AI Powered IOT Transformer Health and Fault Monitoring System Using ESP32

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Abstract- AI-based health monitoring and automatic load sharing system for power transformers to improve operational reliability and efficiency in electrical power distribution networks. Transformers are critical components of power systems, and their failure can lead to significant power outages and economic losses. To address this issue, the proposed system continuously monitors important operating parameters such as voltage, current, oil and winding temperature, and load conditions using appropriate sensors. The collected data is processed using artificial intelligence techniques to analyze transformer health, identify abnormal patterns, and predict potential faults before they become severe. In addition, the system enables intelligent load sharing between multiple transformers by dynamically redistributing load based on real-time conditions. This prevents overloading, reduces thermal stress, and extends transformer lifespan. The system also provides timely alerts for maintenance, enabling condition-based maintenance instead of periodic manual inspection. Overall, the proposed solution enhances power system stability, reduces maintenance costs, and supports the development of smart and reliable electrical grids. The proposed system offers several advantages, including real-time monitoring, predictive maintenance, reduced downtime, cost efficiency, and improved transformer lifespan. It is scalable for deployment in smart grids and industrial power distribution networks. Furthermore, the integration of IoT and AI technologies supports automation and data-driven decision-making in modern power systems

Index Terms **-Transformer health monitoring, Fault dictection, Load sharing of a transformer.**

I. INTRODUCTION

The transformer is the piece of machinery that is most important for the transmission and distribution of electricity. A power system's electrical component transformer delivers power directly to low-voltage customers, and the condition of its operation is essential to the efficient operation of the entire network. To monitor all key parameter activities and provide timely data to the monitoring system, a transformer monitoring system is necessary. It provides the vital information about the state of the transformer. an embedded IoT system that can measure temperature, load currents, over-voltage and transformer oil level is designed and built. An ESP-32 microcontroller and an Internet of Things (IoT) online measurement system are used to do this. 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.

Problem Statement

With the rapid growth of technology and increasing demand for efficient systems, both healthcare monitoring and power distribution require intelligent and automated solutions. Traditional healthcare monitoring systems rely heavily on manual observation and periodic medical checkups, which may not provide continuous monitoring of a patient's vital parameters. This can lead to delayed detection of health abnormalities, especially for elderly patients, people with chronic diseases, or individuals living in remote areas where immediate medical assistance is not readily

available[1],[2] Therefore, there is a need for an integrated IoT-based monitoring system that can continuously collect and transmit real-time data. For healthcare applications, IoT sensors can monitor vital parameters such as heart rate, temperature, and oxygen levels and send the data to healthcare providers through the internet. In power systems, IoT technology can monitor transformer load conditions and automatically distribute the load among multiple transformers to prevent overloading[2], The proposed system aims to improve remote healthcare monitoring and efficient power management by utilizing IoT technology, enabling real-time monitoring, early detection of abnormalities, improved reliability, and enhanced operational efficiency.[3].

Related Works

Recent studies have focused on using Artificial Intelligence (AI) and Internet of Things (IoT) technologies to improve transformer health monitoring. Traditional monitoring methods rely on periodic manual inspection, which often fails to detect early faults such as overheating, insulation degradation, or abnormal load conditions. Researchers have proposed IoT-based monitoring systems where sensors measure parameters such as voltage, current, temperature, oil level, and humidity in real time. These sensors transmit the collected data to cloud platforms where AI or machine learning algorithms analyze the information to detect anomalies and predict potential failures. Such systems allow utilities to perform predictive maintenance instead of reactive maintenance, thereby reducing downtime and improving reliability. Studies also show that AI models can accurately detect abnormal operating patterns and classify transformer faults based on historical sensor data. These intelligent monitoring systems help power utilities monitor transformers remotely and take preventive actions before a major failure occurs[1].

Several researchers have also investigated the use of AI and machine learning techniques for transformer fault prediction and condition assessment. Machine learning algorithms such as Random Forest, neural networks, and ensemble learning models are trained using historical operational data from transformers. These models analyze patterns in parameters like temperature rise, load current, and vibration signals to identify early warning signs of transformer degradation. AI-based systems can also differentiate between normal operating variations and actual faults, which helps reduce false alarms and unnecessary maintenance operations. By continuously analyzing real-time sensor data, these intelligent systems provide accurate predictions of possible failures and remaining useful life of transformers. This enables utility operators to schedule maintenance at the right time and avoid unexpected outages. As a result, AI-driven monitoring systems significantly enhance the reliability and efficiency of power distribution networks while lowering maintenance costs[2].

Another important area of research is automatic load sharing among multiple transformers to prevent overloading and ensure efficient power distribution. In many distribution systems, one transformer may become overloaded while others remain underutilized, which can lead to overheating and equipment damage. Researchers have proposed intelligent load-sharing systems that monitor transformer load in real time and automatically transfer part of the load to a backup transformer when the primary transformer exceeds a predefined limit. These systems typically use microcontrollers, sensors, and communication modules to detect load changes and control switching mechanisms such as relays. When integrated with AI and IoT platforms, the system can analyze load patterns and optimize load distribution dynamically. This approach improves system stability, prevents transformer failure, and ensures uninterrupted power supply. Intelligent load-sharing systems therefore play an important role in developing smart grid infrastructures and modern power management solutions[3].

II. PROPOSEDSYSTEM DESCRIPTION

The proposed AI-based IoT Transformer Health Monitoring System is designed to continuously monitor the operating condition of a power transformer and detect faults at an early stage. Transformers are critical components in electrical power systems, and unexpected failures can lead to power outages, equipment damage, and high maintenance costs. This system uses IoT technology and Artificial Intelligence to provide real-time monitoring, data analysis, and predictive maintenance.[3]

In this system, multiple sensors are installed on the transformer to measure important parameters such as temperature, load current, oil level, voltage, and

humidity. These sensors continuously collect operational data from the transformer. A microcontroller such as ESP32 acts as the central processing unit that reads the sensor data and processes it.

The ESP32 transmits the collected data to a cloud platform through the Internet using Wi-Fi communication. Cloud services store the data and allow remote monitoring through web dashboards or mobile applications.[2] Engineers and operators can view the transformer status in real time from any location.

Artificial Intelligence algorithms are applied to the collected data to analyze patterns and detect abnormal conditions. The AI model can predict possible transformer faults such as overheating, overloading, insulation failure, or cooling system malfunction before they become critical. This predictive capability helps in scheduling maintenance and preventing unexpected breakdowns.[1]

The system also includes automatic protection and alert mechanisms. If abnormal conditions are detected, the system can trigger alarms, send notifications to operators, and activate protective relays to disconnect the transformer or start cooling mechanisms. This improves the safety and reliability of the power system.[3]

Overall, the proposed AI-based IoT transformer health monitoring system provides continuous monitoring, remote accessibility, intelligent fault prediction, and automated protection, making it a modern and efficient solution for smart grid and Industry 4.0 applications.

III. OBJECTIVES

The main aims of this study include:

1. Continuous Monitoring of Transformer Parameters

To continuously monitor important transformer parameters such as temperature, voltage, current, oil level, and load conditions in real time.

2. Early Fault Detection

To identify abnormal operating conditions and detect possible transformer faults at an early stage using AI-based analysis.

3. Remote Monitoring Using IoT

To enable remote monitoring of transformer health through IoT technology and cloud platforms, allowing operators to access data from anywhere.

4. Predictive Maintenance

To apply Artificial Intelligence algorithms to analyze collected data and predict potential failures before they occur.

5. Improving System Reliability

To increase the reliability and efficiency of the power distribution system by preventing unexpected transformer breakdowns.

6. Automatic Alert and Protection System

To generate alerts and notifications when abnormal conditions are detected and activate protection mechanisms if necessary.

7. Data Storage and Analysis

To store transformer operational data in the cloud for long-term analysis, performance evaluation, and maintenance planning.

8. Reducing Maintenance Cost

To minimize maintenance costs and downtime by enabling condition-based maintenance instead of routine manual inspection.

IV. METHODOLOGY

The proposed AI powered IoT based transformer health monitoring and load sharing system works by continuously collecting important operating parameters of the transformer using different sensors such as temperature sensors, voltage sensors, current sensors, and oil level sensors.[2] These sensors are connected to a microcontroller such as an ESP32 or ATmega328P, which gathers real-time data from the transformer. The collected data is transmitted through an IoT communication module (Wi-Fi) to a cloud platform where it can be monitored remotely.[1] The cloud platform stores the data and allows real-time visualization of transformer conditions using dashboards. Artificial Intelligence algorithms are applied to the collected data to analyze patterns, detect abnormal conditions, and predict possible faults before they occur. When the system detects overheating, overload, or any abnormal parameter, it automatically generates alerts and takes protective actions such as activating cooling systems or disconnecting the transformer through relays.[3] In addition, the system also implements load sharing between multiple transformers (for example TR1, TR2, and TR3) by analyzing load conditions and automatically transferring excess load from an overloaded transformer to another transformer with available capacity. This improves efficiency, prevents transformer damage, reduces

downtime, and increases the reliability of power distribution systems.

1. To collect real-time operating parameters of the transformer using sensors.
2. An ESP32 development board acts as the central controller of the system.
3. Artificial Intelligence algorithms analyze the collected sensor data to predict possible faults.
4. The ESP32 sends transformer data to the cloud using Wi-Fi.

V. COMPARACTIVEANALYSIS

The traditional transformer monitoring system mainly depends on manual inspection and periodic maintenance. In conventional methods, parameters such as temperature, oil level, and load conditions are checked manually by technicians. This method is time-consuming and faults are often detected only after a problem occurs. As a result, transformer failures, power interruptions, and higher maintenance costs may occur. compared to traditional monitoring systems, the AI powered IoT system offers real-time monitoring, predictive maintenance, remote access, improved efficiency, and reduced downtime.[1].

Advantage of the proposed system is automatic load sharing between transformers. In conventional systems, load balancing is performed manually and may not respond quickly to overload situations. However, in the proposed system, when one transformer becomes overloaded, the controller automatically transfers part of the load to another transformer through relay control, ensuring balanced operation and preventing damage.[2].

VI. RESEARCHGAPS IDENTIFIED

1. Limited integration of AI with real-time IoT monitoring

Most existing transformer monitoring systems use IoT only for data collection and remote monitoring. However, the integration of Artificial Intelligence for real-time fault prediction and decision making is still limited. Many systems only provide alerts instead of intelligent analysis and automatic corrective actions.

2. Lack of intelligent load sharing between transformers

In many power distribution systems, load sharing between parallel transformers is done using traditional methods. There is still a research gap in using AI algorithms to automatically balance load between transformers based on temperature, load condition, and health status.

3. Insufficient predictive maintenance models

Current monitoring systems mainly detect faults after they occur. More research is required to develop predictive AI models that can forecast transformer failures using historical data, sensor readings, and machine learning techniques.

4. Limited sensor data fusion

Most studies use only a few parameters such as temperature or voltage. A major research gap is the integration of multiple sensor parameters like oil temperature, winding temperature, load current, vibration, humidity, and gas levels to improve accuracy in transformer health assessment.

VII. CONCLUSION

The proposed AI-powered IoT based transformer health monitoring and load sharing system provides an efficient and intelligent solution for improving the reliability, safety, and performance of power distribution transformers. By integrating smart sensors, IoT communication modules, and artificial intelligence algorithms, the system continuously monitors important transformer parameters such as temperature, voltage, current, oil level, and load conditions in real time.[1].

The collected data is transmitted to cloud platforms where AI techniques analyze the operational condition of the transformer and detect early signs of faults or abnormal behavior. This predictive capability helps prevent unexpected transformer failures and reduces maintenance costs. In addition, the automatic load sharing mechanism distributes the load among multiple transformers, preventing overloading and extending transformer life.[2]

Overall, this system enhances the efficiency of power distribution networks, supports smart grid development, and ensures uninterrupted power supply. The integration of AI and IoT technologies makes transformer monitoring more intelligent, scalable, and suitable for modern power systems[3]

VIII. FUTURESCOPE

The future scope of the AI powered IoT based transformer health monitoring and load sharing system

is very broad due to the rapid development of smart grids and intelligent power systems. In the future, more advanced machine learning and deep learning algorithms can be integrated to improve fault prediction accuracy and enable predictive maintenance of transformers. This will help detect problems much earlier and reduce unexpected power failures.

The system can also be expanded by integrating advanced sensors and edge computing, allowing faster local data processing and quicker response to abnormal conditions. In addition, integration with smart grid technology will enable automatic energy management and dynamic load balancing among multiple transformers in large power distribution networks.

Cloud platforms and big data analytics can further enhance long-term performance analysis of transformers, helping utilities make better maintenance and operational decisions. The use of 5G communication and advanced IoT protocols will improve real-time monitoring and data transmission reliability.

In the future, this system can also be connected with renewable energy sources such as solar and wind power systems, enabling intelligent power distribution and improved grid stability. Overall, AI-based transformer monitoring systems will play a key role in building fully automated

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