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Transformer Health Monitoring System Using Iot Based

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Abstract - Power transformers must work well and be reliable to keep the flow of electricity stable and uninterrupted. Standard periodic maintenance often does not find problems in their early stages, which can lead to insulation breakdown, oil breakdown, thermal stress, overloading, and unexpected outages. This paper proposes an IoT-based Transformer Health Monitoring System to address these limitations. The system can continuously and in real time monitor important operating parameters. The system uses sensors for temperature, oil level, load current, and input voltage that are connected to a microcontroller. The microcontroller processes the data and sends it to a cloud-based monitoring platform. The data analyzed by the IOT platform ensures early fault detection for maintenance planning. To support predictive maintenance, the suggested framework provides threshold-based alert notifications, historical logging, real-time data visualization, and remote access. The system creates automated alerts to stop overheating, insulation failure, and possible transformer failures when anomalous conditions are identified. This system monitors multiple transformers at different distributed substation. This IoT- enabled strategy prolongs transformer lifespan, lowers maintenance costs, minimizes downtime, and improves operational safety. The solution offers a scalable architecture for intelligent monitoring across substations and distribution networks and is in line with efforts to modernize smart grids.
Index Terms - Transformer health monitoring, IOT, real-time monitoring, predictive maintenance, sensor integration, cloud computing, microcontroller, thermal analysis, Self-healing transformer.

INTRODUCTION

Although power transformers are essential to transmission and distribution networks, they are constantly subjected to environmental, thermal, and electrical stresses. If not identified early, problems like aging insulation, overheating, moisture, oil reduction, and voltage fluctuations can result in serious faults, outages, and costly repairs. Conventional manual inspections are time-consuming, infrequent, and unable to detect abrupt or early-stage failures.

Transformer parameters like temperature, voltage, current, and oil level can now be continuously and instantly monitored thanks to IoT technology. IOT-based systems offer real-time alerts, long-term data logs, and remote access via cloud platforms by combining sensors, microcontrollers, and wireless communication. Predictive maintenance is supported, accuracy is increased, and manual labour is decreased.

Sensors, an ATmega328P controller, protection relays, and an ESP8266 module for wireless data transfer are all used in the proposed Transformer Health Monitoring System. It sends data to cloud services like Thing Speak for remote monitoring and trend analysis, shows readings locally, and initiates cooling or shutdown in unusual circumstances. This system provides a scalable, contemporary solution for Industry 4.0 and smart grid applications while also improving safety and reducing downtime.

LITERATURE REVIEW

Several researchers have used sensing, wireless communication, and Internet of Things-based technologies to help develop automated transformer monitoring systems. Shelke (2025) highlighted the need for automation in distribution networks by proposing a real-time Transformer Health Monitoring System that uses temperature, oil level, and load sensors to get around the drawbacks of manual inspection. Erramshetti et al. (2024) created a GSM-enabled monitoring strategy that can send SMS alerts in the event of abnormal operating conditions, but their system is notification-focused and lacks immediate protective measures.

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IOT-driven approaches have gained attention in recent years. An IOT-based transformer monitoring architecture that uploads operational parameters to a cloud server for predictive analysis was introduced by Rajashekar et al. in 2023. In a similar vein, Zhang et al. (2020) presented IoT-based algorithms for cloud analytics-based real-time fault diagnosis. Although these systems increase prediction accuracy and accessibility, they primarily concentrate on data visualization rather than active on- site fault mitigation.
GSM-based designs by Babu et al. (2022) and Mishra et al. (2021) focus on remote monitoring with microcontrollers and multi-sensor integration to detect overloading and overheating. Selvaraj et al. (2020) highlighted the role of multi-sensor fusion, which tracks oil temperature, load current, and humidity, to improve diagnostic accuracy. Diagnostic methods like acoustic emission for internal fault detection (Ma et al., 2022) and dissolved gas analysis for insulation deterioration (Bustamante et al., 2019) offer high accuracy. However, they are costly and not ideal for low-cost distribution transformers.
Sharma and Singh (2025) presented a monitoring setup built on LoRa WAN for long-range, low-power data collection. However, it does not include physical safety measures. Many current systems stop at tracking or sending alerts, and they offer little for handling faults as they happen. The new approach tackles this gap by pairing IoT sensors with an automatic cooling fan, so you get real-time readings and an active layer of protection at a low cost.

METHODOLOGY

A structured methodology comprising parameter sensing, data acquisition, processing, wireless transmission, cloud integration, and automated fault response is used to develop the proposed Transformer Health Monitoring System. The goal is to enable prompt intervention during abnormal conditions and to guarantee ongoing monitoring of transformer health parameters.

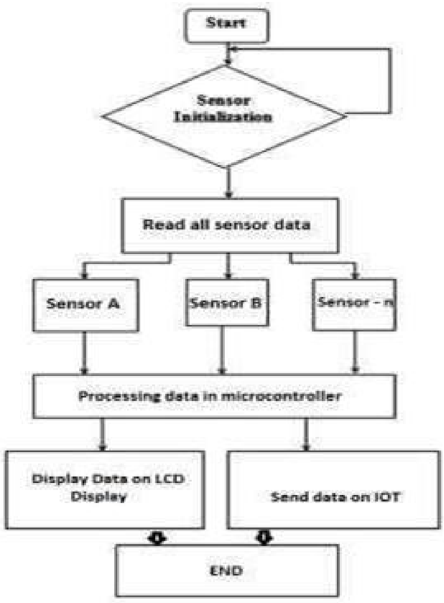

Fig. 1. System Workflow Diagram

Sensing and Data Acquisition: Dedicated sensors built into the transformer system are used to measure critical electrical and thermal parameters, including temperature, oil level, load current, and input voltage and further processed. To identify overheating, the temperature sensor logs changes in temperature. A decrease in insulating oil is detected by the oil level sensor. The current sensor detects overload situations and measures load current. To detect undervoltage or overvoltage issues, the voltage sensor keeps an eye on the input voltage. The ATmega328P microcontroller receives the analog and digital outputs produced by these sensors for additional processing.

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Local Decision Making and Data Processing:
The microcontroller carries out: Signal filtering and calibration includes mapping sensor outputs, converting to engineering units, and removing noise.
Threshold Comparison: Pre-established safe limits are compared to each parameter.
Protective Actions: The controller initiates the following when it detects abnormal values: To isolate the transformer, turn off the relay. Cooling fan for automated thermal defense. For quick local alerts, use a buzzer alarm.
Using a 16x2 LCD module, the system provides local display of real-time values, allowing on-site personnel to view transformer status in real time.
Cloud Integration and Wireless Communication
Depending on deployment requirements, communication modules like ESP8266 Wi-Fi, GSM, or LoRa are used to send processed data wirelessly to a cloud platform. The cloud server uses graphical dashboards to store, process, and display data. It provides support for:
Monitoring in real time, Logging of historical data, Analysis of trends and Planning for predictive maintenance.
Additionally, when parameters surpass safe limits, the cloud system automatically generates alerts (SMS, email, or mobile notifications), allowing utility operators to monitor the system remotely.

Automated Protection Logic and Fault Detection: A multi- fault protection mechanism is implemented by the system: Overvoltage or undervoltage: buzzer ON, relay OFF Overload current: buzzer ON, relay OFF
High temperature → fan ON, buzzer ON, relay OFF
Low oil level → buzzer ON, relay OFF
To ensure safe transformer operation, the microcontroller continuously assesses all sensor values during each cycle and makes a final protection decision.

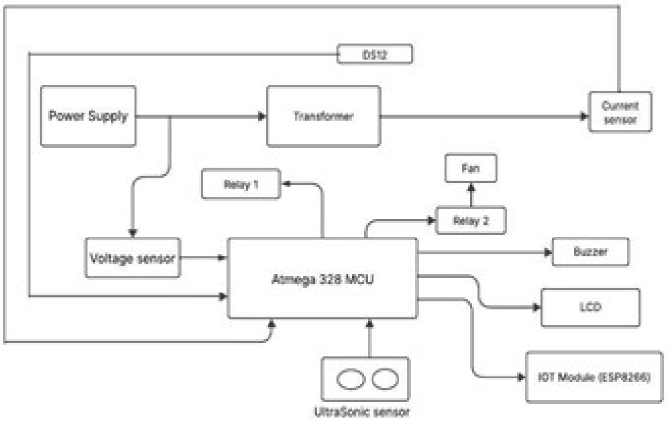

Fig. 2. System Architecture

Scalable and Modular Architecture
Because the design is modular, it is possible to integrate more sensors, sophisticated analytics, or improved communication without changing the hardware core. In distributed substations, this improves scalability for deployment across several transformers.

RESULTS AND DISCUSSION
To assess the Transformer Health Monitoring System's efficacy in real-time distribution transformer monitoring and protection, it was developed, put into use, and tested under a range of simulated operating conditions. The Arduino Uno microcontroller is integrated with voltage, current, temperature, and oil level sensors in the prototype to enable fault detection, alert generation, and automated protective actions. Results from experiments show that the suggested system operates consistently and reacts quickly to unusual operating circumstances.

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Monitoring Parameters in Real Time

The system allows on-site staff to see changes under various load and fault scenarios by continuously measuring transformer parameters and displaying live values on a 16x2 LCD. In order to facilitate remote monitoring, data logging, and analysis, the ESP8266 Wi-Fi module simultaneously sends sensor data to the cloud platform. By offering constant visibility of transformer health, this dual-mode monitoring supports predictive maintenance and does away with the need for manual inspection.

Input for Voltage Regulation and Fault Response

The ZMPT103B voltage sensor was used to measure RMS voltage, which was then compared to predetermined threshold limits. The transformer ran continuously under typical voltage conditions. In order to avoid dielectric stress and possible insulation breakdown during over-voltage conditions, the relay was activated to disconnect the load. A fault alert was produced in under-voltage situations to prevent overheating, core saturation, and inefficient operation. These findings attest to the system's strict maintenance of transformer operation within rated voltage limits, which improves operational safety and prolongs service life which in turn helps transformer to work better.

Overload Protection and Load Current Analysis The load current was measured using the ZMCT101B current sensor. Stable current readings and continuous operation were noted under nominal load conditions. The system immediately disconnected the transformer output through relay activation when the load exceeded the programmed threshold. Both visual and audio alerts were turned on at the same time to notify maintenance staff. This mechanism successfully stops transformer windings from overheating due to extended overload conditions.

Monitoring Oil Levels

An ultrasonic sensor placed vertically above an oil-filled container that served as a model for a transformer conservator tank was used to monitor the oil level. The system continued to function normally when the oil level was stable. The sensor detected an increased distance when oil depletion was simulated, which caused the LCD to display a fault indication and the buzzer to sound a warning. Early detection of oil loss greatly lowers the risk of insulation failure and internal arcing because transformer oil serves as a cooling and insulating medium.

Cooling Control Based on Temperature

A temperature sensor that was positioned close to a heat simulation element was used to track temperature changes. No control action was started at typical operating temperatures. The cooling fan was automatically turned on when the temperature rose above the set threshold.

Display Feedback and Alert Mechanism

To guarantee prompt fault awareness, the system uses a dual- mode alert mechanism. While audible alerts are produced using a buzzer during critical fault conditions, visual alerts are shown on the LCD as parameter values and fault messages. In overvoltage and overload situations, protective control measures like relay cut-off are carried out, while automatic fan activation manages temperature rise. Maintenance teams are guaranteed to receive timely and useful information thanks to this integrated alert strategy.

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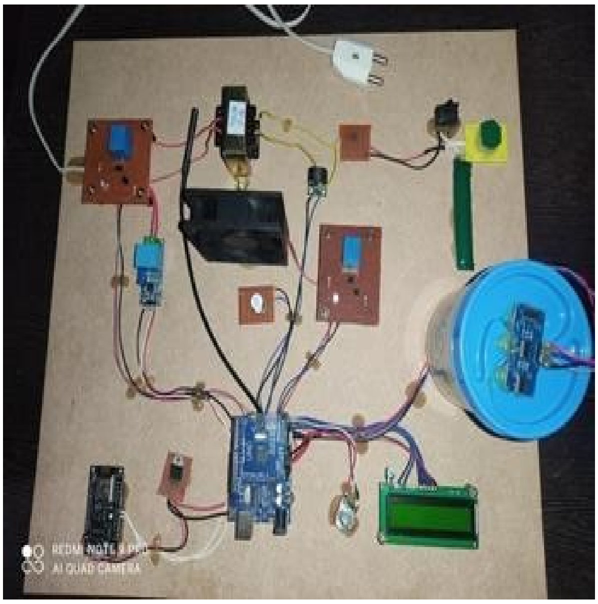

Fig. 3. Transformer Health Monitoring System

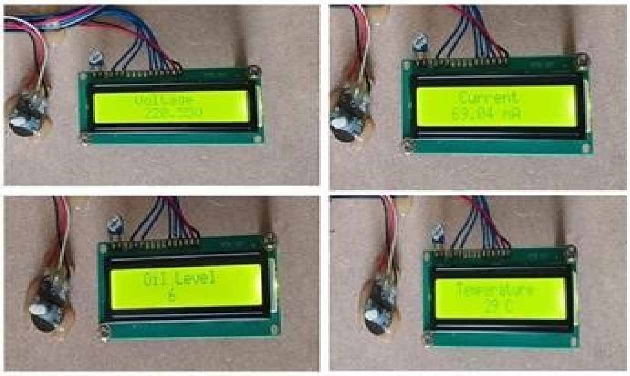

Fig. 4. LED Display Output

Remote Monitoring Enabled by IOT

Every sensor reading was periodically uploaded to the cloud using the Thing Speak IoT platform and the ESP8266 Wi-Fi module. Real-time graphical plots of voltage, current, temperature, and oil level are shown on the cloud dashboard. Storage of historical data allows.

Assessment of System Performance

By examining sensor accuracy, response time, and dependability under various operating conditions, the overall performance of the system was assessed. Overvoltage, undervoltage, overload, temperature rise, and low oil level conditions were all successfully detected by the system, which then took the necessary preventative or remedial action. The system's suitability for ongoing remote monitoring was confirmed by the consistent and dependable cloud data transmission.

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Fig. 5. Obtained Graph

The experimental findings confirm that the suggested Transformer Health Monitoring System offers a practical, affordable, and automated way to monitor transformer conditions in real time. The system provides quicker fault detection, less maintenance work, and increased operational reliability when compared to traditional manual inspection techniques. By avoiding needless power outages, the incorporation of self-healing cooling action during temperature rise further improves system robustness. The IoT-enabled architecture makes the system suitable for contemporary smart grid applications by enabling scalable deployment and supporting predictive maintenance strategies.

CONCLUSION AND FUTURE SCOPE

Conclusion

The following work elaborates on a lightweight, IoT-driven Transformer Health Monitoring System to effect unobtrusive surveillance over key transformer health signals-AC voltage, AC current, body temperature, and oil level. These parameters are important determinants for ascertaining how well the transformer is working and how well and reliably it is likely to perform. By combining easily available sensors with an Arduino-based controller and IoT communication modules, the setup collects precise data and sends it over to cloud platforms in real time to enable remote oversight without resorting to on- site checks.

Tests have shown that the system will reliably flag abnormal conditions such as over- and under-voltage, overloading, excessive temperatures, and low oil levels. Threshold alerts trigger quick notifications and protective actions that support preventive maintenance before failures become major. IoT dashboards provide intuitive views of live data, past trends, and event histories to bolster condition-based and predictive maintenance approaches.

In other words, the presented method demonstrates that an inexpensive, scalable, and energy-efficient transformer monitoring system can be realized using commercially available sensors and microcontroller hardware. This design aims at enhancing operational safety while reducing hands-on visual inspections, unexpected outages, and increasing reliability in distribution networks. This represents a very good option for modern distribution systems and smart grids.

Future Scope

There is a lot of room for future development and widespread implementation of the suggested Transformer Health Monitoring System. The combination of machine learning and artificial intelligence methods is one significant area for development. Advanced predictive maintenance is made possible by the development of predictive models that forecast faults like insulation degradation, oil aging, and abnormal thermal behavior through the analysis of historical sensor data.

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By adding more sensing units like dissolved gas analysis sensors, partial discharge sensors, vibration sensors, and humidity sensors, the system can also be expanded to support three-phase transformers and substation-level monitoring. A more thorough evaluation of transformer condition and early fault detection capabilities would be possible with these additions.

Future work might involve creating a specialized mobile application with an intuitive user interface that offers real-time visualization, alerts, health indices, and maintenance suggestions. By enabling local data processing, lowering communication latency, and boosting dependability during network outages, the use of edge computing platforms like the Raspberry Pi or ESP32 can further improve system performance.

Additionally, to guarantee data integrity, transparency, and tamper-proof storage of transformer health records, secure data management strategies like blockchain can be investigated. By incorporating solar-powered modules, the system can be made energy independent for deployment in remote and rural areas. Additionally, centralized monitoring and coordinated control of numerous transformers across large geographic regions would be made possible by integration with current SCADA and smart grid infrastructures. The suggested system can be developed into a robust, scalable, and industry-ready transformer health monitoring solution with the use of industrial-grade hardware, weatherproof enclosures, and long-range communication technologies like LoRa WAN.

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