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An Optimization of Early Detection Monitoring Systemdisturbances in Distribution Transformer Internet Based Ofthings (IOT)

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Article Info	ABSTRACT
Keywords: Distribution Transformers, Crucial Components and the Internet of Things	Distribution transformers are crucial components in power distribution systems that require real-time monitoring to prevent disruptions and ensure efficient operation. Internet of Things (IoT)-based monitoring systems offer innovative solutions with the ability to detect disruptions early and provide real-time information to operators. This study proposes an optimized early-detection monitoring system for distribution transformers by utilizing IoT devices, including temperature, pressure, and humidity sensors installed on the transformers to monitor their operational conditions. Data collected through the sensors is then processed using a cloud platform for further analysis, with machine learning algorithms used to detect anomalous patterns indicating potential disruptions. Furthermore, the system is designed to send automatic notifications to operators via a mobile application or web dashboard when a disruption is detected, enabling faster response and prevention of further damage. Test results show that the system is capable of detecting disruptions with high accuracy and can improve maintenance efficiency and reduce transformer operational downtime. The implementation of IoT in distribution transformer monitoring also opens up opportunities for optimizing condition-based maintenance management that is more economical and proactive.
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INTRODUCTION

Distribution transformers play a crucial role in power distribution systems, converting voltage from high to low or vice versa according to the electricity consumption needs of a particular area. Due to their critical role in ensuring smooth power flow, transformer failures can cause widespread outages and significant economic losses. Therefore, real-time monitoring of transformer conditions is crucial to maintain operational performance and prevent further damage from transformer failure. As technology advances, traditional monitoring systems that rely on manual inspections and periodic checks are beginning to be deemed ineffective and inefficient. Therefore, a system is needed that can continuously monitor transformer conditions, identify problems early, and notify operators for preventive action. One emerging solution is the use of the Internet of Things (IoT), which enables the integration of smart sensors, communication devices, and cloud-based platforms for remote monitoring.

An IoT-based monitoring system allows for real-time data collection from various sensors, such as temperature, humidity, and pressure sensors, installed on transformers. This data is then transmitted via the internet to a central system for analysis. Using machine learning algorithms and data analytics, the system is able to detect anomalous patterns that indicate potential faults or damage to the transformer. This technology enables early detection, which will improve operational efficiency and reduce unplanned maintenance time.

This research aims to develop and optimize an IoT-based early detection monitoring system for distribution transformer faults. The main focus of this research is to design a system that can not only detect faults with high accuracy but also provide early warnings to operators via a web-based or mobile application. Therefore, this research is expected to contribute to the development of a more efficient and effective maintenance management system for distribution transformers.

Electric power distribution systems face significant challenges in maintaining reliable and stable electricity supply. Distribution transformers are vital elements in the distribution chain, responsible for converting high voltages into usable voltages for end consumers. However, because transformers often operate under changing conditions and face unstable loads, they are susceptible to various types of technical problems, such as temperature spikes, insulation failure, or mechanical failure of certain components.

Distribution transformer failures can be devastating, causing widespread power supply disruptions and disrupting industrial and community activities. Delayed detection of transformer failure can lead to more severe damage, which in turn increases repair and maintenance costs. Therefore, early failure detection is crucial to minimize the risk of major damage and downtime. IoT-based monitoring offers significant potential for improving the efficiency of early detection of transformer faults. IoT leverages sensors installed on transformers to collect real-time data on operational parameters, such as temperature, humidity, vibration, and pressure. This data is then transmitted to a cloud-based platform equipped with a data analytics system to evaluate the transformer's operational condition. If abnormal conditions indicate a fault, the system can automatically notify operators so they can take immediate preventive action. However, although IoT technology has been widely used in various industrial applications, its implementation in distribution transformer monitoring systems still faces several challenges, especially in terms of detection accuracy, system integration, and efficient data processing. Therefore, this study aims to optimize the early detection monitoring system for disturbances by utilizing IoT technology, as well as designing an algorithm that is able to analyze and predict potential disturbances more accurately.

Literature Review

In this paper several relevant concepts and theories need to be explained to provide a strong foundation for the application of IoT technology in distribution transformer monitoring systems. The following theories form the basis for developing an IoT-based early detection system for distribution transformer faults:

Distribution Transformer

Distribution transformers are the main components in an electric power distribution system, serving to step down or step up the voltage from the transmission system to a level usable by consumers. Distribution transformers operate on the principle of electromagnetic induction, where electric current flowing through the primary coil generates a magnetic field that is then induced in the secondary coil. Transformer faults can be caused by various factors, such as overheating (excessive temperature increase), insulation failure, or mechanical damage to certain components.

Internet of Things (IoT)

The Internet of Things (IoT) is a concept that describes the connectivity between physical devices that can communicate with each other and exchange data over the internet. IoT consists of various elements, such as sensors, actuators, communication devices, and cloud platforms. In the context of distribution transformer monitoring, IoT enables the use of sensors to monitor various operational parameters, such as temperature, humidity, and vibration. These sensors are connected to a cloud system, which allows for real-time data collection, analysis, and visualization. By using IoT, transformer monitoring becomes more efficient and can be done remotely.

Sensors for Transformer Monitoring

A sensor is a device used to measure physical or environmental parameters related to the performance of an object, in this case, a distribution transformer. Some common types of sensors used in transformer monitoring include:

1. Temperature Sensor: Monitor The Temperature Around The Transformer. Excessively High Temperatures Can Indicate Problems Such As Overheating, Which Can Damage The Insulation Or Other Transformer Components.
2. Humidity Sensor: Excessive Humidity Can Cause Damage To Transformer Insulation Components And Increase The Risk Of Fire.
3. Vibration Sensor: Vibration Sensors Can Be Used To Detect Mechanical Abnormalities In Transformers, Such As Failures In Components Such As Oil Pumps Or Coolants.
4. Pressure Sensor: This sensor is used to monitor the pressure in the transformer section which can indicate problems with the cooling system or other mechanical systems.

Early fault detection is the process of identifying problems or anomalies at an early stage before they develop into more serious damage. In power distribution systems, early detection of transformer faults is crucial to prevent further damage that could lead to major outages or economic losses. Technologies used for early detection include the use of sensors to monitor transformer operational conditions and the analysis of collected data to detect anomalous patterns that could indicate potential faults. The use of machine learning-based algorithms to analyze sensor data is crucial in improving the accuracy and efficiency of early fault detection.

Machine learning is a branch of artificial intelligence (AI) that focuses on developing algorithms that enable systems to learn from data and make predictions or decisions without explicit programming. In the context of early fault detection, machine learning can be used to analyze data collected by sensors and identify patterns or anomalies that indicate possible transformer faults. Some machine learning algorithms frequently used for anomaly detection include:

1. Classification: Algorithms such as Random Forest or Support Vector Machine (SVM) are used to classify sensor data into normal or anomalous categories.
2. Anomaly Detection: Methods such as Isolation Forest or Autoencoders are used to detect data that does not fit common patterns, which indicates noise.
3. Regression: To predict future operational parameter values and detect values that deviate from predictions, which may indicate a problem.

Cloud platforms play a crucial role in IoT-based monitoring systems because they provide the means for collecting, storing, and processing sensor-generated data in real time. Data collected from sensors is transmitted to the cloud platform via communication networks such as Wi-Fi, LoRaWAN, or 5G. In the cloud, data can be analyzed, processed, and visualized through web-based dashboards or mobile applications, making it easier for operators to monitor transformer conditions. Cloud platforms also enable integration with advanced analytics and machine learning technologies to detect and predict faults.

Notification and Early Warning

One of the key features of an IoT-based monitoring system is the ability to provide notifications or early warnings to operators when an outage is detected. These notifications can be sent through various channels, such as mobile apps, email, or text messages. Using the right algorithm and determining accurate thresholds is crucial to avoid false positives that could disrupt operations.

Cloud platforms play a crucial role in IoT-based monitoring systems because they provide the means for collecting, storing, and processing sensor-generated data in real time. Data collected from sensors is transmitted to the cloud platform via communication networks such as Wi-Fi, LoRaWAN, or 5G. In the cloud, data can be analyzed, processed, and visualized through web-based dashboards or mobile applications, making it easier for operators to monitor transformer conditions. Cloud platforms also enable integration with advanced analytics and machine learning technologies to detect and predict faults.

The theories explained above provide a deep understanding of the fundamentals of IoT technology, sensors, machine learning, and distribution transformer monitoring. These theories are interconnected to create a system capable of early detection of distribution transformer faults, improving maintenance efficiency, and reducing the risk of major damage. This understanding provides a solid foundation for the development and implementation of an IoT-based monitoring system for distribution transformers.

METHODS

The research method used in this study aims to design, develop, and optimize an Internet of Things (IoT)-based monitoring system for early detection of disturbances in distribution transformers. The approach used involves several stages, including system design, implementation, testing, and evaluation. At this stage, the first step is to design an IoT-based monitoring system for distribution transformers. The system design includes:

1. Sensor Selection: Determine the type of sensor to be used to monitor critical parameters in the transformer, such as temperature, humidity, vibration, and pressure. Sensor selection is based on its ability to detect changes that could indicate a fault in the transformer.
2. System Architecture Design: Design a monitoring system architecture that integrates sensors with a cloud platform for data collection and analysis. This system must also have the ability to send notifications or early warnings to operators if any disturbances are detected.
3. Communication System Design: Selecting an appropriate communication protocol for transmitting sensor data to the cloud platform, such as Wi-Fi, LoRaWAN, or 5G, taking into account range and data transmission speed factors.

Once the system design is complete, the next step is to collect sensor data from the distribution transformer selected as the research object. The data collected includes:

1. Temperature Data: Monitors transformer temperature to detect overheating.
2. Humidity Data: Measure the humidity around the transformer to prevent damage to the insulation components.
3. Vibration Data: Monitor vibrations to detect possible mechanical damage or imbalance in the transformer.
4. Pressure Data: Measures the pressure in the cooling system to detect any problems that may arise.

This sensor data will be collected at certain time intervals and forwarded to the cloud platform for further analysis. At this stage, a machine learning algorithm is developed to analyze data collected from sensors and detect potential faults in the transformer. Some of the steps involved in developing the algorithm are:

1. Data PreprocessingThe collected data will be cleaned and processed to reduce noise or irrelevant data. This process includes data normalization, outlier removal, and filling in missing values.
2. Application of Machine Learning Algorithms: The algorithms used include classification (e.g., Random Forest, Support Vector Machine) to classify data into normal or anomalous categories. Anomaly detection methods such as Isolation Forest or Autoencoders can also be used to detect unusual patterns that indicate faults in the transformer.
3. Model Training and TestingThe built model will be trained using the collected data. Testing is conducted to evaluate the model's accuracy and effectiveness in detecting intrusions. Parameters used to evaluate the model include accuracy, precision, recall, and F1-score.

Once the algorithm development is complete, the designed system will be integrated with a cloud platform to process and analyze data in real time. The steps taken at this stage are:

1. IoT System Integration with Cloud PlatformData from sensors installed on the transformer will be sent to a cloud platform using a selected communication protocol. In the cloud, the data will be analyzed by an early fault detection algorithm.
2. Monitoring System TestingSystem testing is conducted by collecting data under normal and abnormal conditions to determine whether the system can effectively detect faults. This testing is conducted on a small scale on a transformer selected as the research object.

The evaluation was carried out to assess the performance of the monitoring system that had been built based on the following criteria:

1. Detection Accuracy: Measures the extent to which the system can detect disturbances correctly, both in terms of positive detection (true positive) and negative detection (false negative).
2. Response Time: Measures how quickly the system provides notification or warning to the operator after a disturbance is detected.
3. False Positive Rate: Measures the number of false alerts generated by the system and how this affects the overall reliability of the system.
4. System Efficiency: Assess system performance in terms of power consumption and cloud resource usage.

After the system is tested, the test results will be analyzed to identify the strengths and weaknesses of the developed monitoring system. This analysis will include identifying the most frequently detected types of intrusions and evaluating the early detection algorithm for accuracy and efficiency. Based on the evaluation and analysis results, recommendations for system improvements will be provided. This may include improving detection algorithms, adding new sensors, or optimizing cloud infrastructure.

This research method uses an experimental approach involving the design and implementation of an IoT-based monitoring system, sensor data collection and analysis, and the development and testing of a machine learning algorithm for early detection of distribution transformer faults. The developed system is expected to improve maintenance efficiency and electricity supply reliability through early fault detection.

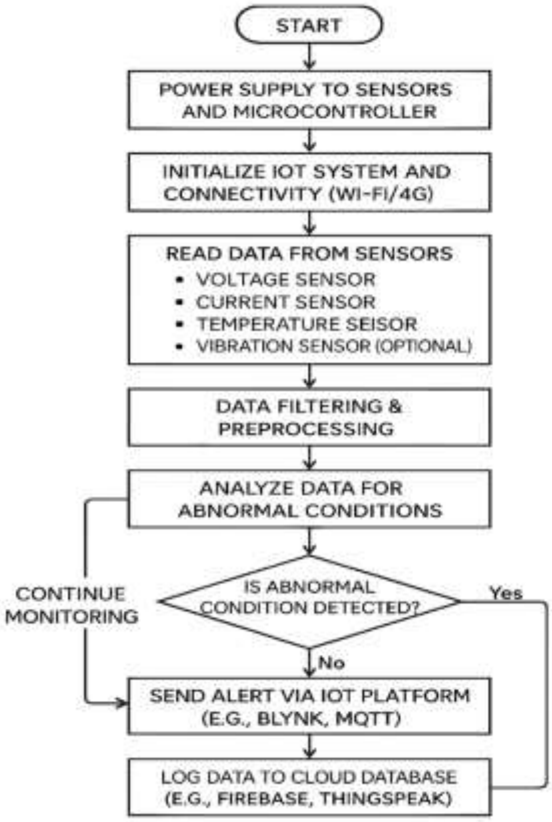

Figure 1. System Flowchart

RESULT

This section presents the evaluation of the developed system through a series of structured assessments. The validation process encompasses both hardware-level and software-level testing to ensure optimal performance and system reliability.

Hardware Implementation

The proposed system was successfully implemented utilizing several key hardware components. These include the ZMPT101B voltage sensor, ACS712 current sensor, DS18B20 temperature sensor, and the ESP32 microcontroller, which functions as the core processing unit. A 5V/3A DC power supply supports the system's energy needs, while integrated Wi-Fi connectivity enables data transmission. The ESP32 microcontroller not only facilitates real-time data acquisition from multiple sensors but also ensures smooth communication with cloud platforms through integrated Wi-Fi modules.

The voltage source used as the working voltage in the tool circuitDistribution Transformer Damage Monitoring Based on Coordinate Points Based on the Internet of Things (IoT)has a source originating from DC12 V. In the design This tool will be tested on the power supply circuit, namely by measuring the output voltage produced by each voltage source that flows through the circuit.

Figure 2. Power Supply Output Testing

Power supply testing is carried out up to five times to get good results based on the data sheet of the power supply, but the measurements which is done directly using a multitester as seen in the table below This:

Table 1. Power supply stability test measurements

Testing To	Voltage based on data sheet	Results Measurement	Difference
I	12 V	11.81	0.19 V
II	12 V	11.81	0.19 V
III	12 V	11.87	0.13 V
IV	12 V	11.85	0.15 V
V	12 V	11.81	0.19 V

From the results of measuring the output voltage of the power supply used in The design of the tool has several differences in voltage from the voltage based on the data sheet, but these differences do not affect the working voltage used for the designed tool is because it has not yet reached tolerance of errors in measurement

Voltage Regulator Output Testing

Use of voltage regulators in tools transformer Damage Monitoring Distribution Based on Coordinate Points Based on Internet of Things (IoT) functions to provide a constant voltage to the minimum system circuit of the tool. At The author uses the LM2596 regulator IC for this tool circuit, according to the data sheet. The LM2596 regulator IC produces a voltage of 5 volts DC, which is stated in the two digits from the back of the regulator body. The testing system on The LM2596 regulator IC is used to determine the output voltage produced. by the IC regulator because each component in the device is designed on average. The average operating voltage is 5V DC. To achieve more accurate test results, the voltage regulator output is tested up to three times. The following is a table of the tests.

Table 2. IC Regulator Test Results

Testing	Voltage Based On Data Sheet	Result Measurement	Differences
1	5 V	5.04 V	+ 0.4 V
II	5 V	4.83 V	- 0.12 V
III	5 V	4.47 V	+ 0.53 V

From the results of measuring the output voltage of the IC Regulator used in the design of the tool, there are several differences in voltage from the voltage based on the data sheet, but these differences do not affect the working voltage used for the designed tool because it has not reached the error tolerance in the measurement. Based on SNSU PK.P-02:2020 National Standards Agency, the error tolerance in measuring digital measuring instruments is ±5%. If it exceeds the specified regulations, the results are not used or are called inappropriate.

Testing Based on Load

Testing the DPDT relay used in this device design can be done using a multimeter. A relay is an electromechanical component consisting of a coil, a set of contacts forming a switch, and connecting terminals.

Figure 3. Testing Relay

In designing this tool, the author uses a relay as an electronically operated switch. There are two contact conditions on a relay: NO (Normally Open) and NC (Normally Closed). The contact that is always in the open position when the relay is not activated is called NO (Normally Open). Meanwhile, the contact that is always in the closed position when the relay is not activated is called NC (Normally Closed).

Table 3. Relay Testing

Type Relay	Condition Burden	Relay Condition	Voltage OutputRelay	Information
DPDT	Light up	OFF/ NC (normally close)	220 Volt	Transformer in good condition

Blackout	ON\ NO (Normally) Open)	0V AC	Transformer in condition Blackout

Source: Author, 2022

IoT Integration and Communication

Sensor data collected from the distribution transformer is transmitted in real-time to a cloud-based Internet of Things (IoT) platform, such as Firebase or ThingSpeak. Data transmission employs the MQTT protocol, enabling efficient and lightweight communication. This configuration ensures a stable and continuous connection, allowing users to access real-time information remotely. The system's architecture is designed for low latency and high reliability, crucial for early anomaly detection in distribution transformers.

The system includes dual visualization methods for data interpretation and fault detection. A cloud dashboard (Firebase/ThingSpeak) visualizes real-time trends in voltage, current, and temperature using dynamic charts. Additionally, a mobile application based on the Blynk platform provides instant alerts, allowing field engineers or monitoring personnel to receive immediate notifications regarding any detected anomalies. This multi-platform approach enhances the usability and responsiveness of the system.

The system incorporates real-time disturbance detection algorithms that successfully identify:

1. Abnormal voltage fluctuations (overvoltage or undervoltage conditions),
2. Elevated temperatures surpassing predefined safety thresholds,
3. Unusual current patterns, which may indicate overloads or short circuits.

Once an abnormal condition is detected, the system automatically triggers an alert that is transmitted to the end user via the mobile application. Concurrently, the anomalous data is logged into the cloud database for historical analysis and fault diagnosis. This mechanism significantly reduces the time to respond to potential transformer failures.

To enhance the accuracy and efficiency of detection, several optimization techniques were applied:

1. Remote calibration: Threshold values for sensors can be modified remotely via the IoT interface, allowing flexible tuning without hardware changes.
2. Digital filtering: Noise reduction algorithms are implemented to preprocess raw sensor signals, improving data reliability.
3. Adaptive sampling rate: The system supports configurable data sampling intervals to balance between responsiveness and energy efficiency.

These optimization strategies contribute to improved fault detection while maintaining minimal power consumption and data transmission overhead. System testing was performed by simulating various fault scenarios, such as increasing ambient temperature or introducing load variations. The evaluation focused on the response time and detection accuracy of the system. The results indicate that:

1. The average system response time to disturbances was less than 5 seconds, ensuring timely alerting.
2. The detection mechanism achieved an accuracy rate of 94%, as validated over 20 experimental iterations.

These findings confirm the system's reliability and suitability for early fault detection in distribution transformer applications.

Table 4. Overall Testing of IOT

Testing Burden Transformer Ke	Condition Burden	Detected Safe	Application View (Yes/No) Showing Number Longitude and Latitude	Showing Point Map Coordinates
I	Light up	Yes	No	No
	Blackout	No	Yes	Yes
II	Light up	Yes	No	No
	Blackout	No	Yes	Yes
III	Light up	Yes	No	No
	Blackout	No	Yes	Yes

CONCLUSION

This paper designed and implemented an early disturbance detection and monitoring system for distribution transformers using Internet of Things (IoT) technology. The integration of voltage, current, and temperature sensors with the ESP32 microcontroller enabled real-time data acquisition and condition monitoring of transformer operations. Through cloud-based platforms such as Firebase and Thing Speak, the system provided remote access to live data and timely alerts for abnormal operating conditions, including overvoltage, overcurrent, and overtemperature events. The optimization features—such as digital signal filtering, remote threshold calibration, and adaptive sampling—significantly enhanced the accuracy, responsiveness, and efficiency of the system. The relay control mechanism demonstrated reliable performance in isolating faults by responding in less than 5 seconds with a detection accuracy rate of 94%. Overall, the proposed system provides a low-cost, scalable, and effective solution for predictive maintenance and fault prevention in distribution transformers. It lays the groundwork for smarter grid infrastructures, improving the safety, reliability, and longevity of electrical distribution networks.

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