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Transformer Health Monitoring System

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Abstract— **Transformers, pivotal components in power transmission systems for maintaining voltage regulation, demand unwavering reliability. Yet, their widespread deployment poses challenges in routine monitoring, particularly when resources are limited. This challenge can lead to unexpected power disruptions stemming from transformer failures. In response, the Transformer Health Monitoring System has been developed to provide real-time monitoring of critical transformer parameters, such as voltage, current, and temperature, leveraging the ESP Now protocol for wireless data transmission. This continuous monitoring serves as an early warning system, enabling the detection of potential faults before they escalate into serious failures. The system excels in identifying common transformer faults, including overloads, over/under voltage incidents, temperature irregularities, and more. This proactive approach not only enhances the reliability and longevity of transformers but also facilitates timely interventions and maintenance, ensuring the seamless operation of power distribution systems.**

Index Terms— **Transformers, ESP Now Protocol.**

1. Introduction

Electricity is fundamental to modern society, powering our homes, businesses, and industries. At the core of electricity distribution networks are transformers, crucial for maintaining voltage levels and ensuring smooth power flow. However, transformers face challenges such as increasing demand, aging infrastructure, and environmental factors, which can lead to disruptions in power supply. To address these challenges, effective monitoring of transformer health is essential. This paper presents the development and implementation of a Transformer Health Monitoring System (THMS) designed to provide real-time insights into transformer performance and enable proactive maintenance. The THMS utilizes a combination of sensors and microcontrollers to measure key parameters such as voltage, current, temperature, and oil level in transformers.

The data collected is processed and displayed on LED displays using the ESP-NOW protocol for wireless communication. By detecting potential faults early and optimizing maintenance efforts, the THMS aims to enhance the reliability of power distribution systems and minimize downtime. This presentation will discuss the technical aspects of the THMS, including the measurement parameters, data transmission using the ESP-NOW protocol, and its potential impact on improving power grid resilience.

2. Comparison With Other Monitoring System

When evaluating transformer health monitoring systems, key considerations include power efficiency and data transmission speed. Traditional monitoring setups often grapple with high energy consumption stemming from outdated components and communication protocols, leading to elevated operational costs and scalability issues. Conversely, our proposed Transformer Health Monitoring System (THMS) implements cutting-edge microcontroller technology and energy-conscious components to minimize power usage while maintaining robust functionality. Additionally, by integrating advanced communication protocols like the ESP-NOW protocol, the THMS facilitates rapid and dependable data transmission over short distances. This seamless communication enables swift interactions between monitoring nodes and central control hubs, enhancing the overall agility and efficacy of the monitoring infrastructure. By prioritizing efficiency and speed, the THMS presents a distinct advantage over conventional systems, rendering it an optimal solution for contemporary power distribution networks.

3. Basic Working Principle

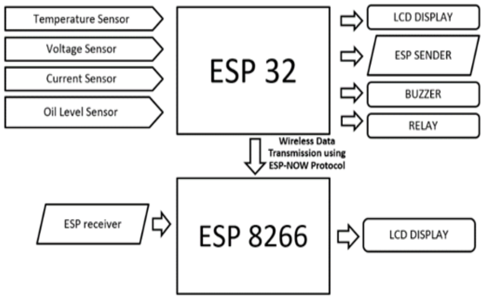

Fig.1. Block diagram of Transformer Health Monitoring System

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The Transformer Health Monitoring System (THMS) serves as a comprehensive solution aimed at ensuring the efficient operation and safety of transformers through continuous monitoring of vital parameters. Central to the THMS are specialized sensors strategically positioned to measure critical transformer health indicators, including temperature, oil level, current, and voltage. Temperature variations are detected using precise thermistors, while ultrasonic sensors gauge oil levels accurately. Voltage levels are monitored through potential divider circuits, and current is measured using ACS712 Hall effect sensors. These sensors interface with an ESP32 microcontroller, acting as the transmitter, which processes the sensor data and utilizes the ESP-NOW protocol for efficient wireless transmission to the receiving end, where a NodeMCU microcontroller is deployed.

Both microcontrollers feature LCD displays for real-time visualization of the measured parameters, offering operators immediate insight into transformer health status. Moreover, the THMS incorporates a proactive approach to monitoring, implementing a threshold mechanism on the transmitting side. Predefined threshold values are set for each parameter, and should any parameter exceed its threshold, an automatic response is initiated. This response includes activating a relay to isolate the transformer from the input side and triggering a buzzer for audible warning signals.

The receiving end NodeMCU microcontroller decodes the transmitted data and processes it for analysis. If any parameter exceeds its threshold, the NodeMCU microcontroller promptly triggers alerts, providing operators with real-time notifications. This prompt alert system empowers operators to take swift corrective action, mitigating potential damage or disruptions to the transformer and ensuring the reliability of the power distribution network.

4. Connection Diagram

The circuit diagram showcases our Transformer Health Monitoring System (THMS), which integrates advanced sensor technologies to ensure accurate and real-time monitoring of critical parameters. This system includes essential components such as sensors, microcontrollers, and LCD displays, strategically arranged to provide comprehensive monitoring capabilities.

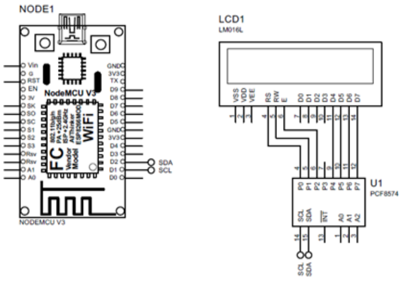

Fig.2. Receiver circuit layout

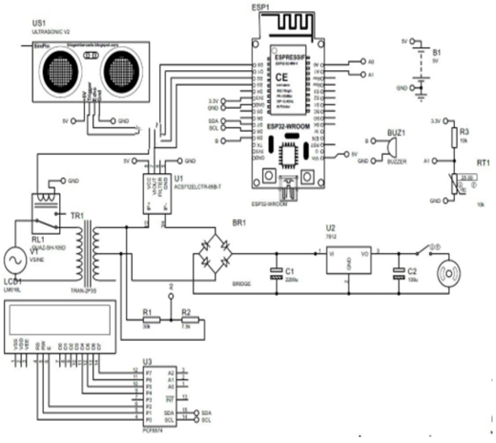

Fig.3. Transmitter circuit layout

5. Hardware

A. Transmitter

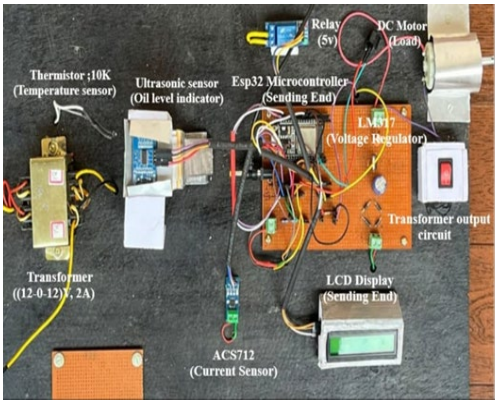

Fig.4. Transmitter

The transmitter side of the Transformer Health Monitoring System (THMS) houses sensors for measuring critical parameters including temperature, oil level, current, and voltage. These sensors are strategically positioned to ensure accurate data acquisition for monitoring transformer health.

At the core of the transmitter side is the ESP32 microcontroller, serving as the central processing unit. It receives data from the sensors, processes it, and transmits it wirelessly using the ESP-NOW protocol to the receiving end. This wireless communication enables remote monitoring of transformer health. A relay is incorporated into the transmitter side to safeguard the transformer. If any parameter exceeds predefined thresholds, the relay is activated to isolate the transformer from the input side, mitigating potential damage. Additionally, a buzzer alarm is triggered to alert operators of threshold breaches, prompting timely intervention. An LCD display is integrated into the transmitter side, providing real-time visualization of measured parameters. This display offers operators immediate insights into transformer health status, facilitating informed decision-making and proactive maintenance.

Temperature Measurement: In our prototype for temperature measurement, we utilize a 10k thermistor connected in series with a standard 10k resistor. One end of this series connection is linked to the 3.3V output from the microcontroller, while the other end is connected to ground. The junction between them is connected to a GPIO pin of the ESP32 microcontroller. The purpose of this setup is to determine the resistance value of the thermistor. By measuring the voltage at the junction point, we can calculate the resistance of the thermistor using a voltage divider formula. This resistance value is then used in conjunction with the Steinhart equation to calculate the temperature at that moment.

Oil Level Measurement: For oil measurement, we implemented an ultrasonic sensor placed at a height of 10cm from the ground level. This positioning was chosen to accommodate the specific requirements of our prototype, which utilized a 230V to 12V transformer for testing purposes. The ultrasonic sensor operates by emitting ultrasonic waves and measuring the time taken for the waves to reflect off the surface of the oil. Based on the time delay, the sensor calculates the distance to the oil surface, providing an accurate measurement of oil level.

Voltage Measurement: Due to the 12V output of our transformer, direct connection to the microcontroller is not feasible. To address this, we implemented a potential divider circuit, which steps down the voltage to a level suitable for measurement by the microcontroller. This is essential for integrating transformer output monitoring into our system. The potential divider circuit consists of a 33kΩ resistor and a 7.5kΩ resistor connected in series. This configuration divides the voltage, ensuring that the output voltage is reduced to below 3.3V, compatible with the input range of our microcontroller.

Current Measurement: We utilized an ACS712 Hall effect sensor for current measurement, connected directly in series with the output of the transformer. This setup enables the sensor to directly monitor the flow of current through the system in real-time. Operating on the principle of detecting the magnetic field produced by current passing through a conductor, the ACS712 Hall effect sensor provides accurate current measurements. Placing the sensor in series with the transformer output allows for precise monitoring of current fluctuations and variations.

B. Receiver

The receiver side of the Transformer Health Monitoring System (THMS) is responsible for receiving, processing, and displaying data transmitted wirelessly from the transmitter side. This side comprises a NodeMCU microcontroller and an LCD display, serving as key components for data reception and visualization. The NodeMCU microcontroller acts as the central processing unit on the receiver side. It receives data packets sent by the ESP32 microcontroller on the transmitter side using the ESP-NOW protocol. Upon receiving the data, the NodeMCU processes it and prepares it for display on the LCD screen.

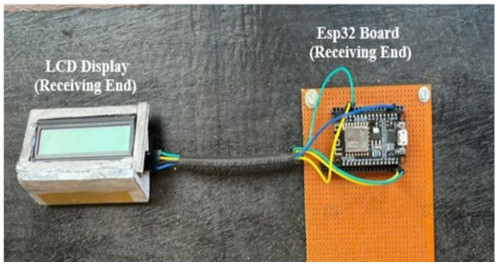

Fig.5. Receiver

6. Final Hardware

The final hardware incorporating together all the hardware components is shown below.

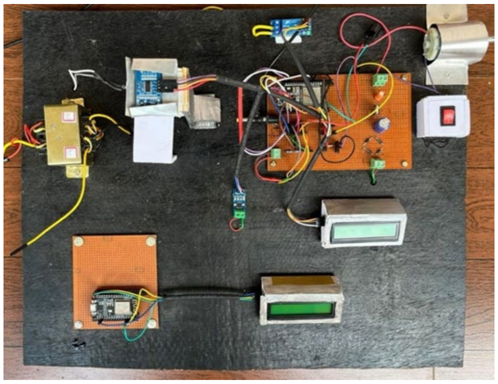

Fig.6. Top view

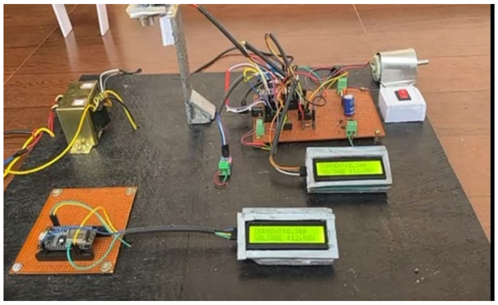

Fig.7. Side view

7. Results And Discussion

The implementation of our Transformer Health Monitoring System (THMS) yielded impressive outcomes, underscoring its efficiency and reliability in operation. A standout accomplishment was the system's remarkable responsiveness, facilitating real-time monitoring and swift detection of critical parameters. Moreover, the THMS showcased commendable energy efficiency with minimal power consumption, enabling prolonged operation without substantial energy usage. These findings were substantiated through rigorous experimental testing, as illustrated in the accompanying visual documentation. We observed compelling evidence of the THMS's efficacy in swiftly detecting and responding to changes in transformer conditions. Its rapid response time allowed for timely interventions and proactive maintenance, mitigating the risk of potential failures and enhancing overall system reliability. Additionally, the system's low power consumption signifies its sustainability and cost-effectiveness, aligning with modern energy conservation practices. Experimental validation further bolstered our confidence in the THMS's performance and reliability. Through systematic testing procedures, we corroborated the system's ability to consistently deliver accurate and real-time data, essential for effective transformer health monitoring. The accompanying visual documentation provides a tangible representation of our findings, reinforcing the robustness and efficacy of the THMS in real-world applications.

The results obtained from our THMS showcase its effectiveness as a short-range monitoring solution, offering reliable performance within a range of up to 150 meters. The fast response time and low power consumption make it an ideal choice for applications requiring quick and efficient monitoring of transformer health. However, for scenarios requiring long-range monitoring capabilities, such as expansive power distribution networks, we suggest the incorporation of LoRa (Long Range) technology. By integrating LoRa, the THMS can extend its monitoring range while maintaining its efficiency and reliability, thereby addressing the needs of larger-scale deployments.

8. Conclusion

The integration of the ESP-NOW protocol into transformer health monitoring systems signifies a significant leap forward in industrial maintenance technology. Its efficient power usage, robust communication capabilities, and ease of deployment make it an ideal choice for ensuring continuous and reliable monitoring of vital transformer parameters. By enabling real-time data transmission over extended distances, ESP-NOW empowers maintenance teams to promptly detect anomalies, prevent costly downtime, and optimize the performance and longevity of critical infrastructure. This transformative technology not only enhances operational reliability but also sets the stage for smarter and more efficient industrial processes, driving innovation and progress in the field of transformer health monitoring.

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