International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Smart Transformer

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Abstract - Power distribution transformers are key infrastructural el-ements whose operational failure introduces network in-stability, high repair liabilities, and customer power dis-ruptions. Standard manual maintenance schemes cannot prevent rapid failures caused by overloading and unex-pected thermal spikes in real time. This paper details the engineering and validation of an automated, Inter-net of Things (IoT)-driven health monitoring system de-signed for a 1 kVA single-phase air-cooled distribution transformer. Centered on an Arduino Uno microcontroller layer, the architecture integrates non-invasive electrical and ambient environment sensors to monitor terminal AC voltage, load current, ambient temperature, and humid-ity. Remote telemetry and geographical asset location are managed via embedded GSM (SIM800L) and GPS (NEO-6M) modules. Testing confirms that the system handles real-time parameter tracking and runs safety trip logic during electrical overcurrent and over-temperature viola-tions.

Keywords: ***IoT, Distribution Transformer, Arduino Uno, GSM SIM800L, NEO-6M GPS, Overcurrent Pro-tection, Condition Monitoring.***

1 INTRODUCTION

Distribution transformers act as critical destination links in modern electrical grids, adjusting primary line distri-bution down to industrial or consumer consumption levels [5, 6]. In spite of their long operational design parame-ters, transformers undergo premature field failure due to uncoordinated residential charging peaks, prolonged over-loading conditions, thermal insulation breakages, and un-stable grid environments. Identifying these parameters via operational line checks by human operators is expensive, spatially limited, and retroactively applied post-failure.

Introducing embedded automation layers and the Inter-net of Things (IoT) addresses these challenges by substi-tuting physical line maintenance with streaming diagnos-tic platforms [1, 2, 4]. By combining modern solid-state sensors with edge controllers, utility operations can pro-cess telemetry trends from remote nodes [7, 8]. This doc-ument focuses on a field-deployable prototype optimized for a 1 kVA air-cooled platform, tracking line voltage, cur-rent loads, tracking coordinates via GPS, and alerting via a GSM link.

2 OBJECTIVES

The core engineering milestones of this project focus on developing an independent tracking framework to:

- Continuously sense and calculate true root-mean-square (RMS) line voltage, current magnitude, am-bient temperature, and local humidity levels [1, 2, 3].
- Intercept fault variations on site to declare multi-tier alarms based on defined hardware safety limits.
- Acquire and bind global geo-positioning coordinates (latitude and longitude) to the asset to enable spatial tracking in utility asset networks [1].
- Manage a physical isolation trip via a dedicated solid-state relay if primary thresholds are compromised.
- Deliver cellular SMS data reports and fault notifica-tions directly to remote maintenance crews [1].

3 LITERATURE REVIEW

The development of state-monitoring technology for distri-bution networks spans multiple structural designs, moving from offline data-logging models to active telemetry frame-works.

Ajitha and Kumar (2017) analyzed wide-area net-work telemetry configurations using LoRa modules, con-firming data packet ranges approaching 10 km. Their layout successfully added chemical monitoring vectors, notably capturing silica gel color transformations in breathers via color-filtering modules, proving the value of expanded sensor profiles.

Roy and Roy (2018) explored transport layer effi-ciency by applying the Message Queuing Telemetry Trans-port (MQTT) communication layer over structural HTTP requests. Using a Raspberry Pi edge gateway topology, their findings verified that MQTT reduced transmission framing sizes, making it an excellent protocol for rural areas with weak cellular coverage.

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Praveenkumar Chandran et al. (2019) evaluated structural design choices for low-power distribution pro-files by implementing a standalone monitoring node on a single-phase 1 kVA 230/115 V oil-immersed assembly. Their prototype logged basic electrical operating trends, driving secondary-side protective circuit breakers to pre-vent winding damage during severe grid variations.

Bethalsha et al. (2020) introduced mechanical anomaly checking by adding vibration arrays alongside conventional electrical monitoring sensors. Running over an ESP8266 Wi-Fi architecture using standard HTTP re-quests, their platform mapped thermal and load variations onto graphic dashboards to catch hardware wear before total failure occurs.

Asmita Sharma et al. (2025) focused on lowering operational costs by demonstrating that modern micro-controller data collection systems outpermed older, high-overhead commercial GSM-only loggers. Their frame-work combined structural sensor readings with cloud dash-boards, verifying that intelligent edge control logic could replace expensive field inspection routines.

4 SYSTEM ARCHITECTURE AND METHODOLOGY

The engineered system features three sequential layers: Data Acquisition, Central Processing/Logic Control, and Remote Communication/Isolation Protection.

4.1 Data Acquisition Unit

- **AC Voltage Profiling:** A galvanic-isolated ZMPT101B active voltage transformer module reads the primary AC terminal waveform. Its onboard LM358 operational amplifier shifts the raw sine wave to align with the positive DC input window of the microcontroller's ADC.
- **Load Current Sensing:** An ACS712 Hall-effect current module tracks load current. It generates an analog voltage output scaled linearly with the sensed AC current, providing physical isolation up to its rated limit.
- **Environmental Monitoring:** A DHT11 composite sensor housing reads ambient temperature and hu-midity. This sensor tracks localized ambient variables to predict thermal stress under load without needing direct structural changes inside the casing.
- **Geographical Tracking:** A NEO-6M GPS receiver board paired with a ceramic patch antenna parses NMEA data sentences from overhead tracking satel-lites. This enables real-time tracking of latitude and longitude coordinates for remote field placement.

4.2 Processing Layer and Control Logic

The processing layer uses an **Arduino Uno** reference platform running an ATmega328P 8-bit RISC microcon-troller operating at a 16 MHz clock speed. The processor reads the analog values from the sensors, applies RMS filtration and calibration adjustments, and runs localized protection logic.

4.3 Communication and Protection Layer

- **Cellular Telemetry Module:** Remote notification uses a SIM800L quad-band GSM module. Interfaced over serial UART using standard AT commands, it bypasses on-site internet dependencies to send direct SMS warnings during system failures.
- **Isolation Trip Interface:** A 5V electromechanical relay board connects directly to an active low-level trigger digital pin on the Arduino Uno. This allows the system to physically isolate the transformer sec-ondary from the load when a fault is validated.

5 BLOCK DIAGRAM

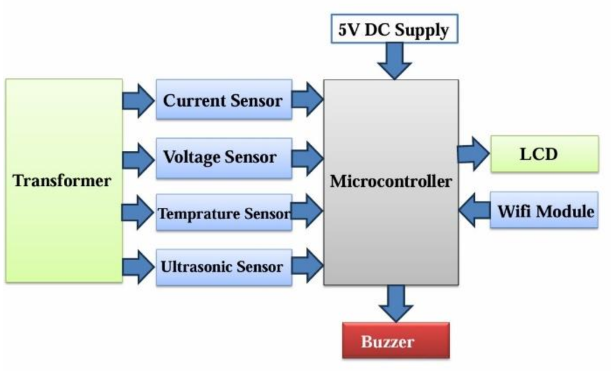

Figure 1: Hardware Block Architecture of the Arduino-Based Transformer Monitor

As illustrated in Figure 3, the physical system routes parameter signals from the 1 kVA single-phase air-cooled transformer into three distinct hardware subsystems. Sensed operational variants (Current, Voltage, Ambient Temperature/Humidity) pass from the isolated sensor ar-ray directly into the Arduino microcontroller processing module. A regulated 5V DC circuit drives the controller, which continuously executes safety check loops. The out-put side manages local and remote protective tasks, using a serial UART connection to handle SIM800L GSM cellu-lar alerts and satellite positioning updates via the NEO-6M GPS layer, while a digital control pin triggers a high-power relay interface to trip the line circuit breaker during faults.

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6 CIRCUIT DIAGRAM

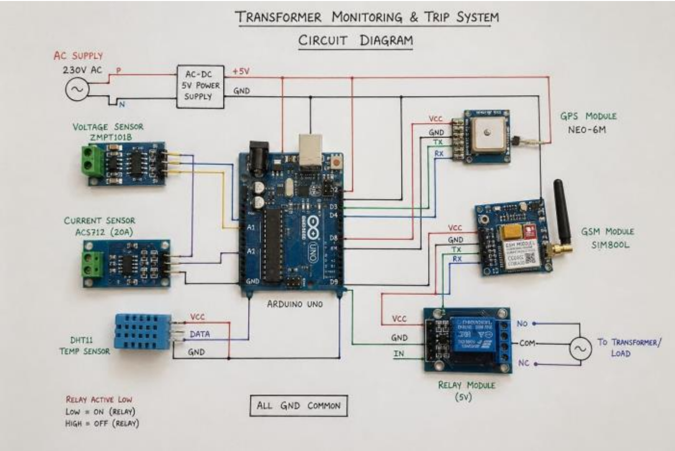

Figure 2: Circuit Diagram of the Proposed Smart Transformer Monitoring System

Figure 2 illustrates the complete circuit implementation of the proposed IoT-based smart transformer monitoring system. The Arduino Uno serves as the central processing unit and interfaces with all sensing, communication, and protection modules.

The transformer terminal voltage is monitored using a ZMPT101B voltage sensor module, which provides an isolated and scaled analog signal suitable for the Arduino's analog-to-digital converter (ADC). Load current is mea-sured using an ACS712 Hall-effect current sensor that of-fers electrical isolation and linear current measurement characteristics.

Environmental conditions surrounding the transformer are monitored using a DHT11 sensor, which continuously measures ambient temperature and humidity. These parameters help assess operating conditions and identify potential thermal stress situations.

For remote communication, a SIM800L GSM module is connected to the Arduino through serial communica-tion (UART). The module transmits SMS notifications whenever abnormal operating conditions such as overvolt-age, undervoltage, overcurrent, or excessive temperature are detected. A NEO-6M GPS receiver is also interfaced through serial communication to provide real-time geo-graphical coordinates of the transformer location.

A 5V relay module is connected to a digital output pin of the Arduino and acts as the protection interface. When the measured parameters exceed predefined safety thresh-olds, the controller energizes the relay to disconnect the load and prevent transformer damage. A regulated 5V power supply provides operating power to the controller and peripheral modules.

The integrated circuit architecture enables continuous monitoring, fault detection, remote alert generation, and automatic protective action, thereby improving trans-former reliability and reducing maintenance requirements.

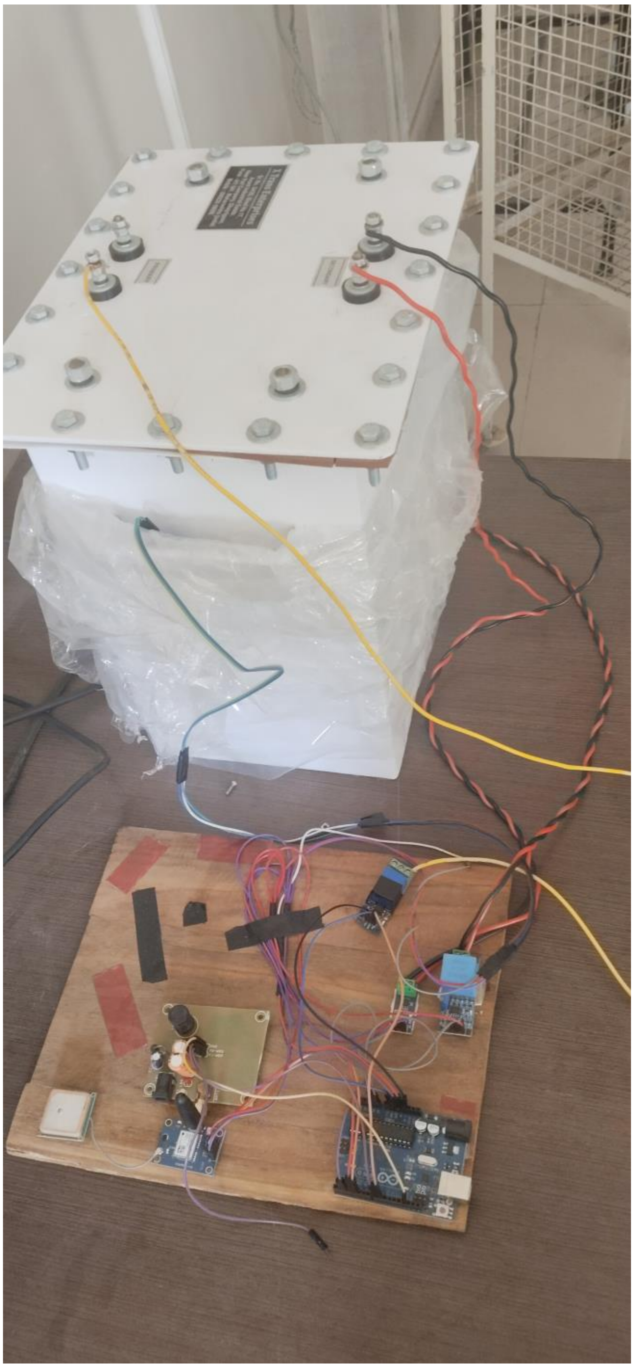

Figure 3: Actual image of working model

7 RESULTS AND PERFORMANCE DIS-CUSSION

The prototype system was validated through controlled laboratory tests using a 1 kVA, single-phase, 230V/115V air-cooled transformer assembly. The control logic re-sponded successfully to three core test conditions:

1. **Preventive Maintenance Window:** Activated when line voltage drops below 210V or climbs past 250V while load currents reach 80% to 90% of rated

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limits. The system issues a non-critical update via the GSM network.

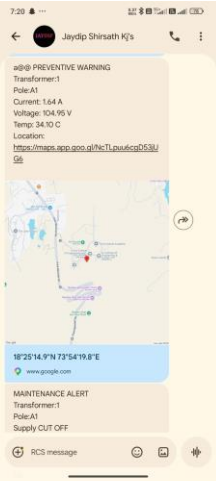

Figure 4: Preventive Maintenance Message

2. **Maintenance Alert Level:** Triggered when termi-nal voltage shifts outside standard operating toler-ances (±10%) or load currents hit 90% of nominal capacity. The system sends an urgent status text to update maintenance teams.

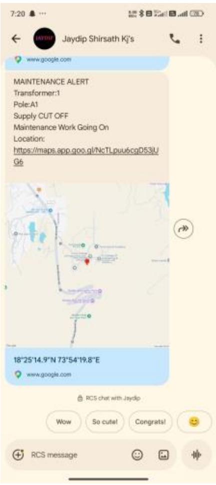

Figure 5: Maintenance Alert Message

3. **Over-current Trip Activation:** Triggered when load currents surge past 120% of rated thresholds. The Arduino pulls the digital control pin low to ac-tivate the relay, isolating the secondary line within milliseconds to prevent winding burnout.

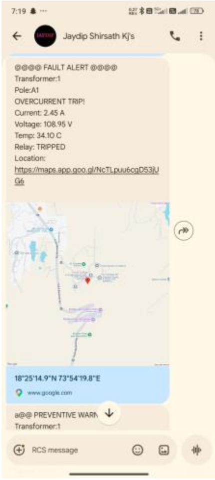

Figure 6: Over-current Trip Message Calibration

checks against high-precision multimeters confirm that the system handles data capture accurately, proving it can safely monitor low-power distribution as-sets.

8 CONCLUSION AND FUTURE WORK

This project successfully demonstrates an affordable, reli-able smart monitoring framework built around an Arduino Uno architecture. The prototype handles continuous elec-trical sampling, reads GPS asset tracking data, and acts automatically during overload conditions without needing continuous human intervention.

Future upgrades will replace the surface-mounted ther-mal tracking with direct winding Resistance Temperature Detectors (RTDs) to improve accuracy. We also plan to design a dedicated PCB with proper isolation spacing to achieve compliance with industrial electromagnetic com-patibility (EMC) and field safety certifications.

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