

Design and Implementation of IoT-Based Transformer Health Monitoring System Using Multi-Parameter Sensing

¹Pratiksha Tulashiram Bhui, Sujata Ashok Galgund, Monali Suresh Landage, Priya Malhari Tandale, Shubhangi Samadhan Ingawale, Madhura Santosh Gaikwad, ²Sawant V. A, Suhas B Khadake

¹TYEE SVERI's College of Engineering, Pandharpur. India

²Assistant Professor SVERI's College of Engineering, Pandharpur. India

Abstract: *Power transformers are critical assets in electrical power systems, and their reliable operation is essential for uninterrupted power supply. Failures in transformers can result in severe economic losses and system instability. Conventional monitoring techniques rely on periodic inspection, which is inefficient and unable to detect real-time faults.*

This paper presents a comprehensive Internet of Things (IoT)-based transformer health monitoring system that measures temperature, voltage, current, power, and humidity continuously. The system uses multiple sensors integrated with a microcontroller to collect and process real-time data. The processed data is transmitted to a cloud platform using wireless communication, enabling remote monitoring and predictive maintenance.

The proposed system enhances transformer reliability, reduces maintenance costs, and enables early fault detection. Experimental analysis demonstrates the effectiveness of the system under different operating conditions..

Keywords: IoT, Transformer Monitoring, Smart Grid, Temperature Sensor, Current Sensor, Voltage Sensor, Humidity Sensor, Predictive Maintenance

I. INTRODUCTION

Electrical power systems rely heavily on transformers for efficient transmission and distribution of electricity. Transformers operate under varying load and environmental conditions, making them susceptible to faults such as overheating, insulation failure, and overloading [1-10].

Traditional transformer monitoring systems are manual and involve periodic inspections. These methods are time-consuming and fail to provide real-time insights into transformer health. As a result, faults are often detected only after significant damage has occurred.

The emergence of IoT has revolutionized monitoring systems by enabling real-time data acquisition, remote access, and intelligent decision-making. IoT-based monitoring systems allow continuous observation of transformer parameters and provide alerts when abnormal conditions are detected [11-69].

This paper proposes a multi-parameter IoT-based monitoring system that integrates electrical and environmental sensing for comprehensive transformer health analysis.

PROBLEM STATEMENT

In modern power systems, transformers are essential components for efficient transmission and distribution of electrical energy. However, transformers are often subjected to various electrical and environmental stresses such as overloading, overheating, voltage fluctuations, and humidity, which can lead to insulation failure and unexpected breakdowns. Traditional monitoring methods mainly rely on periodic manual inspection, which is time-consuming, less accurate,



and unable to provide real-time information about the transformer's condition. This lack of continuous monitoring increases the risk of sudden failures, power interruptions, and high maintenance costs. Therefore, there is a need to develop a smart and reliable system that can continuously monitor transformer parameters in real time and provide remote access to the data. The proposed solution is an IoT-based transformer health monitoring system using the ESP32 microcontroller, which can measure important parameters such as voltage, current, power, temperature, and humidity, and transmit the data wirelessly to users. This system aims to detect faults early, reduce manual effort, improve efficiency, and ensure the safe and reliable operation of transformers.

II. LITERATURE REVIEW

The reliability and efficient operation of power transformers are essential for maintaining stability in electrical power systems, as their failure can lead to significant economic losses and service interruptions. Traditionally, transformer monitoring has relied on manual inspections and periodic maintenance practices, which are often time-consuming and incapable of detecting faults in real time. With the advancement of the Internet of Things (IoT), modern monitoring systems have evolved to provide continuous and remote supervision of transformer parameters, significantly improving fault detection and system reliability. Researchers have increasingly focused on IoT-based solutions that integrate sensors, communication technologies, and cloud computing to enhance transformer health monitoring. Several studies have highlighted the transition from conventional monitoring techniques to smart IoT-enabled systems. These systems typically employ various sensors to measure critical parameters such as temperature, voltage, current, oil level, and vibration. The collected data is processed using microcontrollers such as Arduino or ESP-based modules and transmitted through wireless communication protocols like Wi-Fi, GSM, or GPRS. This real-time data transmission allows operators to monitor transformer conditions remotely and receive alerts in case of abnormal behaviour, thereby reducing response time and preventing potential failures. The adoption of low-cost and energy-efficient hardware has further accelerated the implementation of such systems in practical applications. In addition to real-time monitoring, recent research has emphasized the integration of machine learning techniques with IoT systems to enable predictive maintenance. By analysing historical and real-time data, these intelligent systems can identify patterns and predict potential faults before they occur. Techniques such as deep belief networks, support vector machines, and regression models have been applied to improve fault detection accuracy. This shift from reactive to predictive maintenance not only enhances transformer lifespan but also reduces maintenance costs and operational downtime. Despite the numerous advantages, IoT-based transformer health monitoring systems face several challenges. Issues related to data security, network reliability, and system scalability remain significant concerns. Moreover, the integration of IoT systems with existing power infrastructure can be complex and may require substantial initial investment. Researchers have also pointed out the lack of standardized frameworks, which can hinder interoperability between different systems and devices. Recent trends in this field indicate a growing interest in incorporating advanced technologies such as artificial intelligence, edge computing, and digital twin models to further enhance monitoring capabilities. These innovations aim to provide faster data processing, improved decision-making, and more accurate fault prediction. Overall, the literature suggests that IoT-based transformer health monitoring systems offer a promising approach to improving the efficiency, reliability, and sustainability of modern power systems, although further research is needed to address existing limitations and ensure large-scale implementation.

IV. PROJECT DESCRIPTION

An **IoT-based Transformer Health Monitoring System** is an advanced solution that integrates sensing technology, embedded systems, and wireless communication to ensure the safe and efficient operation of power transformers. Transformers are critical components in electrical power systems, and their failure can lead to power outages, equipment damage, and economic loss. Therefore, continuous monitoring of transformer health is essential. In this system, multiple parameters are measured simultaneously to give a complete picture of the transformer's condition. **Voltage and current sensors** are used to monitor the electrical performance. Any abnormal rise or drop in voltage may indicate supply issues, while excessive current may suggest overloading or fault conditions. Using these values, **power**



consumption is calculated, which helps in analysing load behavior and efficiency. In addition to electrical parameters, **temperature monitoring** plays a very important role. Transformers generate heat during operation, and excessive temperature can damage insulation and reduce lifespan. A temperature sensor continuously checks the thermal condition of the transformer. If the temperature exceeds a safe limit, the system can trigger alerts. Similarly, a humidity sensor monitors moisture levels in the surrounding environment. High humidity can lead to insulation failure and corrosion, especially in outdoor transformers. The core of the system is the ESP32 microcontroller, which has built-in Wi-Fi capability. This eliminates the need for additional communication modules. The ESP32 collects data from all connected sensors, processes it, and converts it into meaningful information. It is programmed using embedded C through platforms like the Arduino IDE, making it easy to interface with different sensors. The collected data is displayed locally on an LCD or OLED display, allowing technicians to view real-time values directly at the site. At the same time, the data is transmitted over the internet using Wi-Fi. This data can be sent to cloud platforms such as ThingSpeak or mobile applications, where it is stored, visualized, and analyzed. Users can monitor transformer conditions remotely through graphs, dashboards, and alerts on their smartphones or laptops. One of the key features of this system is **real-time alert generation**. If any parameter crosses a predefined threshold (such as high temperature or overcurrent), the system can send notifications via mobile apps, email, or SMS. This helps in taking immediate action before a failure occurs. Another important aspect is **data logging and analysis**. The system continuously records operational data, which can be used for trend analysis and predictive maintenance. For example, a gradual increase in temperature over time may indicate insulation degradation. By analyzing such trends, maintenance can be scheduled proactively rather than reactively. This system is also scalable and cost-effective. It can be extended by adding more sensors like oil level sensors, gas sensors, or vibration sensors for more advanced transformer monitoring. Compared to traditional manual inspection methods, this IoT-based approach reduces human effort, increases accuracy, and ensures continuous monitoring without interruption. However, there are some challenges to consider. Reliable Wi-Fi connectivity is necessary for continuous data transmission. Proper calibration of sensors is required to ensure accurate readings. Additionally, protection circuits must be used to safely interface sensors with high-voltage transformer systems. In conclusion, the IoT-based transformer health monitoring system represents a smart and efficient approach to modern power system management. By combining real-time sensing, wireless communication, and cloud-based monitoring, it enhances transformer reliability, prevents unexpected failures, and supports intelligent decision-making in maintenance and operation.

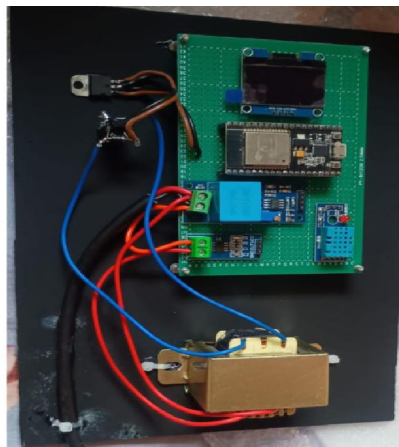


Fig: Real circuit connection

OBJECTIVE OF SYSTEM

The main objective of the IoT-based transformer health monitoring system is to ensure the safe, reliable, and efficient operation of transformers by continuously monitoring their important parameters in real time. The system aims to



measure electrical parameters such as voltage, current, and power, along with environmental conditions like temperature and humidity, using sensors connected to a controller like the ESP32 microcontroller. By collecting and analyzing this data, the system helps in detecting abnormal conditions such as overheating, overloading, or environmental risks at an early stage.

Another important objective is to enable remote monitoring through wireless communication. The system sends real-time data to mobile phones or laptops via Wi-Fi and cloud platforms such as ThingSpeak, allowing users to access transformer status from anywhere. It also aims to reduce manual inspection, improve accuracy, and support predictive maintenance by storing and analyzing historical data. Overall, the objective is to increase transformer lifespan, prevent unexpected failures, enhance system reliability, and make power system monitoring smarter and more efficient.

III. ADVANTAGES & APPLICATIONS

Advantages:-

- Real-time monitoring of transformer parameters (voltage, current, power, temperature, humidity)
- Early fault detection and quick alert generation
- Remote monitoring using Wi-Fi through devices connected via the ESP32 microcontroller
- Reduces need for manual inspection and human effort
- Improves transformer lifespan by preventing overheating and overloading
- Supports predictive maintenance using stored data
- Cost-effective and easy to implement
- Increases safety and system reliability
- Continuous data logging and analysis
- Scalable system (can add more sensors in future).

Application:

- Power generation, transmission, and distribution systems
- Electrical substations for transformer monitoring
- Industrial plants and factories
- Smart grid systems for intelligent energy management
- Renewable energy systems (solar and wind power plants)
- Remote and rural area transformer monitoring
- Commercial buildings and large facilities
- Utility companies for centralized monitoring
- Research and educational projects
- Any system requiring continuous transformer condition monitoring

IV. RESULT

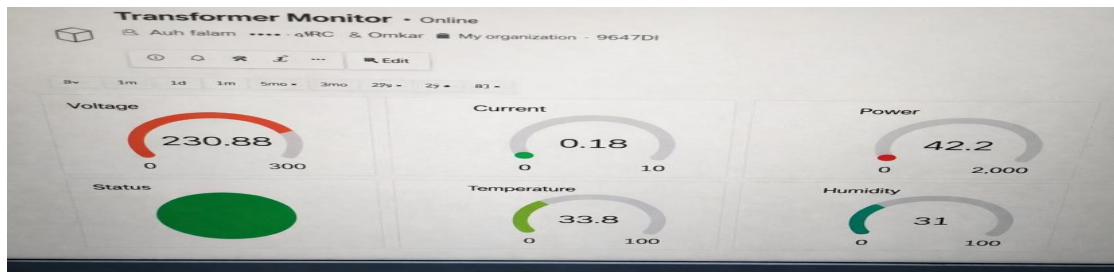


Fig. A Original Result



The result shown in the image represents the **real-time monitoring dashboard** of the IoT-based transformer health monitoring system. This dashboard displays all the important parameters of the transformer in a clear and user-friendly graphical format, making it easy to understand the current operating condition.

In the result, the **voltage value is approximately 230.88 V**, which indicates that the transformer is operating under normal supply conditions. The **current is around 0.18 A**, showing that the load on the transformer is relatively low. Based on these values, the **power is calculated as 42.2 W**, which reflects the actual energy consumption at that moment.

The environmental conditions are also displayed. The **temperature is about 33.8°C**, which is within a safe operating range, indicating that the transformer is not overheating. The **humidity level is around 31%**, which is also normal and does not pose any immediate risk to insulation or performance.

Additionally, the system includes a **status indicator**, which is shown in green. This indicates that all parameters are within safe limits and the transformer is functioning properly without any fault or abnormal condition.

Overall, this result demonstrates that the system is successfully collecting, processing, and displaying real-time data. It also shows how users can easily monitor transformer health remotely through a digital interface, helping in early detection of faults and improving reliability and maintenance efficiency.

V. FUTURE SCOPE

The future scope of the IoT-based transformer health monitoring system is highly promising with the integration of advanced technologies such as artificial intelligence and machine learning. In the future, the system can be enhanced to perform predictive maintenance by analyzing historical and real-time data to detect faults before they occur. By identifying patterns like gradual temperature increase, abnormal current flow, or voltage fluctuations, the system can provide early warnings and help prevent transformer failures. Additionally, more advanced sensors such as oil level, oil quality, dissolved gas, and vibration sensors can be added to obtain a more detailed and accurate assessment of transformer health, making the system suitable for large-scale industrial and substation applications.

Furthermore, the communication system can be improved by incorporating technologies like GSM, LoRa, or NB-IoT to enable long-distance monitoring, especially in remote areas where Wi-Fi is not reliable. The system can also be integrated with smart grid and SCADA systems for centralized monitoring and automatic control of multiple transformers. Enhancements in cloud computing and mobile applications will allow better data visualization, storage, and real-time alerts. In addition, implementing strong cybersecurity measures will ensure safe data transmission. Overall, future developments will make the system more intelligent, scalable, secure, and efficient, contributing significantly to modern power system management and reliability.

VI. CONCLUSION

The IoT-based transformer health monitoring system provides an efficient and modern solution for monitoring transformer performance. By integrating sensors, embedded systems, and cloud technology, it ensures continuous supervision and enhances reliability. It supports predictive maintenance and reduces the risk of unexpected failures..

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