

# Smart Transformer Health Monitoring Using AI-ML and IoT Integration

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**Abstract-** Power Transformers are considered critical and costly equipment in electrical power systems. Sudden transformer failures can cause considerable economic losses. Conventional transformer monitoring systems have used periodic manual inspection for transformer monitoring. Such methods may be ineffective for detecting faults at the primary stage. This paper proposes an IoT-based transformer health monitoring system in real-time using ESP32 and Raspberry Pi Zero 2W. The system monitors various critical transformer parameters in real time, including temperature, gas concentrations (Hydrogen, Methane), oil level, load currents, operating voltage, and ultrasonic fault signals. The ESP32 module will be used to collect the transformer parameters and transmit the values to Firebase for cloud storage. In addition, Machine learning (ML) models like Random Forest, KNN, Gradient Boosting, and Support Vector Machine (SVM) are used for fault prediction. The collected data is sent to Firebase, where a web-based dashboard built with ReactJS provides visualization and overall analysis of the system. This system enables early fault detection and extends the transformer's lifespan.

**Keywords:** Transformer monitoring; ESP32; Raspberry Pi; Machine Learning algorithms; Predictive maintenance; Dashboard.

## I. INTRODUCTION

Power transformers are important in systems that generate, send and distribute electricity. They have to handle heat and the environmental conditions, which can make them break down over time. Issues like overheating and overloads can really affect how long transformers last. If we do not solve these problems, they can lead to inefficient power systems. So it is crucial to make sure transformers work properly to keep the power supply going continuously. Traditional ways of maintaining power transformers include manual checks and scheduled maintenance. Many people use these methods. It is difficult to keep track of the transformer's condition, and we might not notice faults until a serious issue occurs. Also, manual inspections require a lot of man-power.

New technologies such as embedded systems, wireless communication, and data processing have enabled the development of monitoring systems for transformers. By integrating IoT components and some ML models, we can also predict the faults before it damages the entire system. A dashboard using ReactJS is created to ensure continuous monitoring. Thus, ensuring the optimum

performance of the power distribution system. The main aim of this system is to predict the faults at an early stage.

## II. LITERATURE SURVEY

Recent research works have aimed at enhancing transformer performance and reliability by adopting smart monitoring techniques and traditional inspection methods. Whereas traditional methods mainly relied on periodic inspections, which are not simple and accessible in remote places. These methods are not efficient for detecting faults before they occur. With the vast development of IoT, systems can monitor parameters such as temperature and voltage continuously through the cloud, improving the efficiency of the designed system. In addition, machine learning algorithms like KNN, Random Forest, Gradient Boosting and Support Vector Machine (SVM) are used to analyze transformer data and recognize unusual activities. However, many existing systems don't have proper integration of real-time monitoring with fault prediction. Therefore, there is a requirement for a system that integrates both IoT and machine learning.

The proposed system overcomes these limitations by continuously monitoring and predicting the faults.

### III. PROPOSED SYSTEM

#### System Architecture:

The proposed system is designed as an intelligent and connected monitoring system for power transformers.

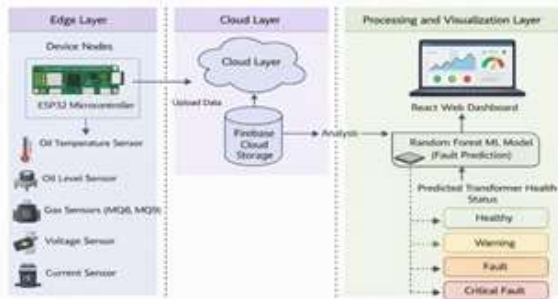


Fig. 1 System Architecture

The Fig.1 shows the overall architecture of the proposed system, where the data is collected at the edge layer, stored in the cloud and processed later. **Data Collection:** Firstly, the high-voltage AC supply will be stepped down and regulated using a DC-DC converter to supply power to the electronic devices. Sensors such as temperature, gas, oil level, current, and ultrasonic sensors are placed at certain positions to collect the health status of the transformer.

**Microcontroller Module:** These sensors will send collected data to the ESP32 microcontroller, which will act as a communication and sensing module. The collected data will be sent to the Raspberry Pi Zero 2W for further processing.

**Processing and machine learning:** On the Raspberry Pi, machine learning algorithms such as Random Forest, K-Nearest Neighbors(KNN), and Support Vector Machine (SVM) are applied to analyze patterns in sensor data and predict faults before they occur. This enables predictive maintenance rather than reactive maintenance.

**Cloud Storage:** The Raspberry Pi will be able to sense abnormal patterns, which may lead to failure in future. Then, the information will be uploaded to the cloud server via Firebase, which stores and accesses the data. The real-time data is then visualized using the ReactJS-based web dashboard at the power grid. **Alerts and Notification:** In addition, in case the values of collected data exceed the limit, the proposed system will be able to send an alert to the user or operator at the power grid via SMS and EMAIL.

This architecture gives a complete workflow from sensing to smart monitoring, which makes the maintenance of the transformer more efficient.

#### Hardware Requirements:

Fig. 2 shows the sensors used and their connections to achieve the final desired output. The components used:

1. **Transformer:** A 20-volt,3A transformer is used as a prototype transformer. It allows a maximum of 20volts and 3A voltage and current only.
2. **DC-DC Converter:** A DC-DC converter is used to convert one DC voltage into another DC voltage level. It is also used to step up or step down the voltage in electronic circuits.
3. **Raspberry Pi Zero 2W:** It is a compact, low-cost single-board computer with built-in Wi-Fi and Bluetooth.
4. **ESP 32:** This is a microcontroller with built-in Wi-Fi and Bluetooth, used in IoT and embedded systems. It monitors and processes transformer data like temperature, current, and voltage.

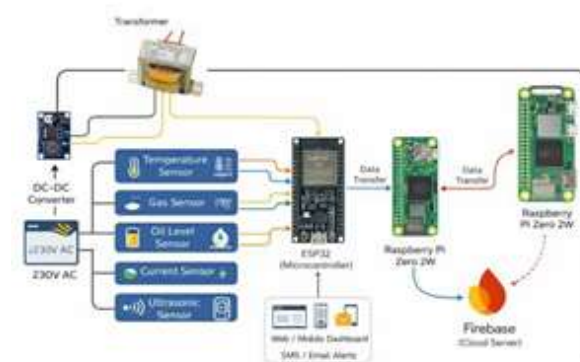


Fig. 2 Connections of Hardware Equipment.

**Sensors:** temperature sensor measures transformer overheating to prevent damage, Gas sensor detects harmful gases like hydrogen, methane, carbon monoxide, Oil-level sensor(ultrasonic sensor) checks the oil level, current and voltage sensors monitor electrical parameters, and by assigning certain thresholds, if the limit is reached, it gives an alert.

**ML Algorithms:**

In this study, three machine learning techniques are used for transformer health monitoring, namely Random Forest, K-Nearest Neighbors(KNN), Gradient Boosting, and Support Vector Machine (SVM). Random Forest is selected for its strength and robustness in handling data, which is collected by the sensors; thus, accurate predictions of faults are possible. KNN is selected due to its simplicity and the relatively small size of the data set. Finally, SVM is selected due to its reliability in making the best decisions. Gradient boosting is a machine learning technique that creates a strong predictive model by sequentially combining many weak models, basically decision trees.

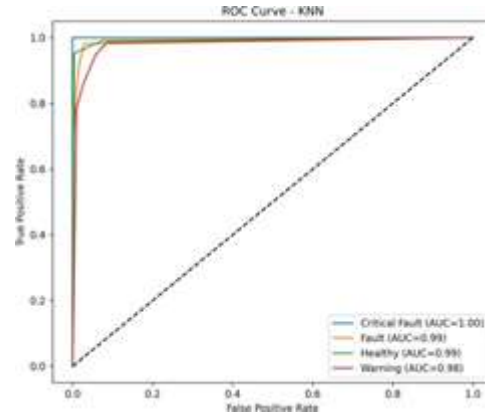


Fig. 5 Roc curve - KNN

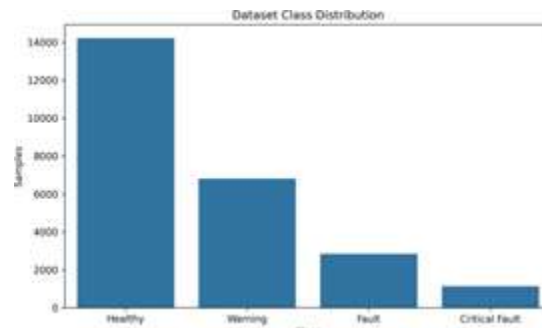


Fig. 7 Dataset classification

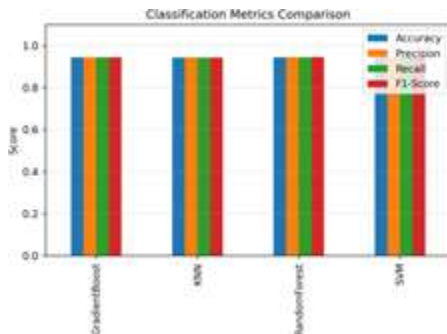


Fig. 3: classification metrics comparison

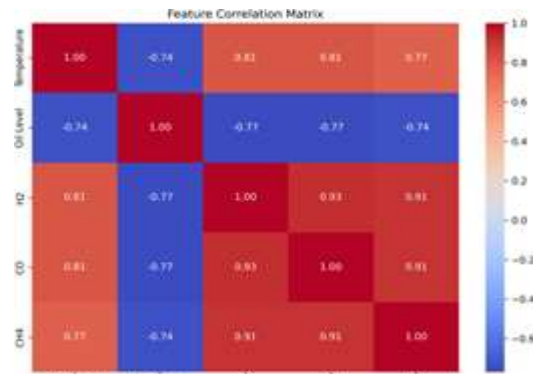


Fig. 8 Correlation matrix

**RESULTS:**

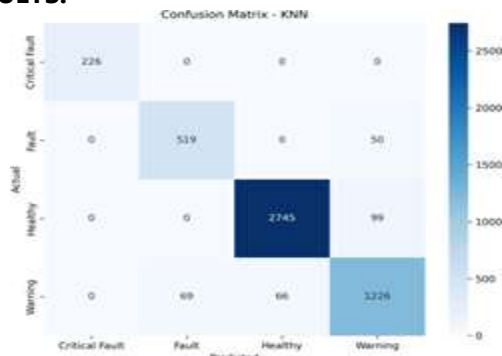


Fig. 4 Confusion matrix - KNN

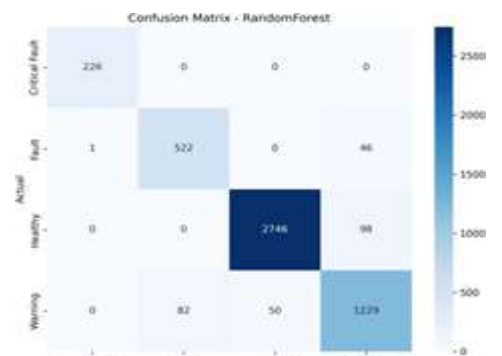


Fig. 9 Confusion matrix-Randomforest

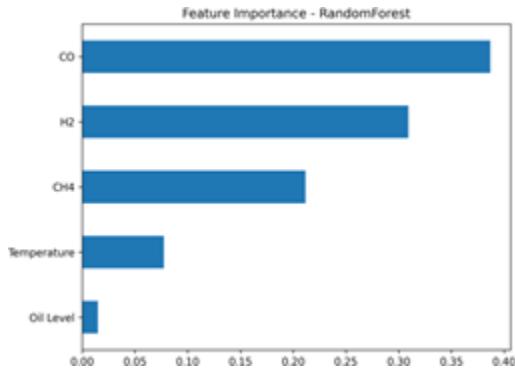


Fig. 10 Randomforest features

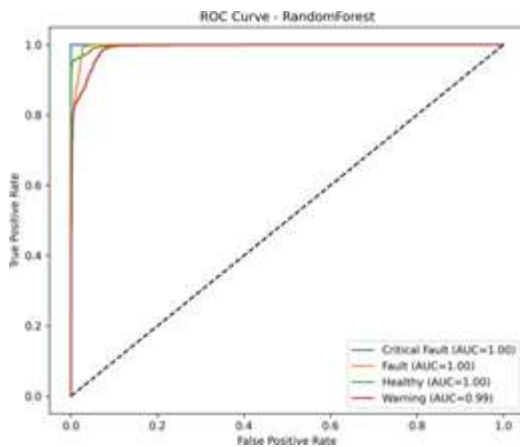


Fig. 11 Roc curve- RandomForest

## IV. CONCLUSION

The Smart Transformer Health Monitoring System developed in this project provides an efficient and intelligent solution for monitoring the condition of power transformers. The system uses IoT technology with ESP32, various sensors, and cloud storage through Firebase to continuously collect and store important transformer parameters such as oil temperature, oil level, voltage, current, and dissolved gas concentrations. By integrating these components, the system enables real-time monitoring and remote access to transformer data, which helps in detecting abnormal operating conditions at an early stage.

In addition, the project incorporates a machine learning model (Random Forest) deployed on a Raspberry Pi Zero 2W to analyse the collected data and predict the transformer health condition. The system classifies the transformer status into

categories such as Healthy, Warning, Fault, and Critical Fault. A React-based dashboard provides real-time visualization of the monitored parameters, making it easier for operators to track transformer performance. Overall, the proposed system improves transformer reliability, reduces maintenance costs, and helps prevent unexpected failures in power systems.

### Future Work:

Although the proposed system effectively monitors transformer parameters and predicts faults, several improvements can be implemented in the future to enhance its performance. Additional sensors can be integrated to monitor other important parameters such as humidity, vibration, and oil quality, which would provide more comprehensive transformer condition analysis. Advanced machine learning or deep learning algorithms could also be implemented to improve fault prediction accuracy and detect more complex transformer faults.

Furthermore, the system can be extended by developing a mobile application for easier access to monitoring data and alerts. Real-time notification systems such as SMS, email, or mobile alerts can also be integrated to immediately inform operators about critical transformer conditions. Future work may also include integrating the system with smart grid infrastructure and implementing automated control mechanisms that can take preventive actions when abnormal transformer conditions are detected.

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