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Research on IOT-Based Transformer Monitoring and Fault Detection System Using ESP32

Nandini Datir,Khushi Dubey,Shrvan Dhande,Sahil Isal,Prof.S.S.Kulkarni

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Abstract

Distribution transformers are among the most vital and capital-intensive assets of a power network, yet they are still maintained through periodic manual inspections that cannot detect rapid, incipient faults. This paper presents an Internet of Things (IoT) based system for continuous transformer health monitoring and fault diagnosis. A NodeMCU ESP8266 acts as the main controller and collects data from a DHT11 temperature and humidity sensor, an SW-420 vibration sensor, and an LM393-based acoustic sound sensor mounted on a 12-0-12 V, 2 A step-down transformer. The controller compares the readings with predefined thresholds and transmits the processed data over Wi-Fi to the Blynk IoT Cloud, where gauges, charts, and status widgets display the live condition of the transformer. Push notifications and e-mail alerts are generated automatically when a threshold is crossed, so that engineers are informed before a catastrophic failure occurs. During testing under progressive loading, the dashboard reflected a temperature rise within 1.2 seconds and the alerts were delivered with no packet loss. The system offers a low-cost alternative to expensive SCADA-based solutions for predictive maintenance.

Keywords: Transformer Monitoring, IoT, NodeMCU ESP8266, Blynk, Predictive Maintenance.

Introduction

Distribution transformers step down high distribution voltages to consumer-level utility voltages and operate continuously under demanding electrical and environmental stress.

Because power grids are heavily interconnected, an unexpected breakdown of a distribution transformer can cause widespread outages, disrupt industrial productivity, and impose large financial losses on utility providers.

Conventional maintenance relies mainly on scheduled manual inspections by utility technicians. These routines are labor-intensive, hazardous for personnel working in energized high-voltage yards, and unable to detect rapid faults that develop between two inspections. If a transformer develops sudden winding insulation failure, core looseness, or a cooling anomaly, a manual inspection provides no real-time notification.

To address these limitations, this paper presents an IoT-based transformer health monitoring and fault diagnostic system. By combining embedded sensors with Wi-Fi telemetry and cloud computation, the system monitors thermal escalation, internal mechanical vibration, and abnormal acoustic emissions around the clock and sends live diagnostics to cloud dashboards, notifying engineers before a catastrophic failure occurs.

Literature Review

The IEEE guide for the interpretation of gases generated in mineral oil-immersed transformers (IEEE, 2019) forms a standard reference for diagnosing the internal condition of transformers. Biren et al. (2020) described an IoT-based smart transformer health monitoring system built around the ESP8266, which demonstrates



the suitability of low-cost Wi-Fi microcontrollers for this task.

The ESP8266EX technical reference manual (Espressif Systems, 2021) documents the processor, memory, and wireless features of the controller used in this work, while Sawhney (2018) covers the measurement and instrumentation principles behind sensor-based monitoring. The Blynk platform documentation (Blynk Inc., 2024) describes the virtual-pin architecture used here to connect the hardware with the cloud dashboard.

Methodology

The methodology is divided into three coordinated tiers: physical sensing and transduction, embedded signal processing, and IoT cloud telemetry and alerting.

Transduction layer. A sensor array consisting of the DHT11 digital temperature sensor, the SW-420 mechanical vibration module, and the LM393-based acoustic noise sensor is physically coupled to the chassis and core assembly of a 12-0-12 V, 2 A transformer. These sensors continually capture the thermal, kinetic, and acoustic behavior of the transformer.

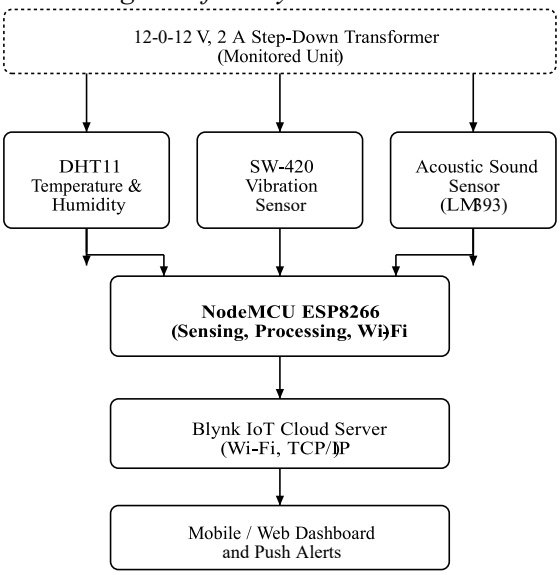
Embedded processing layer. The NodeMCU ESP8266 samples the sensor data using calibrated polling routines and hardware interrupts. The raw data is conditioned, parsed, and evaluated against the safety thresholds programmed in the firmware.

Cloud and application layer. The processed telemetry packets are sent over the 2.4 GHz IEEE 802.11 b/g/n wireless link to the Blynk IoT Cloud Server through encrypted TCP/IP sockets. The data is mapped to dashboard widgets, and instant push notifications are triggered whenever an abnormal threshold is breached.

Block Diagram

Figure 1

Block Diagram of the System



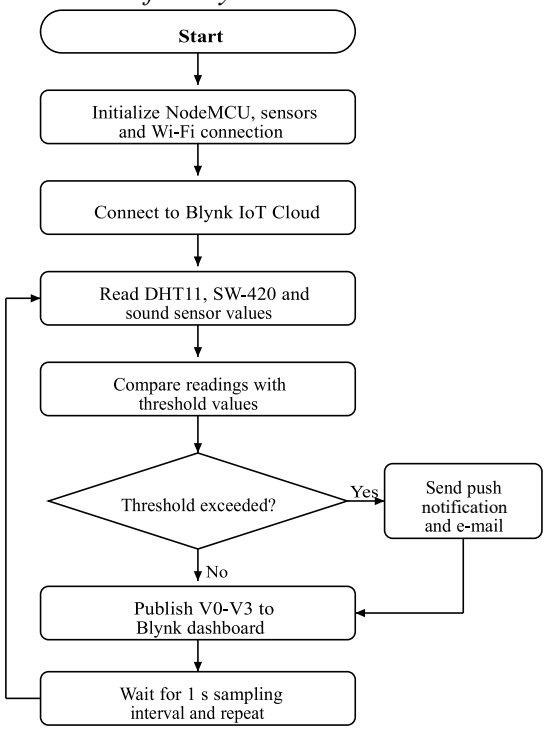
Description

The block diagram shows the overall architecture of the proposed system. The three sensors are attached to the monitored transformer and send their measurements to the NodeMCU ESP8266, which analyses the readings against predefined thresholds. The controller then publishes the values to the Blynk IoT Cloud over Wi-Fi, and the cloud forwards the live data and alerts to the engineer's smartphone or web terminal.

Flow Chart

Figure 2

Flow Chart of the System





Circuit Connections

The physical assembly needs careful wiring to preserve signal integrity and to keep the 3.3 V DC digital electronics isolated from the AC secondary output of the transformer. The interconnections between the modules and the NodeMCU are listed in Table 1.

Table 1

Hardware Interconnections of the System

Hardware Module	Module Pin	NodeMCU Pin	Description
DHT11 Sensor	VCC, GND, DATA	3V3, GND, GPIO D4	One-wire digital temperature and humidity bus
SW-420 Sensor	VCC, GND, DO	3V3, GND, GPIO D5	Digital interrupt pin for kinetic shock
Sound Sensor	VCC, GND, AO, DO	3V3, GND, A0, GPIO D6	Analog amplitude and digital peak trigger
Step-Down Transformer	Primary (P, N), Secondary (12-0-12)	230 V AC mains	Monitored unit and load under resistive load

Monitored Unit: 12-0-12 V, 2 A Step-Down Transformer

A 12-0-12 V, 2 A center-tapped step-down transformer is used as the monitored specimen for testing and validating the platform. It converts the 230 V AC utility mains into a dual 12 V AC secondary output (Table 2).

The transformer operates on Faraday's law of mutual induction. Continuous loading 2 produces Joule heating (I R copper loss) in the primary and secondary windings, together with hysteresis and eddy-current losses in the silicon steel EI core laminations. The alternating flux also induces magnetostrictive strain in the core sheets, which causes the baseline acoustic hum and vibration. Monitoring these phenomena gives direct insight into the electrical and structural health of the unit.

Table 2

Specifications of the Monitored Transformer

Parameter	Technical Specification
Transformer Classification	Step-down center-tapped iron core transformer
Primary Input Voltage	230 V AC, 50 Hz single phase
Secondary Output Voltage	12 V - 0 - 12 V AC (center-tapped)
Nominal Current Rating	2.0 A continuous output (max power about 48 VA)
Core Construction	Laminated cold-rolled grain-oriented (CRGO) silicon steel (EI plates)
Winding Conductor	Super-enameled grade-1 pure copper winding

Microcontroller: NodeMCU ESP8266

The NodeMCU ESP8266 is the master processing unit and telemetry engine of the system. It is built around the Tensilica Xtensa 32-bit LX106 RISC microprocessor and integrates a complete TCP/IP Wi-Fi stack on a single chip (Table 3).

The processor runs an embedded C++ control loop compiled with the Arduino IDE. It reads the DHT11 digital pulses, measures the analog noise level through the on-board 10-bit successive approximation register (SAR) ADC, and monitors the vibration interrupts on a digital GPIO pin. The metrics are buffered, structured into Blynk telemetry payloads, and transmitted at regular sampling intervals without blocking the main execution loop.

Table 3

Specifications of the NodeMCU ESP8266

Parameter	Technical Specification
Processor Architecture	Tensilica Xtensa 32-bit LX106 RISC CPU at 80 / 160 MHz
Operating Voltage	3.3 V DC native logic (5 V via Micro-USB / Vin)
Integrated Memory	4 MB SPI flash, 64 KB instruction RAM, 96 KB data RAM



Wireless Protocol	IEEE 802.11 b/g/n (2.4 GHz, WPA/WPA2 Personal)
Peripheral Interfacing	13 digital GPIOs, 1 ADC input (0 - 3.3 V scaled), hardware timers
Development Framework	Arduino Core for ESP8266 / C++ embedded toolchain

DHT11 Temperature and Humidity Sensor

Operating temperature is the most critical indicator of transformer health, because exceeding the thermal limits rapidly degrades the cellulose insulation and the dielectric strength of the oil. The DHT11 is an integrated sensor that acquires the ambient and chassis temperature together with the relative humidity.

The DHT11 contains an NTC (negative temperature coefficient) thermistor for temperature sensing and a resistive-type element for humidity measurement. An embedded 8-bit microcontroller conditions the analog signals and sends calibrated 40-bit data frames over a single-wire digital bus to NodeMCU pin D4. This keeps pin usage low while providing good immunity against electromagnetic noise (Table 4). **Table 4**

Specifications of the DHT11 Sensor

Parameter	Technical Specification
Supply Voltage	3.3 V to 5.5 V DC
Temperature Range	0 °C to 50 °C (accuracy ±2.0 °C)
Relative Humidity Range	20% to 90% RH (accuracy ±5.0% RH)
Sampling Frequency	1.0 Hz (one measurement frame per second)
Communication Protocol	Single-bus bi-directional serial protocol (40-bit frame)
Power Consumption	Operating: 2.5 mA (max), standby: 100 µA

SW-420 Vibration Sensor Module

Mechanical degradation, such as loose core clamp bolts, winding displacement during external through-faults, or unbalanced electromagnetic forces, produces excessive vibration. The SW-420 sensor is mounted on the transformer frame to detect these abnormal signatures.

The SW-420 uses a normally-closed internal rolling spring element. Under stable conditions the spring completes the circuit. When the vibration exceeds the damping threshold, the spring deflects and momentarily breaks the circuit. The on-board LM393 comparator compares this signal with a reference voltage set by a potentiometer and outputs a clean digital pulse to NodeMCU pin D5 (Table 5).

Table 5

Specifications of the SW-420 Vibration Sensor Module

Parameter	Technical Specification
Sensor Mechanism	SW-420 normally-closed conductive spring element
Comparator IC	LM393 precision low-power voltage comparator
Operating Voltage	3.3 V to 5.0 V DC
Output Signal	Digital switching signal (active HIGH pulse on vibration)
Sensitivity Adjustment	Multi-turn precision trimmer potentiometer
Visual Indicators	Power status LED (red), trigger state LED (green)

Acoustic Sound Sensor

An energized transformer emits a steady 100 Hz magnetostrictive hum. Abnormal conditions such as severe harmonic distortion, inter-turn insulation puncture, or internal arcing produce irregular, high-decibel noise. The acoustic sound sensor monitors these audible anomalies in real time.

The sensor uses a high-sensitivity electret condenser microphone (ECM) with a flexible conductive diaphragm and a fixed backplate. Incoming sound waves deflect the diaphragm, change the capacitance, and produce small AC voltage variations. This signal is amplified by an LM393-based circuit, which gives an analog output (AO) proportional to the sound amplitude and a digital output (DO) that triggers when the intensity crosses the set limit (Table 6).

Table 6

Specifications of the Acoustic Sound Sensor

Parameter	Technical Specification
Acoustic Transducer	High-sensitivity electret condenser microphone (ECM)



Signal Conditioning IC	LM393 operational amplifier and comparator
Operating Voltage	3.3 V to 5.0 V DC
Output Interfaces	Analog output (AO) and digital threshold output (DO)
Frequency Response	50 Hz to 20,000 Hz (full audible spectrum)
Threshold Calibration	10k multi-turn precision potentiometer

Cloud Telemetry and Blynk IoT Dashboard

Blynk IoT is a cloud-based telemetry platform designed for fast visualization of edge devices on mobile and web screens. In this system it forms an encrypted two-way link between the NodeMCU ESP8266 and the engineer's smartphone or web terminal.

The data is encapsulated in Blynk virtual pins, which separate the raw hardware GPIO mapping from the cloud data channels. The firmware periodically publishes the telemetry values over virtual pins V0, V1, V2, and V3. On the client application, radial gauges, numeric displays, and trend charts show the live parameters (Table 7). Automated event rules monitor the incoming datastreams and trigger push notifications and alert e-mails when a safety threshold is breached. **Table 7**

Blynk Virtual Pin Mapping and Alert Thresholds

Virtual Pin	Parameter	Widget	Threshold
V0	Core temperature (°C)	Radial gauge (0 - 100 °C)	> 65 °C: overheat warning
V1	Ambient relative humidity (%)	Value display (0 - 100%)	> 85%: condensation alert
V2	Vibration alarm status	Status LED / banner	Logic HIGH: excessive shock
V3	Acoustic noise level (dB / raw)	Live gauge / stream chart	> 75 dB: arcing / noise alert

System Requirements

Hardware Requirements

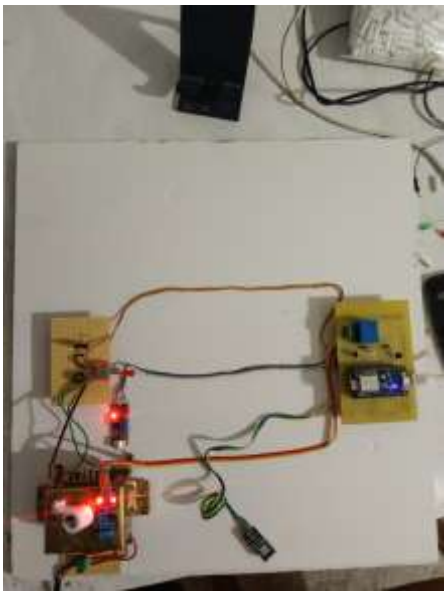
1. NodeMCU ESP8266
2. DHT11 temperature and humiditysensor
3. SW-420 vibration sensor module
4. Acoustic sound sensor module
5. 12-0-12 V, 2 A step-down transformer
6. Variable power rheostat (loading)

Software Requirements

1. Arduino IDE
2. Blynk IoT Cloud and mobile application**Experimental Setup**

Figure 3

Top View of the Hardware Setup





Results

The system was validated by subjecting the 12-0-12 V, 2 A transformer to progressive electrical loading with variable power rheostats, which simulated sustained overload conditions. The sensor data was tracked at 1-second intervals. When the winding temperature rose beyond 55 °C, the Blynk dashboard reflected the change within 1.2 seconds, and the automated event engine sent the push notifications with zero packet loss. Artificial mechanical vibrations and acoustic noise pulses produced immediate visual LED state changes on the mobile application, which confirmed the end-to-end responsiveness of the system.

Discussion

The main advantages of the system are the following:

1. **Autonomous continuous telemetry.** It removes the need for scheduled physical inspections and gives 24/7 visibility into the operating condition of the transformer.
2. **Predictive maintenance.** It identifies developing mechanical and thermal anomalies well before insulation failure occurs, which prevents costly outages.
3. **High economic feasibility.** It uses low-cost, open-source electronics (ESP8266) instead of very expensive legacy SCADA architectures.
4. **Instant mobile notification.** It sends immediate alarms to field engineers through smartphone notifications, which ensures rapid intervention.

The system also has two limitations. First, the standard 2.4 GHz IEEE 802.11 b/g/n link needs local Wi-Fi coverage or an
industrial cellular gateway in rural substations. Second, the DHT11 sensor is limited to a measurement range of 50 °C, so higher-grade thermocouple or RTD sensors (for example, PT100) are needed for high-temperature distribution substations.

The proposed system is well suited to electrical distribution utilities, industrial manufacturing substations, smart city microgrids, rural electrification networks, and educational high-voltage research laboratories.

Conclusion

This work realized a fully operational, responsive, and economically viable IoT-based transformer health monitoring system. By interfacing a 12-0-12 V, 2 A step-down transformer with a NodeMCU ESP8266 and a sensor suite consisting of a DHT11, an SW-420, and an acoustic sound module, the system acquired, processed, and broadcast real-time multi-parameter health data to the Blynk IoT Cloud. The platform bridges the gap between traditional manual inspection routines and modern predictive maintenance.

Future scope. The system can be extended in three directions. Non-invasive Hall-effect current transformers (CT) and potential transformers (PT) can be added to calculate the power factor, active power, and overcurrent conditions. Optical oil-level sensors and dielectric breakdown probes can be integrated for large oil-immersed
transformers. Solid-state relay modules can be added for automated protective relaying, so that the transformer is isolated from the
primary feeder during critical fault states.

References

Biren, P. S., et al. (2020). IoT based smart transformer health monitoring system using ESP8266. *International Journal of Electrical Engineering & Technology, 11*(4), 112–121.

Blynk Inc. (2024). *Blynk IoT platform architecture & virtual pin documentation*. Official Blynk Developer Docs.

Espressif Systems. (2021). *ESP8266EX technical reference manual* (Version 1.4). Espressif Documentation.

IEEE Power and Energy Society. (2019). *IEEE guide for the interpretation of gases generated in mineral oil-immersed transformers* (IEEE Standard C57.104-2019).

Sawhney, A. K. (2018). *A course in electrical and electronic measurements and instrumentation* (19th ed.). Dhanpat Rai & Co.