|| Volume 9 || Issue 12 || December 2025 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH
AND ENGINEERING TRENDS

A Review on Distribution Transformer Monitoring System Using IoT

Jaydip Shirsath[1], Saurabh Balerao[2], Chintamani Bonde[3], Prathamesh Waghmare[4], Shruti Gour[5]

Students Department of Electrical Engineering, Trinity College Of Engineering And Research, Pune-411048[1 2 3 4]

Ass prof, Department of Electrical Engineering, Trinity College Of Engineering And Research, Pune-411048[5]

Abstract: Power transformers are critical assets in electrical distribution networks. Their failure due to overloading, overheating, or oil theft leads to significant financial losses and power outages. Traditional manual monitoring is inefficient and cannot prevent catastrophic failures in real-time. This paper reviews the design and implementation of an Automatic Distribution Transformer Monitoring System using the Internet of Things (IoT). The system continuously monitors key parameters such as load current, volt- age, oil temperature, oil level, and humidity. It utilizes mi- crocontrollers and wireless communication protocols (Wi- Fi, GSM, LoRa, MQTT) to transmit data to cloud plat- forms. Recent advancements in Edge Computing and Dig- ital Twins are also explored to enhance predictive maintenance capabilities.

Keywords: *IoT, Transformer Health Monitoring, NodeMCU, LoRa, MQTT, Edge Computing, Predictive Maintenance, Digital Twins.*

---***---

I INTRODUCTION

Distribution transformers act as the heart of the power grid, stepping down high voltage to usable levels for consumers. However, they are prone to failure caused by un- expected overloading, voltage fluctuations, and poor maintenance [1]. In remote agricultural and semi-urban areas, these units are also vulnerable to oil theft and physical tampering.

Manual inspection of these assets is labor-intensive, error-prone, and often dangerous. To address this, recent advancements in the Internet of Things (IoT) have en- abled the development of low-cost, real-time monitoring solutions. By integrating sensors with wireless communication modules, utility companies can monitor transformer health remotely [2]. This paper explores various IoT-based architectures, ranging from GSM and Wi-Fi to advanced Edge AI implementations [5, 6].

II OBJECTIVE

The primary objective is to develop a smart monitoring system that can:

- Continuously sense Voltage, Current, Temperature, and Oil Level.
- Detect anomalies like overloading, overheating, and oil theft.
- Transmit real-time data to a cloud dashboard for re- mote visualization.
- Implement automatic load shedding or disconnection to prevent burnout.
- Send immediate alerts (SMS/Email) to maintenance personnel.

III LITERATURE REVIEW

The evolution of transformer monitoring systems has progressed from basic SMS alerts to complex cloud-based analytics. The following review is presented in chronological order to highlight technological advancements.

Ajitha and Kumar (2017) introduced LoRa (Long Range) technology for monitoring transformers in wide- area networks (up to 10km). Their system was unique in that it also monitored the status of the silica gel in the breather using a color sensor (TCS230). This allowed for the detection of moisture ingress, a major cause of insulation failure, validating LoRa as a viable protocol for rural deployment [3].

Roy and Roy (2018) proposed using the MQTT protocol instead of HTTP for data transmission. MQTT is lightweight and consumes less bandwidth and power, making it ideal for rural areas with poor connectivity. Their system utilized a Raspberry Pi gateway to collect data from multiple sensor nodes, emphasizing bandwidth efficiency [4].

Hasan et al. (2019) designed a ”Smart Transformer” system using NodeMCU (ESP8266). Their system not only monitored temperature and humidity but also im- plemented a priority-based load shedding mechanism. If the transformer overheated, the system automatically dis- connected low-priority loads (e.g., residential) while keep- ing high-priority loads (e.g., hospitals) active, thereby pre- venting burnout without total blackout [1].

Bethalsha et al. (2020) focused on a comprehen- sive health monitoring system that included vibration sen- sors to detect physical tampering or internal mechanical faults. They utilized the Adafruit IO platform for real- time graphing of voltage, current, and temperature data, demonstrating a cost-effective solution for detecting ”crit- ical points” before failure [2].

Perumal et al. (2022) developed a real-time health monitoring framework specifically utilizing the Node MCU ESP-12E and the Ubidots platform. Their experimen- tal setup integrated an ACS712 current sensor, a vibra- tion sensor (SW-420), and temperature sensors. Vali- dated in a laboratory environment, the system success- fully demonstrated the ability to detect abnormalities in current and temperature, automatically cutting the load to avoid power supply blackouts while visualizing data re- motely on a mobile dashboard [5].

Bajwa et al. (2025) conducted a systematic review of IoT-enabled condition monitoring, analyzing 84 peer- reviewed studies. They identified a paradigm shift toward Edge Computing to reduce latency and data congestion. Their findings highlight that while thermal and Dissolved Gas Analysis (DGA) remain dominant diagnostics, there is a growing trend toward using AI/ML (CNN, LSTM) and Digital Twins for predictive maintenance. However, they noted a significant gap in cybersecurity protocols, urging future designs to incorporate stronger encryption and intrusion detection systems [6].

|| Volume 9 || Issue 12 || December 2025 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH AND ENGINEERING TRENDS

IV RESEARCH GAPS AND FUTURE DIRECTIONS

The chronological review of the literature reveals a clear evolution of technology driven by the need to address specific limitations, moving from simple reporting to advanced predictive protection.

Chronological Research Gaps and Up- grades

Gap (Pre-2017): Limited Rural Coverage. Manual monitoring or short-range GSM/Wi-Fi systems were insufficient for remote assets.

Upgrade (2017): Introduction of LoRa technology

[3] to achieve long-range, low-power data collection for rural transformers.

Gap (2017): Inefficient Communication. LoRa telemetry was often tied to power-intensive protocols (like HTTP).

Upgrade (2018): Adoption of the lightweight MQTT protocol [4] to improve bandwidth efficiency and minimize power consumption for continuous data streaming.

Gap (2018): Reactive Monitoring. Systems could detect faults but not proactively prevent them by managing the load.

Upgrade (2019): Implementation of Priority- based Load Shedding [1] for autonomous, proactive fault mitigation when overheating occurred.

Gap (2019): Limited Scope of Sensing. Monitoring was focused on electrical and thermal parameters, neglecting mechanical integrity and physical tampering.

Upgrade (2020): Integration of Vibration Sensors [2] to detect internal faults and physical security breaches.

Gap (2022): Lack of Intelligence and Latency. Despite comprehensive sensing [5], systems still rely on the cloud for complex analysis, causing delays in safety-critical responses and failing to predict failure.

Current Research Gaps and Future Directions (Post-2025)

The current challenges necessitate a shift toward intelli- gent, self-sufficient, and secure monitoring systems:

Edge Computing: Integrate local data processing power to achieve near-zero-latency protection. This involves porting lightweight AI/ML models onto microcontrollers for on-site anomaly detection, re- moving the cloud dependency for critical trip decisions [6].

Predictive Maintenance and Digital Twins: Move beyond monitoring to forecasting. Develop Digital Twins to simulate the transformer's behav- ior and degradation, combined with **CNN/LSTM** deep learning models to predict the exact time re- maining before a specific failure mode occurs [6].

Cybersecurity Enhancement: Address the severe risk posed by connected devices. Future designs must incorporate rigorous encryption, authentication protocols, and embedded intrusion detection systems directly within the IoT gateway hardware [6].

V METHODOLOGY

5.1 Sensing Unit

- Voltage & Current: A voltage sensor (ZMPT101B or PT) and Current Sensor (ACS712 or CT) measure the electrical load.
- Temperature: DS18B20 or LM35 sensors measure the oil and winding temperature.
- Oil Level: An Ultrasonic Sensor (HC-SR04) mounted on the conservator tank detects low oil levels caused by leakage or theft.
- Vibration: SW-420 sensors are used to detect me- chanical looseness or tampering attempts [5].

5.2 Processing and Communication

The central processing unit is a microcontroller (Arduino or NodeMCU). It processes raw sensor data and compares it against safety thresholds.

- IoT Gateway: The processed data is sent via Wi-Fi (ESP8266) or GSM (SIM800L) to a cloud platform.
- Protocols: HTTP is used for simplicity (ThingS- peak/Ubidots), while MQTT is used for low-latency applications [4].

5.3 Protection Mechanism

A Relay Module is interfaced with the microcontroller. If the current exceeds the rated limit or temperature rises critically, the microcontroller triggers the relay to trip the circuit breaker, isolating the transformer from the load to prevent explosion [1].

VI BLOCK DIAGRAM

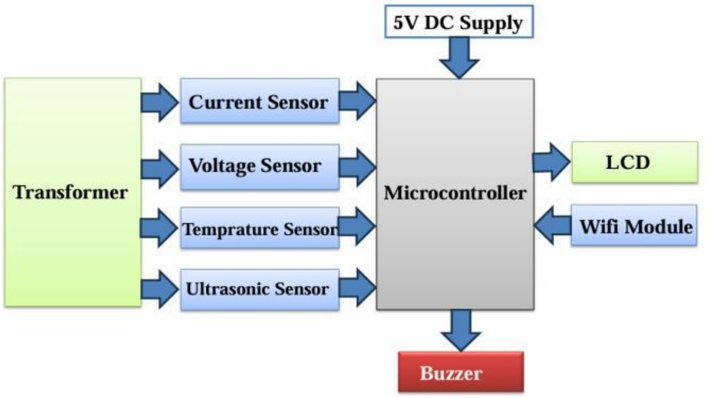

Figure 1: System Architecture of IoT Based Transformer Monitoring

The system architecture for the Transformer Monitor- ing System is organized into three essential blocks: Data Acquisition, Processing/Control, and Out- put/Communication. The Data Acquisition block is responsible for continuously sensing critical parameters from the transformer, utilizing a Current Sensor to detect overloads, a Voltage Sensor to check for abnormalities, a Temperature Sensor to monitor against overheating, and an Ultrasonic Sensor to measure the insulating oil level, all powered by a 5V DC Supply. The Processing/Control block is centered around the Microcontroller, which re- ceives all sensor inputs, processes the data, and compares the measured values against pre-set safety thresholds before executing the necessary control logic. Finally, the Output/Communication block provides both local and remote indication of the transformer's health via an LCD for on-site display, a Buzzer for immediate audible alarms upon fault detection, and a WiFi Module to enable Internet of Things (IoT) capability for remote data transmission to a cloud server and instant alert notifications to maintenance staff.

VII RESULTS AND CONCLUSION

The review of existing prototypes confirms that IoT-based monitoring significantly reduces maintenance costs and failure rates.

- Systems using LoRa and NB-IoT are best suited for rural wide-area coverage due to low power consump- tion [3, 6].
- Platforms like Ubidots and ThingSpeak provide ef- fective visualization for NodeMCU-based urban de- ployments [5].
- Future Scope: As highlighted by recent studies, fu- ture systems must integrate Edge Computing to handle data locally and employ Digital Twins to simulate and predict faults before they occur, while strictly addressing cybersecurity vulnerabilities [6].

In conclusion, replacing manual inspection with an auto- matic IoT system ensures reliable power delivery, protects expensive assets, and enhances safety for utility workers.

REFERENCES

[1] W. K. A. Hasan, Y. Ran, A. Alraddad, M. A. Alkelsh,

A. Ashour and R. A. M. Ajele, “Design and Imple- mentation Smart Transformer based on IoT,” 2019 IEEE International Conference on Cyber Security and Protection of Digital Services (Cyber Security), 2019.

[2] C. Bethalsha, A. Jennifer, S. Karthik, and Ms. Sreejavijay, “Real-Time Transformer Health Mon-

itoring using IOT,” International Journal for Re- search in Applied Science & Engineering Technology (IJRASET), vol. 8, no. IX, pp. 521-526, Sep. 2020.

[3] A. Ajitha and T. A. Kumar, “Development of IOT based solution for monitoring and controlling of dis- tribution transformers,” 2017 International Confer- ence on Intelligent Computing, Instrumentation and Control Technologies (ICICICT), Kerala, 2017, pp. 1457-1461.

[4] T. K. Roy and T. K. Roy, “Implementation of IoT: Smart Maintenance for Distribution Transformer us- ing MQTT,” 2018 International Conference on Com- puter, Communication, Chemical, Material and Elec- tronic Engineering (IC4ME2), Rajshahi, 2018.

[5] B. Perumal, Y. GopiShankar, P. Nagaraj, A. SaiKu- mar, R. Venkatesh, A. Koushik, V. Muneeswaran, and B. Anil, “Real Time Transformer Health Mon- itoring System,” 2022 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, Jan. 2022.

[6] A. Bajwa, A. A. R. Tonoy, and M. A. M. Khan, “IoT-enabled condition monitoring in power transformers: A Proposed Model,” Review of Applied Science and Technology, vol. 04, no. 02, pp. 118-144, 2025. DOI: 10.63125/3me7hy81.