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Smart Transformer Monitoring and Alert System

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KEYWORDS

Arduino Uno, Node MCU ESP8266, Temperature Sensor, Current Sensor, Voltage Sensor, GSM Module, 2x16 LCD Display.

ABSTRACT

This project presents an IoT-based Smart Transformer Monitoring and Alert System that continuously measures critical transformer parameters such as temperature, current, and voltage using dedicated sensors. The collected sensor data is processed using an Arduino Uno and Node MCU ESP8266, displayed locally on a 16×2 LCD module, and transmitted wirelessly to a Blynk cloud platform for real-time remote monitoring. A GSM module is integrated to send SMS alert notifications when any monitored parameter crosses predefined safe threshold limits. The proposed system also includes an automatic protection mechanism using a relay to trip the transformer during overload conditions and a cooling fan to regulate excessive temperature rise. A buzzer provides immediate local alerts to indicate abnormal operating conditions. The developed prototype demonstrates a low-cost, reliable, and scalable solution for real-time transformer condition monitoring and protection, making it suitable for distribution substations and smart grid applications.

INTRODUCTION

Electrical power is one of the most critical resources for modern society and plays a vital role in domestic, commercial, industrial, and agricultural sectors. Power transformers are key components of electrical distribution systems, responsible for stepping up or stepping down voltage levels to ensure efficient and reliable power delivery. The continuous and safe operation of transformers is essential to maintain uninterrupted power supply and protect electrical infrastructure. In recent years, the increasing demand for electricity, rapid urbanization, industrial expansion, and unplanned load growth have led to frequent transformer overloading and failures. Transformers are often subjected to abnormal operating conditions such as overcurrent, overvoltage, and excessive temperature rise. These conditions can cause insulation degradation, reduced efficiency, permanent damage, or complete transformer failure. In developing countries like India, transformer failures result in power outages, economic losses, and increased maintenance costs, emphasizing the need for effective transformer monitoring and protection systems. Transformer health is determined by various electrical and thermal parameters such as current, voltage, and temperature. Conventional transformer monitoring methods rely on periodic manual inspection and offline testing, which are time-consuming, labor-intensive, and incapable of providing real-time condition assessment. In many cases, faults are detected only after severe damage has occurred, leading to unplanned outages and costly repairs. These limitations highlight the necessity for automated, continuous, and real-time transformer monitoring solutions. The Internet of Things (IoT) offers an efficient approach for continuous and remote monitoring of transformer operating conditions. IoT-based systems integrate sensors, microcontrollers, wireless communication modules, and cloud platforms to collect, process, and visualize data in real time. Such systems enable early fault detection, reduce human intervention, improve system reliability, and support predictive maintenance strategies in power distribution networks. This project presents an IoT-based Smart Transformer Monitoring and Alert System using Arduino Uno, NodeMCU ESP8266, GSM technology, and the Blynk cloud platform. The system continuously monitors key transformer parameters such as temperature, current, and voltage using appropriate sensors and provides both local display through an LCD module and remote cloud-based visualization. SMS alerts, a buzzer, an automatic cooling fan, and relay-based transformer tripping mechanisms are incorporated to enhance safety and protection. The proposed system offers a low-cost, reliable, and scalable solution for real-time transformer condition monitoring, making it suitable for distribution substations and smart grid applications.

LITERATURE SURVEY

Power transformer failures and distribution losses have become major concerns due to rapid urbanization, industrial growth, increased electricity demand, and unplanned load expansion. Several studies report that transformer failures are not only caused by aging equipment but also by continuous overloading, excessive temperature rise, and abnormal voltage and current conditions. Poor monitoring of transformer operating parameters reduces reliability and increases maintenance costs, even when adequate power infrastructure is available. These issues highlight the need for automated and real-time transformer condition monitoring systems to ensure efficient and reliable power distribution. Conventional transformer monitoring techniques mainly rely on periodic manual inspections and offline testing methods, which are time-consuming and unsuitable for continuous operation. Chan et al. proposed an internet-based substation monitoring system that enables remote supervision of electrical equipment parameters, reducing dependence on manual inspection. Similarly, Chopade introduced an IoT-based smart transformer protection system that integrates sensors and microcontrollers to monitor transformer health and generate alerts during abnormal conditions. These studies demonstrate that automated monitoring systems significantly improve response time and fault detection compared to traditional methods. Wireless Sensor Networks (WSNs) and IoT technologies play a crucial role in real-time transformer monitoring applications. Pule et al. surveyed WSN-based monitoring systems and discussed commonly used sensors, communication architectures, and challenges such as data reliability, energy efficiency, and network scalability. Sattar et al. demonstrated that low-cost IoT-enabled systems using current, voltage, and temperature sensors can effectively transmit transformer operating data to cloud platforms for remote monitoring and fault diagnosis. These works confirm the feasibility of sensor-based IoT solutions for continuous transformer condition assessment. Several researchers have focused on automation and real-time visualization of transformer parameters. Keshipeddi developed an IoT-based smart monitoring system using Arduino and NodeMCU to continuously observe electrical parameters without manual intervention. Shelke et al. proposed a transformer health monitoring system that displays sensor data locally and remotely through cloud platforms, enabling real-time visualization and early fault detection. These studies highlight the importance of combining automation with real-time data visualization to enhance transformer protection and maintenance efficiency. Recent studies have also emphasized the role of intelligent data processing and predictive analysis in transformer monitoring. Shi et al. applied advanced data analysis techniques to high-frequency sensor data for early fault detection and anomaly prediction in electrical systems. Wu et al. demonstrated that integrating IoT data with cloud computing improves fault identification and decision-making in smart grid applications. The base work by Bakar et al. validated the importance of real-time monitoring and accurate sensor calibration by comparing IoT-generated data with conventional measurement techniques, showing improved accuracy and system reliability. Overall, these studies indicate that integrating real-time sensing, IoT platforms, automation, and data analytics significantly enhances transformer monitoring and protection in modern power distribution networks.

METHODOLOGY

The proposed system adopts an IoT-based methodology to continuously monitor and protect a distribution transformer by measuring critical electrical and thermal parameters in real time. The system is designed using a combination of sensors, microcontrollers, wireless communication, cloud computing, and automatic protection techniques to ensure reliable transformer operation and fault prevention. Initially, key transformer parameters such as temperature, current, and voltage are measured using respective sensors. These sensors are interfaced with an Arduino Uno, which acts as the primary processing and control unit. The Arduino continuously acquires sensor data, converts raw electrical signals into meaningful values, and compares them with predefined safe threshold limits to detect abnormal operating conditions. The processed sensor data is displayed locally on a 16×2 LCD module, enabling on-site monitoring without the requirement of internet connectivity. For remote monitoring, the system employs a NodeMCU ESP8266 module, which transmits the sensor data wirelessly to the Blynk IoT cloud platform through Wi-Fi. The Blynk application provides real-time visualization of transformer parameters using dashboards and graphical widgets, allowing users to monitor transformer health from any location.

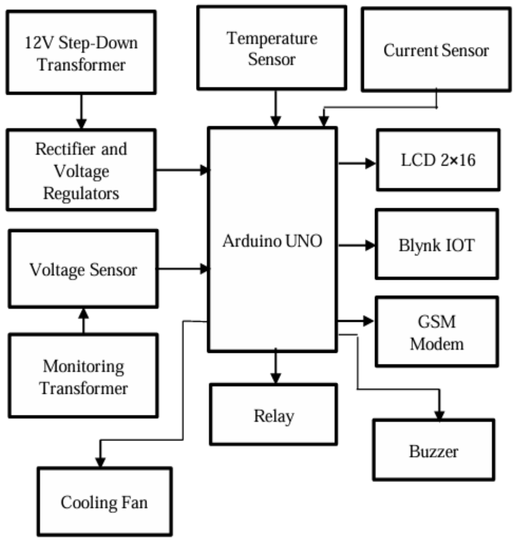

Fig 1: Block Diagram of Proposed Method

To enhance system safety and reliability, a GSM module is integrated to provide alert notifications. Whenever any monitored parameter exceeds its safe operating range, the system automatically sends an SMS alert to a registered mobile number and activates a buzzer for immediate local warning. In addition, an automatic protection mechanism is implemented using a relay circuit. If critical overload conditions occur, the relay disconnects the transformer from the load to prevent damage. A cooling fan is also activated automatically when excessive temperature is detected to reduce thermal stress on the transformer. A regulated power supply unit consisting of a step-down transformer, full-wave rectifier, filter capacitors, and voltage regulators ensures stable operation of all hardware components. The overall methodology enables real-time monitoring, remote accessibility, automated alerts, and intelligent protection, making the system suitable for transformer health monitoring in distribution substations and smart grid environments.

3.1 Current Sensor: The current sensor measures the load current flowing through the transformer. It produces an analog output proportional to the current magnitude, which is continuously read by the Arduino Uno. Overcurrent conditions caused by excessive load or short circuits are detected by comparing measured values with threshold limits. When an overcurrent condition is identified, the relay is triggered to disconnect the transformer, preventing damage.

3.2 Temperature Sensor: The DS18B20 temperature sensor is used to continuously monitor the operating temperature of the monitoring transformer in the proposed system. It provides precise digital temperature readings using a one-wire communication protocol, which allows reliable data transmission with minimal wiring complexity. The sensor is interfaced with the Arduino Uno, which regularly reads the temperature values and compares them with predefined safe threshold limits. When the transformer temperature exceeds the allowable limit, the system automatically activates the cooling fan to reduce excessive heat and prevent thermal damage. If the temperature continues to rise beyond safe conditions, alert mechanisms such as the buzzer and GSM module are triggered, and the relay can trip the transformer to ensure safe operation and protect connected components.

3.3 Voltage Sensor: The voltage sensor is implemented using a voltage divider circuit to step down the transformer voltage to a safe measurable level. The AC voltage is rectified and converted into a proportional DC signal suitable for the Arduino's analog input. Continuous voltage monitoring helps in detecting overvoltage or undervoltage conditions that may affect transformer efficiency and safety.

3.4 16×2 LCD Module: The 16×2 LCD module is used for local display of transformer operating parameters in real time. It displays temperature, current, voltage, and overload status, allowing operators to easily observe transformer conditions without relying on internet connectivity. This improves usability and provides immediate feedback at the installation site.

3.5 Buzzer: The buzzer provides an audible alert when abnormal conditions such as overcurrent, overvoltage, or overheating are detected. It acts as a local warning system, ensuring that nearby personnel are immediately notified of faults or overload situations.

3.6 Relay Module: The relay module acts as an automatic protection switch. It is controlled by the Arduino Uno and is used to disconnect the transformer from the load when any parameter exceeds safe operating limits. This tripping mechanism protects the transformer from severe damage due to prolonged overload or fault conditions.

3.7 Cooling Fan: The cooling fan is activated automatically when the transformer temperature exceeds the permissible limit. It helps in dissipating excess heat and maintaining safe operating temperature levels. This feature reduces thermal stress and enhances transformer reliability.

3.8 Node MCU ESP8266: The NodeMCU ESP8266 is used to provide Wi-Fi connectivity to the system. It receives processed data from the Arduino and uploads it to the cloud platform for remote monitoring. With built-in TCP/IP support, the NodeMCU enables real-time data transmission to the Blynk application. This allows users to access water quality data from anywhere using a mobile phone.

3.9 GSM Module: The GSM module is used to send SMS alerts to authorized personnel when fault or overload conditions are detected. This ensures reliable communication even in locations where internet connectivity is unavailable, improving system responsiveness and safety.

3.10 Blynk Platform: The Blynk platform is an IoT-based cloud service used for real-time monitoring of water quality parameters. In this project, sensor data collected by the Arduino and transmitted through the Node MCU ESP8266 is uploaded to the Blynk cloud. The platform displays live values using dashboards and enabling easy remote access. This improves monitoring efficiency and supports timely decision-making.

EXPERIMENTAL RESULTS

4.1 Circuit Implementation:

Below figure shows the complete circuit diagram of the proposed Smart Transformer Monitoring & Alert System. The circuit integrates a temperature sensor, current sensor, and voltage divider circuit with the Arduino Uno microcontroller. The Arduino continuously acquires sensor data, processes the signals, and displays real-time values and overload status on a 16×2 LCD module. The NodeMCU ESP8266 is interfaced with the Arduino to enable wireless data transmission to the Blynk IoT cloud platform for remote monitoring. A GSM module is
incorporated to send SMS alert notifications during overload or fault conditions.

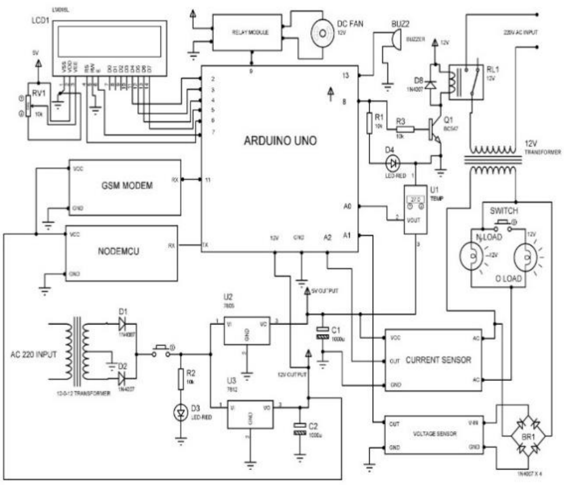

Fig 2 : Circuit Diagram of Proposed Method

A relay module is used to disconnect the transformer from the load when safe operating limits are exceeded, while a cooling fan is activated automatically during temperature overload conditions. A regulated power supply unit ensures stable and reliable operation of all system components. The circuit design confirms correct integration of hardware modules and reliable system functionality.

4.2 Hardware Prototype:

Below figure illustrates the developed hardware prototype of the Smart Transformer Monitoring & Alert System. The prototype demonstrates real-time acquisition of temperature, current, and voltage data from the monitoring transformer and successful processing by the Arduino Uno controller. Sensor readings and overload conditions are displayed locally on the LCD module and simultaneously transmitted to the Blynk platform via the NodeMCU ESP8266 for remote monitoring. When any parameter exceeds its predefined threshold value, the relay automatically trips the transformer, the buzzer provides an audible alert, and an SMS notification is sent through the GSM module. During temperature overload, the cooling fan is activated to reduce heat buildup. The prototype results validate the effectiveness of the system in real-time transformer condition monitoring and automatic protection.

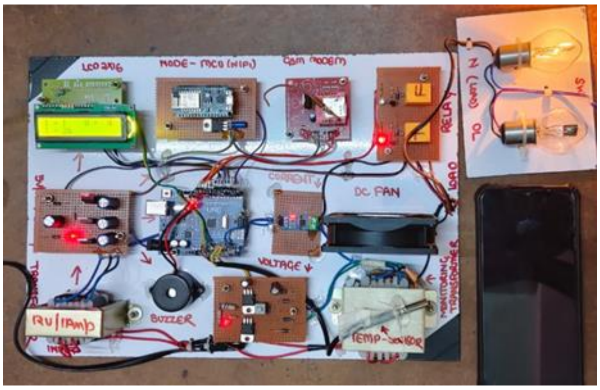

Fig 3 Hardware Prototype of Proposed Method

4.3 Blynk Console:

The Blynk Console provides a cloud-based dashboard for real-time monitoring of transformer operating parameters in the proposed system. As shown in Fig. 4, sensor data such as temperature, current, and voltage transmitted by the NodeMCU ESP8266 is displayed using value widgets and graphical indicators. The dashboard allows users to view live transformer conditions, observe parameter variations over time, and analyze operational trends. With premium features enabled, historical data storage and graphical analysis can be accessed for better performance evaluation. This cloud integration enables remote monitoring, improves data accessibility, and supports early detection of overload and fault conditions, enhancing overall transformer reliability and safety.

RESULTS

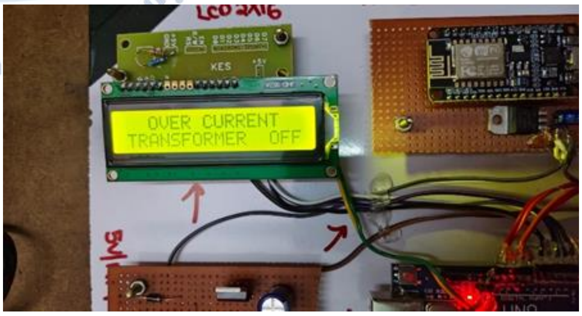

Fig 5.1 Output of Current Sensor

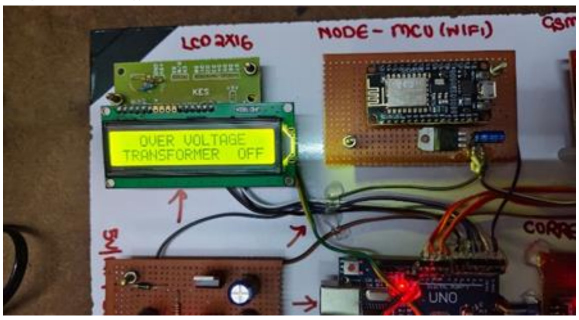

Fig 5.2 Output of Voltage Sensor

Fig 5.3 Output of Temperature Sensor

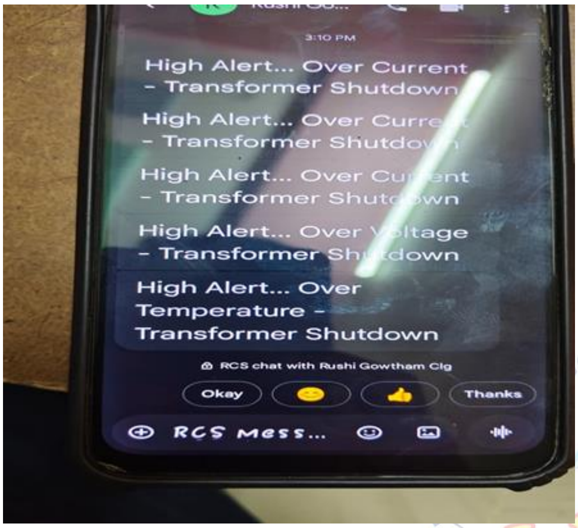

Fig 5.4 GSM Modem (SMS Alert) for all sensors

Fig 5.5 Buzzer Output for all Sensors

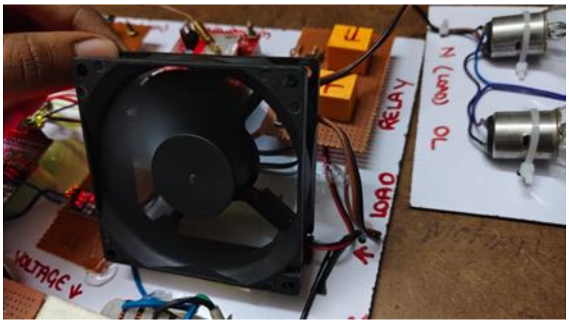

Fig 5.6 Cooling Fan

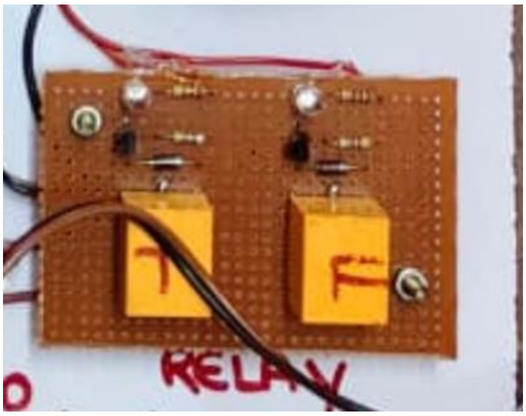

Fig 5.7 Relay Off (Transformer Trip)

Fig 5.8 Blynk IOT (App Notification)

CONCLUSION

This project presents an IoT-based real-time Smart Transformer Monitoring and Alert System designed to overcome the limitations of conventional transformer monitoring and protection methods. By integrating temperature, current, and voltage sensors with Arduino Uno and Node MCU ESP8266, the system enables continuous monitoring of critical transformer parameters and reliable data transmission. Real-time visualization through the Blynk cloud platform and alert notifications via the GSM module ensure timely detection of overload and fault conditions. The inclusion of a local LCD display, buzzer alerts, automatic cooling fan, and relay-based transformer tripping mechanism further enhances system safety and operational reliability. The developed prototype demonstrates stable performance and effective overload protection under real-time operating conditions, making the system suitable for applications such as distribution transformers, electrical substations, and smart grid infrastructure. The proposed solution is cost-effective, scalable, and adaptable, allowing future enhancements such as advanced fault prediction algorithms, improved sensor calibration, integration of additional transformer health parameters, and cloud-based data analytics. Overall, the project highlights the effectiveness of IoT and embedded systems in enabling intelligent transformer monitoring, preventive maintenance, and reliable power distribution systems.

FUTURE SCOPE

In the future, this project can be enhanced by adding more advanced sensors such as gas sensors, and vibration sensors to monitor the transformer's health more accurately. Cloud-based platforms other than Blynk can be used to store large amounts of data for long-term analysis. Machine learning algorithms can also be implemented to predict transformer failures before they occur. This will help in preventive maintenance and reduce power outages. The system can be scaled for use in real-time power substations. Further improvements can include replacing GSM with newer communication technologies like NB-IoT, LoRa, or 5G for faster and more reliable alerts. A mobile and web dashboard can be developed for utility operators to monitor multiple transformers at once. Automatic load balancing and smart cooling control can also be added to improve efficiency. The system can be integrated with smart grid technology for better power management. These upgrades will make the system more intelligent, reliable, and suitable for industrial applications.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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