earthing system may deteriorate over time due to variations in soil moisture, electrode corrosion, loose connections, environmental influences, and modifications to the electrical installation. Although periodic inspections and earth resistance measurements are essential for ensuring safety, assessments conducted at scheduled intervals may not always identify developing abnormal conditions at an early stage.

This paper presents a low-cost, microcontroller-based framework for supplementary monitoring of earthing conditions. The proposed prototype integrates soil moisture sensing with electrical measurements to assess the observed condition of the earthing system. The acquired sensor data are processed using predefined decision rules to classify the condition into three categories: Normal, Warning, and Maintenance Required. A local indication system comprising an LCD, LEDs, and a buzzer provides status alerts, while GSM or Wi-Fi communication can be incorporated to enable remote notifications. The proposed framework is intended to support timely maintenance decisions and complement conventional earthing inspection and testing procedures, rather than replace established earth resistance testing methods or electrical protective devices. As the project is currently under development, no quantitative performance results are claimed. A validation methodology involving sensor calibration, measurement repeatability, threshold selection, and comparison with established earthing test methods is also outlined.

Keywords—earthing, grounding, condition monitoring, soil moisture, microcontroller, preventive maintenance, fault indication, Internet of Things

1. Introduction

An earthing system is designed to support electrical safety by connecting appropriate parts of an installation to earth and providing a path for fault current. Its effectiveness depends on the electrode and conductor arrangement, the surrounding soil, the integrity of connections, and the way fault current returns through the installation. International guidance on earthing arrangements emphasizes that earthing and protective conductors must be selected and installed to satisfy the safety requirements of the installation [1].

The condition of an earth electrode and its surrounding soil is not necessarily constant. Soil moisture and resistivity may vary with weather and local conditions, while corrosion or mechanical damage can alter electrode performance. Work on high-voltage earth-grid monitoring has highlighted that environmental changes and changes in fault-current paths can affect the interpretation of grounding-system safety [2]. These factors motivate monitoring approaches that can help maintenance staff notice changes between scheduled inspections.

Conventional earth-resistance measurement remains important and should be carried out with suitable instruments and safe procedures. IEEE guidance describes methods for measuring earth resistivity, grounding impedance, and earth-surface potentials, as well as factors that can affect measurement reliability [3]. A small sensor-based prototype cannot measure all these quantities or certify an installation as safe. Its more limited role is to provide supplementary indications from selected parameters and prompt qualified personnel to carry out proper inspection and testing when a warning appears.

This work proposes an economical monitoring arrangement based on a microcontroller, soil-moisture sensing, current and voltage sensing, and local alarm devices. The design goal is to make selected measurements visible, apply consistent threshold rules, and organize the output into clear condition categories.

2. Problem Statement and Research Motivation

A maintenance team may be responsible for monitoring multiple earthing pits and electrical assets distributed across a facility. Conducting manual inspections at each location can be time-consuming and requires physical access to the respective sites. Furthermore, measurements obtained during a

particular inspection represent the conditions at that specific time and do not provide continuous information about subsequent changes. As a result, developing abnormalities may remain undetected until the next scheduled inspection. Moreover, relying on a single parameter may not provide sufficient information to identify different earthing-related issues. Soil moisture indicates the surrounding environmental conditions, whereas current and voltage measurements provide complementary information about the electrical behaviour of the system.

The research problem addressed in this study is the development of a simple, low-cost prototype that integrates selected environmental and electrical parameters into an understandable warning system. The proposed system aims to provide preliminary indications of changes in earthing conditions without treating its sensor readings as a replacement for certified earth resistance testing. The primary focus is on supporting condition monitoring, facilitating the early identification of potential abnormalities, and assisting maintenance teams in prioritizing inspection and maintenance activities.

3. Literature Review

Damodare et al. described an intelligent earthing concept in which a moisture sensor informs a controller and moisture management is used to respond to dry soil conditions [4]. This work demonstrates the practical relevance of monitoring the local environment around an earthing electrode. However, moisture alone cannot establish the electrical integrity or safety of a complete grounding installation.

Nassereddine et al. examined advanced earth-grid monitoring for high-voltage network safety compliance and discussed how soil resistivity and fault-current return paths influence grounding-system assessment [2]. Their work addresses a more complex grid-level problem than the low-cost prototype presented here, but it reinforces the need to consider environmental and electrical conditions together.

Zhang et al. presented an Internet-of-Things-based ground-grid monitoring system, covering system architecture, hardware, software, data communication, processing, and fault diagnosis [5]. This illustrates the growing role of connected monitoring and structured data processing in grounding applications. Kumar et al. proposed an automated earthing-health monitoring and alert concept that uses electronic sensing and a display to support earth-pit observation [6].

The reviewed work suggests three useful design directions: (i) measure more than one relevant parameter, (ii) convert readings into clear maintenance information, and (iii) keep remote communication modular so the basic prototype can operate locally. At the same time, the literature and relevant measurement guidance indicate that sensor monitoring should be distinguished from formal grounding-system testing [3].

3.1 Research Gap

For a student-scale, economical prototype, a practical gap remains between basic sensor readings and a maintenance-oriented status output. The proposed design addresses this implementation gap by combining selected sensor inputs with transparent threshold-based classification and local alerts. It is not presented as a new earth-resistance measurement method, nor does it claim to replace established inspection practices.

4. Aim and Objectives

Develop a microcontroller-based prototype for supplementary monitoring of selected earthing-related conditions.

Acquire soil-moisture and selected electrical sensor readings at regular intervals.

Apply configurable threshold rules to categorize readings as Normal, Warning, or Maintenance Required.

Indicate the condition locally through an LCD, LED, and buzzer.

Provide an optional path for GSM/Wi-Fi notifications to support remote awareness.

Define a validation procedure that checks sensor calibration and compares alerts with independent measurements.

5. Proposed System and Methodology

5.1 System Overview

The proposed system follows a sensing–processing–indication workflow. A soil-moisture sensor measures the local soil condition around the monitored electrode. A current-sensing channel and an isolated voltage-sensing module provide additional electrical observations. The sensor outputs are read by a microcontroller, which checks data validity, compares readings with configured limits, determines a status category, and updates the display and alarm outputs. A communication module can be included as an optional extension.

The prototype described in the project material uses an Arduino-class controller, a soil-moisture sensor, an ACS712 current sensor, a ZMPT101B voltage-sensing module, a 16×2 LCD, an LED, and a buzzer. The final sensor range, electrical interface, isolation arrangements, and calibration must be verified against the actual hardware used.

5.2 Functional Sequence

Sensing: collect soil-moisture, current, and voltage readings at defined sampling intervals.

Input checking: detect missing, out-of-range, or unstable readings and avoid classifying invalid data as normal.

Processing: filter short-lived fluctuations where appropriate and compare valid readings with configured thresholds.

Classification: assign Normal, Warning, or Maintenance Required according to the implemented rule set.

Indication: show values and status on the LCD; activate the LED and buzzer when a warning condition is present.

Maintenance response: treat an alert as a prompt for inspection and formal testing by qualified personnel.

Optional communication: transmit a timestamped status message through GSM/Wi-Fi where connectivity is implemented.

5.3 Condition Classification Logic

A transparent rule-based approach is suitable for an early prototype because its decisions can be inspected and adjusted during calibration. The exact limits must be selected from sensor calibration, the intended installation, and engineering review; universal threshold values are not assumed in this paper.

Status	Indicative rule	Suggested response
Normal	All monitored readings are valid and remain within the configured operating bands.	Continue monitoring and retain readings.
Warning	A reading approaches a configured limit or a short-duration abnormal pattern is detected.	Display warning and check the trend.
Maintenance Required	A reading crosses a critical configured limit, or repeated warnings persist.	Sound alarm and arrange qualified inspection/testing.
Sensor/Data Fault	A sensor is disconnected, implausible, or outside its measurable range.	Report data fault; do not label the earthing system Normal.

The categories above describe a proposed logic framework, not measured results. In implementation, hysteresis or a persistence timer can reduce repeated alarm switching when a reading fluctuates near a threshold. The chosen thresholds and timing parameters should be documented and verified during testing.

5.4 Hardware and Functional Roles

Component	Role in the prototype	Design consideration
Arduino-class microcontroller	Reads sensor outputs and runs the classification logic.	Confirm input voltage, ADC range, and timing.
Soil-moisture sensor	Tracks moisture changes near the monitored electrode.	Calibrate for the actual soil; probe readings are soil-dependent.
ACS712 current sensor	Provides a current-related signal for monitoring.	Verify range, bandwidth, wiring, and whether the measured current is the intended quantity.
ZMPT101B voltage module	Provides a scaled, isolated voltage-sensing interface when correctly configured.	Use appropriate mains-rated construction and qualified supervision.
16×2 LCD	Displays sensor readings and current status.	Keep labels and units clear.
LED and buzzer	Provide immediate local status and warning.	Use suitable drivers and fail-safe output behavior.
Optional GSM/Wi-Fi module	Sends remote status messages.	Consider network availability, message delay, and communication failure.

5.5 Safety and Measurement Boundaries

The prototype is a supplementary monitoring aid. A moisture reading, a neutral-to-earth voltage reading, or a current-sensor output by itself does not establish earth-electrode resistance or prove that an installation meets safety requirements. Grounding-system measurements require appropriate instruments, test methods, and safe procedures [3]. Any mains-connected construction and testing must be performed under qualified supervision, with suitable isolation, protective enclosures, and applicable electrical codes. The monitoring circuit must never be inserted in a way that compromises the protective-earth conductor.

6. Expected Outcomes and Validation Plan

The expected outcome is a working prototype that displays sensor values, categorizes monitored conditions, and provides a local warning when a configured limit is crossed. If a communication module is added, the system may also send remote notifications. These are design expectations; numerical accuracy, response time, false-alarm rate, and reliability have not been claimed because completed experimental data were not provided in the project material.

6.1 Proposed Test Plan

Sensor calibration: compare each sensor against an appropriate reference instrument or known test condition and record the calibration curve.

Repeatability: collect repeated readings under stable conditions and calculate the spread of readings.

Threshold tests: apply safe, controlled input changes around each configured limit and verify the expected status transition.

Alarm behavior: confirm LCD, LED, buzzer, and optional remote notification for each status.

Fault handling: disconnect or simulate invalid sensor input and verify that the system reports a sensor/data fault rather than a normal condition.

Independent comparison: compare system indications with qualified earthing inspection and accepted test methods; record discrepancies.

Environmental checks: evaluate sensor response across representative soil conditions and document limitations.

A future results table should report the test condition, reference value, prototype reading, error, classification, and observed response time. Only measured values obtained during actual testing should be inserted into that table.

7. Discussion

The key design advantage is the combination of several indicators with an easily understood status output. Local alarms can provide immediate awareness without requiring a network connection, while optional communication can help staff monitor installations that are difficult to visit frequently. A rule-based system is also relatively easy to explain and maintain compared with a complex model requiring a large labeled dataset.

Several limitations must be recognized. Soil-moisture sensors are affected by soil composition, placement, corrosion, and calibration. Current and voltage sensors have finite ranges and measurement errors. Thresholds that work at one site may not transfer directly to another site. Communication links may fail, and an alert may be missed if the system lacks a power-failure strategy. Most importantly, selected sensor readings do not directly replace a formal measurement of grounding resistance, impedance, or touch/step potential.

For these reasons, the system should be used to prioritize inspection rather than make an unconditional safety declaration. Future iterations could add timestamped data logging, trend analysis, sensor self-diagnostics, backup power, secure remote reporting, and a calibration record. Any automated moisture-control feature, such as a pump, should be assessed separately to avoid introducing corrosion, water-management, or electrical hazards.

8. Prototype



Fig. 1. Prototype of the Proposed Intelligent Earthing Health Monitoring System

The developed prototype integrates a microcontroller with sensing and alert units to monitor selected earthing-related parameters. The system processes sensor readings and indicates abnormal conditions through visual and audible alerts.

9. Conclusion

This paper has presented a low-cost framework for intelligent earthing-condition monitoring using soil-moisture and selected electrical measurements, a microcontroller, threshold-based classification, and local alerts. The proposed Normal, Warning, and Maintenance Required categories are intended to translate sensor observations into practical maintenance prompts. Optional GSM/Wi-Fi communication can extend awareness beyond the installation site. The contribution is a clearly defined prototype workflow and validation plan, not a claim that the system can certify earthing safety. Before deployment, the hardware must be calibrated, the threshold logic must be tested, and alerts must be compared with appropriate independent earthing measurements. With these safeguards, the prototype can serve as an educational and maintenance-support tool alongside established electrical-safety practices.

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