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Studies on Health Parameters and Real-Time Safeguarding of Distributed Transformers Using the Internet of Things

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Abstract
The reliability and efficiency of transformers are crucial for the stable operation of power distribution systems. This project focuses on the Condition Monitoring of Transformers Based on IoT Technology, enabling real-time monitoring of critical parameters such as temperature, oil level, voltage. By integrating sensors, Arduino Uno, and the NodeMCU ESP8266 WiFi module, the system continuously collects data and transmits it to a cloud-based platform for remote monitoring and analysis. The implementation of IoT technology enhances predictive maintenance, reducing unexpected failures and minimizing downtime. Additionally, data-driven insights help optimize transformer performance, extend its lifespan, and reduce maintenance costs. This approach ensures a more efficient, reliable, and cost-effective power distribution network.
Keywords: *Condition Monitoring; Arduino uno; IoT-based Monitoring; Real-time Data Collection; Failure Prevention; Transformer Performance Optimization.*

1. Introduction
Transformers play a crucial role in electrical power distribution, ensuring a stable and efficient power supply. However, failures in transformers due to overheating, voltage fluctuations, oil level depletion, or excessive current can lead to severe power outages and costly repairs. Traditional transformer monitoring methods involve manual inspections, which are time-consuming, labor-intensive, and often inefficient in detecting early faults. To overcome these challenges, an IoT-based Transformer Monitoring System is developed to provide real-time monitoring, fault detection, and predictive maintenance. This system integrates Arduino, NodeMCU (ESP8266), GSM (SIM800L), and various sensors to measure key parameters such as temperature, voltage, current, oil level, and humidity. The collected data is transmitted wirelessly to a cloud platform or a web server via Wi-Fi or GSM technology. Users can remotely access this data through a web dashboard or a mobile application, allowing them to monitor transformer health in real-time. If any parameter exceeds the predefined threshold, the system generates instant alerts via SMS or email, enabling quick preventive actions. One of the major advantages of this system is its ability to reduce maintenance costs and prevent unexpected failures by enabling predictive maintenance. By continuously analyzing transformer performance, power utilities can schedule maintenance activities efficiently, thus minimizing downtime and extending transformer lifespan. Additionally, the IoT-based monitoring system helps in improving energy efficiency and reducing the risk of transformer explosions due to overheating or overload conditions. The integration of IoT technology in transformer monitoring enhances reliability, automation, and efficiency in power distribution networks. This system is particularly beneficial in remote areas where regular manual inspections are difficult. With the increasing demand for smart grids and automation in power management, IoT-based transformer monitoring systems are becoming an essential tool

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for ensuring an uninterrupted and efficient power supply. [1]

2. Block Diagram

The given block diagram represents the IoT-based transformer condition monitoring system. It includes sensors such as voltage, current, temperature, and ultrasonic sensors to monitor essential parameters. These sensors are connected to an Arduino Uno, which processes the data. A power supply provides the necessary voltage. The system displays real-time values on an LCD. The WiFi module transmits data to a server for remote monitoring. Although a GSM module is shown in the diagram, it is not required for the user's project. This setup helps in predictive maintenance by identifying faults before failures occur, enhancing transformer reliability. (Figure 1)

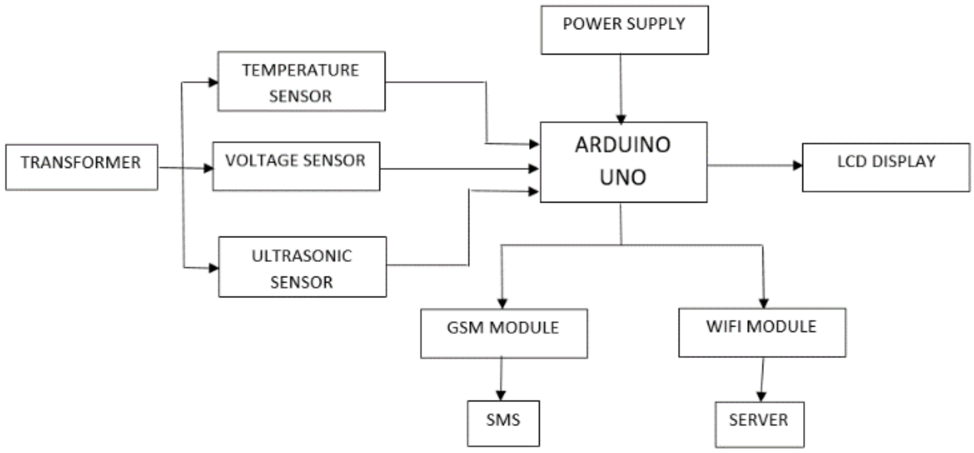

Figure 1 Block Diagram of Transformer Monitoring System

2.1.Hardware Setup

The hardware setup includes an Arduino Uno R3 and NodeMCU ESP8266 for control and wireless communication. Sensors LM35 temperature sensor, ZMPT101B voltage sensor, and HC-SR04 ultrasonic sensor to monitor key transformer parameters. Data is displayed on an LCD and sent to the Blynk cloud via Wi-Fi. (Figure 1) [2]

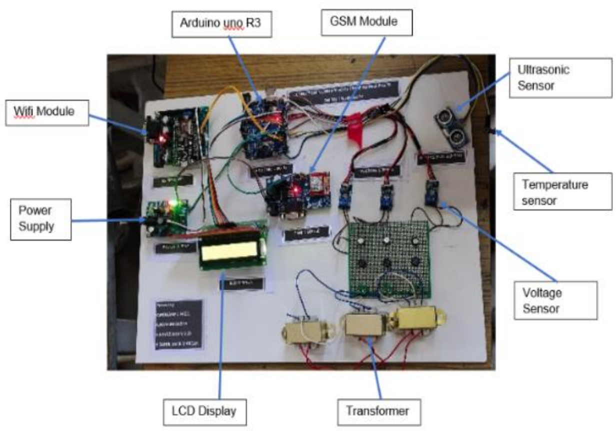

Figure 1 Hardware Setup

2.2.Transformer

The transformer used in this system operates at a primary voltage of 415V, stepped down to 280V. It is the core electrical component, and its essential parameters voltage, current, temperature, and oil level are continuously monitored. Monitoring these parameters helps in detecting faults early and preventing unexpected failures. Overheating, oil depletion, or excessive current flow can lead to transformer damage. By integrating IoT-based monitoring, real-time data can be collected and analyzed for predictive maintenance. This ensures efficient power distribution and enhances the lifespan of the transformer while reducing operational costs and downtime. (Figure 2)

Figure 2 Transformer

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2.3.Voltage Sensor (ZMPT101B)

The ZMPT101B voltage sensor is used to measure the transformer's voltage accurately. It provides electrical isolation, ensuring safe and reliable voltage measurement without direct contact with high-voltage lines. The sensor outputs an analog signal proportional to the measured voltage, which is then processed by the Arduino Uno. Accurate voltage monitoring helps in identifying fluctuations, overvoltage, or undervoltage conditions that may affect transformer performance. This sensor is widely used in IoT-based applications for real-time voltage monitoring, making it an essential component for ensuring transformer safety and efficiency. (Figure 3)

Figure 3 Voltage Sensor ZMPT101B

2.4.Temperature Sensor (LM35)

The LM35 temperature sensor is used to monitor the temperature of the transformer’s oil and windings. It provides an accurate analog voltage output directly proportional to the temperature in degrees Celsius. Overheating can lead to insulation failure and transformer breakdown, making temperature monitoring critical. The sensor is interfaced with the Arduino to continuously track temperature variations and trigger alerts if the set threshold is exceeded. This helps in preventing thermal runaway conditions, improving transformer efficiency, and extending its operational life. The LM35 is preferred for its high accuracy and ease of integration in IoT-based monitoring systems. (Figure 4)

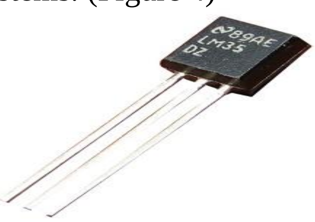

Figure 4 Temperature Sensor LM35

2.5.Ultrasonic Sensor (HC-SR04)

The HC-SR04 ultrasonic sensor is used to measure the transformer’s oil level. It works by emitting ultrasonic waves and calculating the time taken for the waves to reflect back from the oil surface. The Arduino processes this data to determine the oil level. Maintaining adequate oil levels is essential for cooling and insulation in transformers. A low oil level can lead to overheating and electrical faults. By integrating this sensor, real-time oil level monitoring is possible, ensuring timely refilling and preventing transformer failure due to oil depletion. (Figure 5)

Figure 5 Ultrasonic Sensor HC-SR04

2.6.Arduino Uno R3

Arduino Uno R3 serves as the central processing unit of the transformer monitoring system. It collects data from all sensors, processes the information, and controls communication modules. The microcontroller (ATmega328P) allows real-time data acquisition and decision-making. It sends processed sensor readings to the LCD display for local monitoring and transmits critical alerts via the GSM and WiFi modules. The Arduino is chosen for its ease of programming, versatility, and compatibility with multiple sensors, making it an ideal platform for IoT-based transformer condition monitoring systems. (Figure 6) [3]

Figure 6 Arduino Uno R3

2.7.WiFi Module (NodeMCU ESP8266)

The NodeMCU ESP8266 WiFi module is responsible for transmitting real-time sensor data to an online server or cloud platform. It enables remote monitoring of transformer parameters via a web dashboard or mobile application. The module connects to a WiFi network, allowing authorized users to access and analyze transformer health data from any location. This helps in predictive maintenance and early fault detection, reducing manual inspection efforts. The ESP8266 is widely used in IoT applications due to its low power consumption, cost-effectiveness, and ease of integration with microcontrollers like Arduino. (Figure 7)

Figure 7 ESP8266 WIFI Module

2.8.GSM Module (SIM800L)

The SIM800L GSM module is used for sending SMS alerts in case of abnormal transformer conditions. When the Arduino detects a fault such as high temperature, overvoltage, or low oil level, it triggers the GSM module to send an SMS notification to maintenance personnel. This enables real-time fault detection and quick response, reducing downtime and preventing damage. The SIM800L operates on a SIM card and communicates over mobile networks, ensuring remote access to critical alerts even in areas with no internet connectivity. This feature enhances the reliability of transformer monitoring systems. (Figure 8) [4]

Figure 8 GSM Module (SIM800L)

2.9.LCD Display

An LCD display is included in the system to provide real-time readings of transformer parameters. The display shows essential data such as voltage, current, temperature, and oil level, enabling on-site personnel to monitor transformer health without requiring internet connectivity. The LCD is directly interfaced with the Arduino, which continuously updates the display with live sensor readings. This local monitoring capability ensures quick identification of issues, improving maintenance efficiency and response time. The LCD used in the project is typically a 16x2 display, providing a clear and readable interface for essential transformer diagnostics. (Figure 9)

Figure 9 LCD Display

2.10. Power Supply

A stable power supply is crucial for the proper operation of all components in the transformer monitoring system. The system requires a regulated 5V or 12V DC power supply to operate sensors, the Arduino, and communication modules. Voltage regulators ensure that each component receives the required voltage without fluctuations, preventing potential malfunctions. A reliable power source enhances system stability, making sure that real-time monitoring and data transmission continue uninterrupted. The power supply may include backup options like batteries or capacitors to ensure continued operation during power failures.

2.11. Transformer Specifications

This is an 750 kVA, 11kV/415V three-phase distribution transformer. It uses copper windings and ONAN (Oil Natural Air Natural) cooling for efficient thermal management. The high voltage side is delta-connected and the low voltage side is star-connected, operating at 50 Hz frequency. It has an insulation level of 28 kV/3 kV and a total weight of 2260 kg including 520 litres of oil.

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3. Results

This study presents an IoT-based monitoring system for distribution transformers, focusing on oil level, voltage, and temperature parameters. The system employs an ultrasonic sensor for oil level detection, a voltage sensor for voltage measurement, and an LM35 sensor for temperature monitoring. Data is transmitted via a WiFi module to a cloud platform for real-time analysis and remote monitoring. This approach enhances transformer reliability by enabling predictive maintenance and fault prevention. [5]

3.1.Measurement of Voltage

Figure 10 **Measurement of Voltage**

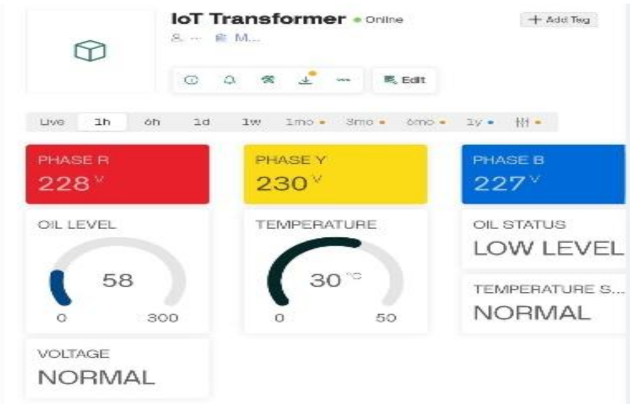

Figure 11 **Normal Condition in All Phases**

In the initial testing phase under normal operating conditions, the voltage levels of all three phases—R, Y, and B—were monitored. Each phase consistently registered a voltage in the range of 226V to 234V, indicating a healthy and balanced three-phase supply This graph illustrates the phase voltage (in volts) of R, Y, and B phases from 12:00 pm to 2:00 pm. The B phase generally maintains the highest voltage among the three. The R phase shows noticeable fluctuations, especially a drop at 1:00 pm. The Y phase remains relatively stable but dips slightly at 2:00 pm. To evaluate the system's fault detection capability, the R phase was removed during testing. The monitoring system accurately detected a voltage drop to 0V in the R phase, while the Y and B phases continued to display stable voltages of approximately 230V, confirming normal operation on those lines. (Figure 10,11,12)

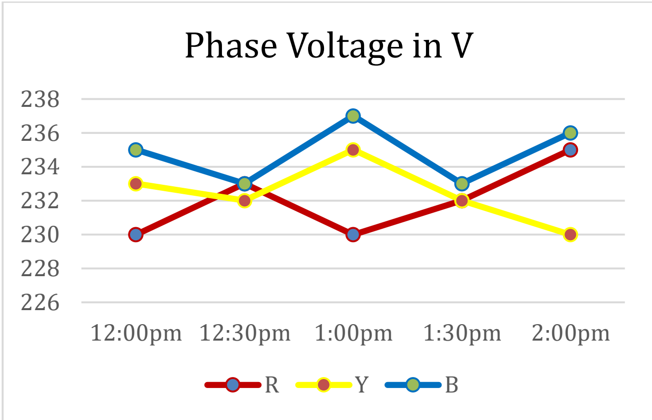

Figure 12 **Variation in Voltage with Respect to Time**

To simulate fault conditions, the R and Y phases were disconnected. As a result, the monitoring system accurately detected a drop to 0V in both the R and Y phases, while the B phase continued to display a stable voltage of approximately 230V. This clearly demonstrates the system's ability to effectively detect phase loss and abnormal operating conditions in real time. (Figure 13) [6]

Figure 13 **Open Circuit Fault in R-Phase**

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Figure 14 Open Circuit Fault in R and Y Phase

3.2.Measurement of Oil Level

The transformer oil level was monitored using an ultrasonic sensor. The system was calibrated to trigger a low oil level alert when the distance exceeded 8cm. During normal conditions, the oil level remained below 8 cm with no alert. When the oil level reduced and distance exceeded 8 cm, the system generated a low oil level warning. [7]

Figure 15 Normal Set Value

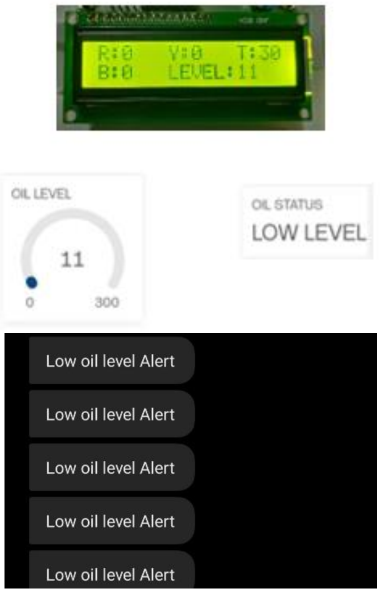

Figure 16 Low Oil Level Indication and SMS Alert

3.3.Measurement of Temperature

The radiator temperature around the transformer was monitored using an LM35 sensor. A high temperature alert was set to trigger when the ambient temperature exceeded 38°C.Under normal conditions, the ambient temperature stayed below 38°C, with no alert. When the ambient temperature rose above 38°C, the system generated a high temperature warning. [8]

Figure 17 Measurement of Radiator Temperature in 750KVA

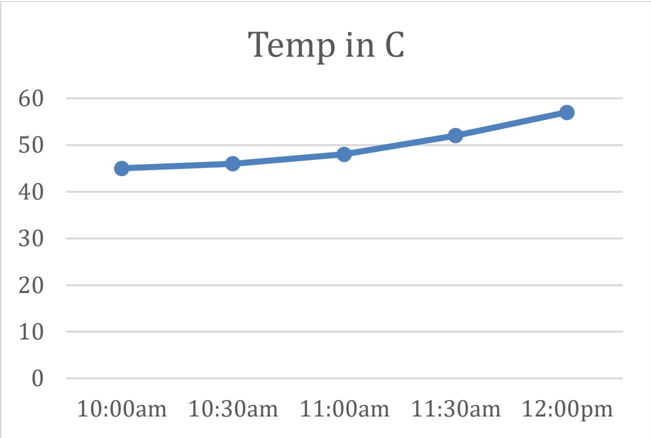

Figure 18 Temperature in Time Graph

This line graph shows the temperature variation (in °C) from 10:00 am to 12:00 pm. The temperature gradually increases over time, starting from around 46°C. A noticeable rise occurs between 11:30 am and 12:00 pm, reaching nearly 58°C. This indicates a steady heating trend, possibly due to continuous equipment operation. [9]

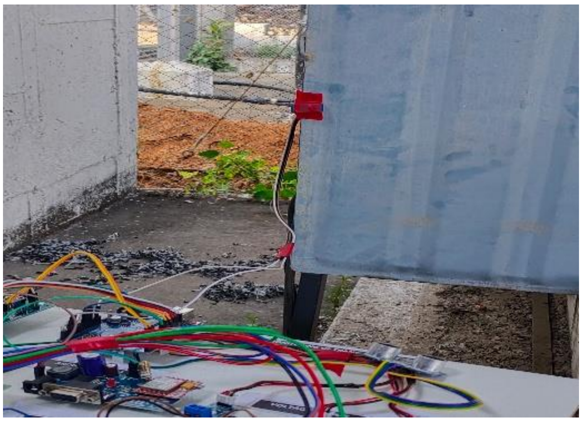

Figure 19 Radiator in Temperature Monitoring

Conclusion

This study presents an IoT-based system for real-time transformer condition monitoring, focusing on temperature, oil level, voltage. Using sensors and a WiFi module, the system continuously collects data and transmits it to the cloud for analysis. This enables early fault detection, preventing potential failures and enhancing operational reliability. The proposed solution is cost-effective, efficient, and scalable, making it suitable for power grids and industrial applications. By reducing unexpected outages and optimizing maintenance, the system improves transformer lifespan and performance. Overall, this IoT-driven approach enhances Transformer reliability while minimizing maintenance costs and downtime. [10]

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