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Original Article

Design and Implementation of Distribution Transformer Monitoring System Using GSM Technology

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Abstract - *This research paper presents designing and implementing a distribution transformer monitoring system to protect transformers from faults. In many developing countries, existing monitoring systems rely heavily on manual intervention, making it difficult to predict potential faults promptly. To address this, an Arduino microcontroller, sensors, and GSM technology were utilized in this research work to develop a system that automatically monitors and protects distribution transformers. The proposed system monitors key transformer parameters, such as low, high, and open circuits. The design was developed using Proteus software and C++ programming, and the results were analyzed in Microsoft Excel. The system detects transformer faults and automatically sends SMS alerts via the integrated GSM module. Validation was carried out through simulation and experimental testing of the prototype, and the results closely matched the design expectations, confirming the reliability of the proposed system.*

Keywords - *Distribution transformers, Fault detection monitoring, Open-circuit, High-voltage, Low-voltage, GSM technology.*

1. Introduction

Power and distribution transformers are the heart of electrical power generation and distribution systems, making them indispensable and among the most expensive components in an electrical power system. Therefore, it is imperative to design an effective protective mechanism for transformers to prevent extended downtime, loss of revenue, fatalities in healthcare facilities, and the high capital costs associated with their replacement in case of a breakdown. Operating distribution transformers within their rated limits extends their lifespan. However, when these transformers are overloaded, their longevity significantly decreases, leading to unexpected failures and disrupting power supply to many customers, thereby compromising system reliability. Overloading and insufficient cooling are the primary causes of distribution transformer failure. While many power companies use Supervisory Control and Data Acquisition (SCADA) systems to monitor power transformers in real-time, extending SCADA to distribution transformers is a costly solution. Distribution transformers are monitored manually, requiring personnel to visit the site regularly for maintenance and to record key operational parameters. However, this method cannot detect intermittent overloads or other transient issues [1]. Meanwhile, maintaining the health and reliability of distribution substations has always been challenging. Maintenance staff sometimes manually switch transformers off alongside circuit breakers to ensure proper operation. However, this approach often leads to excessive maintenance and delayed response to transformer failures [2]. Besides, power transformers can exceed $1 million in cost, while distribution service transformers range from around $1,000 to over $100,000, depending on size. Utilities should be motivated to proactively anticipate transformer failures, as preventing or minimizing these failures can reduce maintenance and operational costs and enhance system reliability [3]. Moreover, Pathak et al. [4] developed a system for monitoring key parameters of distribution transformers, including load currents, voltage, oil levels, and temperature. The system integrates a GSM modem with a microcontroller and sensors at the transformer site. Data is collected, processed, and stored using an analog-to-digital converter. In an emergency, a text message is sent to pre-designated mobile phones, allowing for early detection of issues and preventing transformer failures. Issa et al. [5] implemented a cloud-based monitoring system on a prototype 10 kVA, 0.415 kV distribution transformer connected to three homes for data collection. Over 14 days, the system monitored key parameters in real-time, including load current, phase voltage, oil level, and temperatures of both the ambient environment and transformer oil. These readings were compared with standard measuring instruments to validate accuracy. The data was transmitted to the ThinkSpeak cloud server via a NodeMCU (ESP 8266) module, with results accessible through ThinkSpeak's graphical interface. The findings demonstrated that the system effectively collects and transmits vital transformer data to monitoring centers. Meanwhile, a system was proposed for transformer protection using a PLC to monitor and manage key parameters like current, voltage, and temperature for both power and distribution transformers. The PLC continuously tracks these values, and if they exceed safe thresholds, the system automatically shuts down the transformer using relays to prevent damage. Additionally, real-time data is displayed on an HMI screen for easy access, enhancing the resilience and reliability of the power distribution system [6].

Besides, research in [7] focused on developing and testing a wireless sensor network to monitor distribution transformers, which is essential for reducing voltage levels for residential and commercial use. The system monitors key parameters like current and temperature to prevent damage and fires. Using Atmega 16 microcontrollers, the system was simulated and tested with real hardware. Results indicated that it effectively monitors and protects transformers by accurately tracking current and temperature in real-world conditions. Furthermore, research in [8] proposed an IoT-based system for real-time monitoring of distribution transformers to prevent issues like overheating and overloading. Sensors connected to an Atmega328 microcontroller track voltage, current, temperature, frequency, and oil levels. The data is transmitted to the cloud via a Wi-Fi module, enabling remote access from anywhere. This system helps detect potential problems early, eliminating the need for manual inspections.

It also supports local monitoring with an LCD and allows users to view the data remotely via the Blynk app on smartphones. However. a study in [9] proposed a method to detect phase failures in distribution transformers and notify the power distribution office when a fuse blows. The system employs an open fuse detector using an optocoupler, operational amplifier, and D-type flip-flop to identify and signal blown fuses. It detects rerouted current through the optocoupler when a fuse fails.

Nonetheless, Kavya et al. [10] introduced a method for monitoring the health and insulation of distribution transformers by utilizing data from existing smart meters, which are already prevalent in the U.S. This approach eliminates the need for additional sensors. The system can identify transformers with deteriorating insulation by analyzing voltage and power data, enabling utility companies to replace them before they fail. The method minimizes false alarms by comparing voltage ratios with neighboring transformers and increases accuracy by averaging data from multiple transformers. Meanwhile, Salihu et al. [11] emphasized that transformer overloading, caused by excessive current drawn by connected loads, leads to overheating, reduced operational efficiency, shorter lifespan, and potential failure. They proposed a sustainable protection system that monitors current during load conditions, isolates the transformer when exceeding its rated capacity, and immediately displays overload status, with validation through simulation and experimental testing confirming its effectiveness. Moreover, power and distribution transformers are vital components in electric power systems. They can be significant sources of outages for utility providers and disrupt power supply to customers when they fail. Regular maintenance and servicing of transformers are necessary but can be time-consuming and costly. By detecting transformer faults early with high accuracy, power system maintenance and servicing can be proactively scheduled, reducing the need for unplanned shutdowns.

Therefore, effective monitoring and diagnostic techniques for power transformers are essential to prevent unexpected failures and ensure the reliability of the power supply [12]. Various techniques have been implemented to monitor distribution transformer parameters. However, researchers have not focused on a comprehensive design, analysis, and implementation of a distribution transformer monitoring system that simultaneously detects parameters such as normal voltage, open circuit voltage, low voltage, and high voltage. Such a system should also send corresponding feedback signals via GSM technology to a control room or mobile device, enabling engineers to take timely measures to prevent transformer damage and reduce downtime.

This highlights a significant research gap in distribution transformer monitoring systems. Additionally, the improper monitoring or manual supervision of these transformer parameters is a major cause of distribution transformer failures or damage. Therefore, based on the analysis of existing literature on distribution transformer monitoring systems, this research proposes a solution that integrates a microcontroller, GSM module, LED, and buzzer to monitor key transformer parameters, including open circuits, high voltage, and low voltage. The system is designed to detect real-time faults and issue alerts, along with an audible warning, to the maintenance team whenever these parameters exceed safe limits. By incorporating the ability to monitor these critical parameters, the proposed system offers a more reliable and effective solution than existing systems lacking such capabilities. The novelty of the proposed transformer monitoring system lies in its ability to address existing gaps in distribution transformer monitoring designs.

It presents a comprehensive solution capable of monitoring and detecting normal voltage, open circuit voltage, low voltage, and high voltage conditions. Additionally, the system sends real-time status feedback via GSM to a control room or the operator’s mobile phone, enabling the maintenance team of the power utility provider to take prompt engineering actions. This proactive approach helps prevent total transformer failure, reduces downtime, and ensures a more reliable power system.

2. Design Materials and Methods

2.1. System Design and Simulation Analysis

The system modeling began with creating a block diagram, as shown in Figure 1, followed by the design and simulation of the distribution transformer monitoring system using GSM technology. Key components such as an Arduino Uno microcontroller, a GSM module, an LCD screen, a buzzer, and a rectifying circuit were integrated to ensure smooth operation. The system monitors critical parameters, including open circuits and high and low voltage. The microcontroller processes this data in real-time, detecting abnormalities and transmitting the information to a central server or monitoring station via the GSM network. This setup facilitates remote monitoring of the transformer, providing real-time status reports.

The LCD screen displays the data in a user-friendly format, allowing operators to address any issues easily. Additionally, the buzzer provides immediate audible alerts, ensuring swift responses to potential problems. The Arduino IDE was used to upload the operating instructions to the Arduino Uno via a USB programmer, facilitating the writing, building, and debugging of the C++ code. After compiling the program, the IDE's compiler generated a Hex file, which was imported into Proteus for simulation, allowing for an assessment of the code's performance in a real-world context. Proteus Design Suite (PDS), a Windows application, was used for simulation and schematic capture. Figure 2 illustrates the circuit diagram of the distribution transformer monitoring system designed with GSM technology for further clarity.

2.2. Construction Procedure and Analysis

The components for the construction were first tested using a multimeter to ensure proper operation. A 5V power supply from the SMPS was connected to the Arduino Nano and other components via the power rails, while a voltage regulator maintained a steady output. The primary windings of Transformers (TR1 and TR2) were connected to AC voltage sources (V1 and V2), with their secondary windings linked to bridge rectifiers (BR1 and BR2). Capacitors (C1 and C2) were connected across the DC output of the rectifiers to smooth the voltage. Switches (SW1 and SW2) were integrated in series with the transformer inputs to simulate open-circuit faults. A potentiometer (RV1) was connected to adjust the contrast of the LCD, which was wired to the Arduino Nano's A4 and A5 pins for power. The GSM module (SIM900D) was connected to the Arduino Nano's TX and RX pins, and a SIM card was inserted for communication. A transistor (Q3) linked to the Arduino controlled a buzzer, which triggered audible alerts during fault detection. After connecting all components as presented in Figure 3, the Arduino code was uploaded via the Arduino IDE to monitor parameters such as voltage levels and open circuits, display data on the LCD, and send SMS alerts using the GSM module. Tests were conducted by adjusting voltage levels with potentiometers and toggling the switches to simulate faults. Once verified, the circuit was constructed on a Veroboard and enclosed in a plastic casing, as shown in Figure 4.

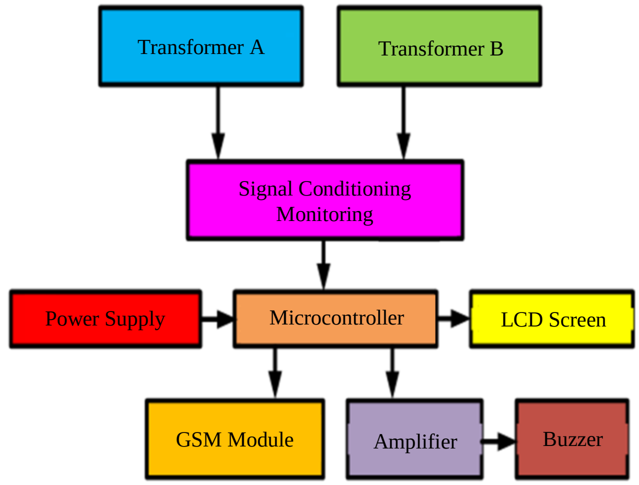

Fig. 1 The block diagram of the distribution transformer monitoring system using GSM technology

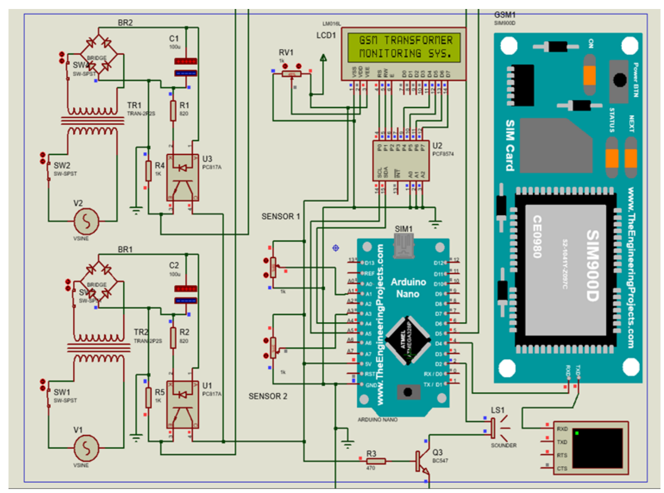

Fig. 2 Circuit diagram of the distribution transformer monitoring system using GSM technology

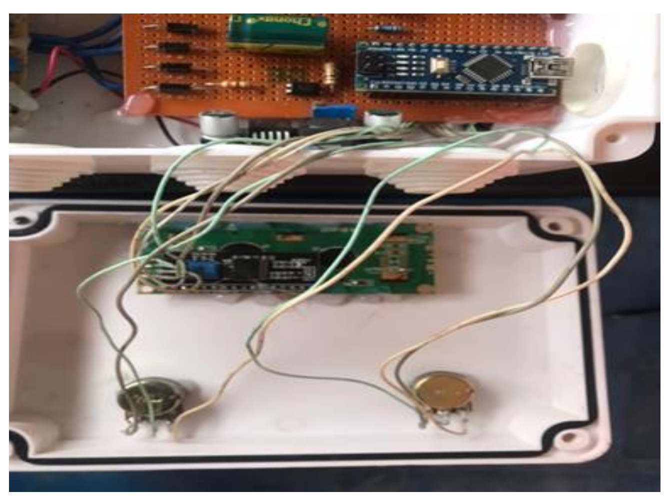

Fig. 3 Circuit construction analysis of the distribution transformer monitoring system

Fig. 4 Final packaging of the distribution transformer monitoring system

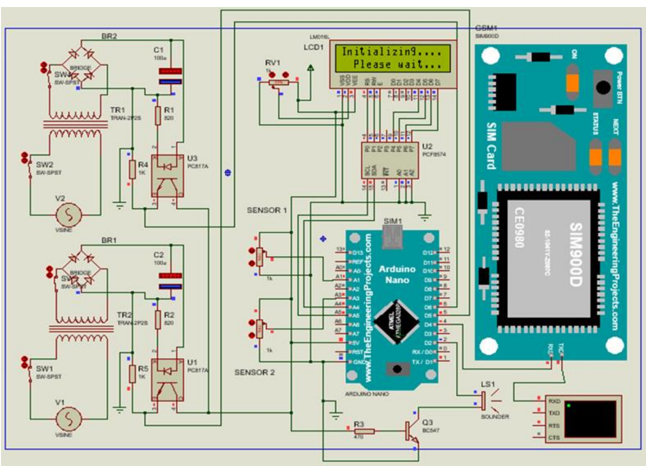

Fig. 5 The initialization state of transformer 1 and transformer 2 of the proposed design

3. Results and Discussion of the Design

3.1. Simulation Results

Based on the simulation results from the Proteus Software, the designed system was tested by initializing it, as shown in Figure 5. When a high-voltage, low-voltage, or open-circuit condition occurs, the microcontroller activates the system and sends an alert via GSM. The LCDs the fault in text format, allowing for easy identification, while the buzzer emits an audible alarm immediately upon fault detection. Transformers 1 and 2, as shown in Figure 6, display the current operational status. The results indicate that both transformers are functioning within their normal operating modes. Figure 7 illustrates the status of Transformers 1 and 2. Transformer 1 has experienced a fault, specifically an open circuit or no voltage condition, while Transformer 2 remains in its normal operating state. In Figure 8, the status of Transformers 1 and 2 is illustrated. Transformer 2 has encountered a fault, specifically an open circuit or no voltage condition, halting its normal function.

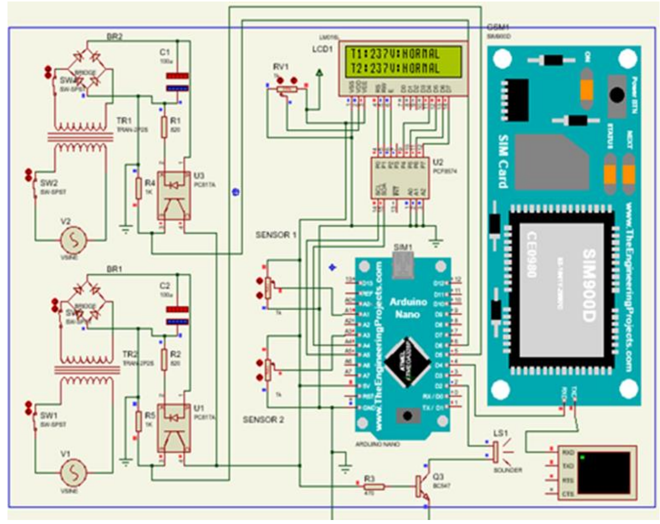

Fig. 6 The state of transformer 1 and transformer 2 at its normal condition

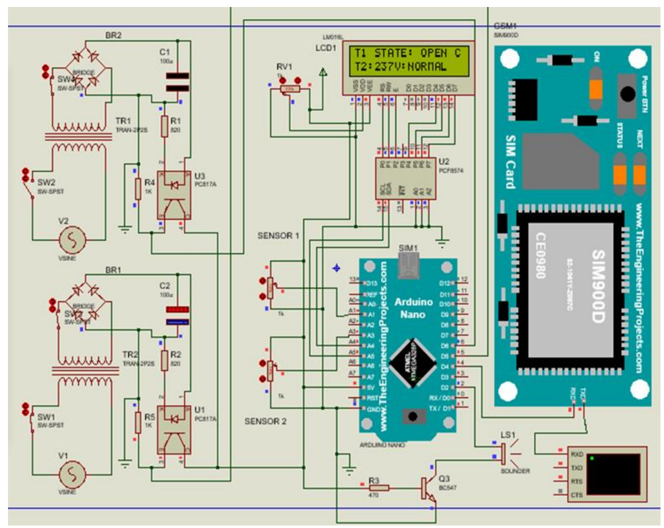

Fig. 7 Transformer 1 at its open circuit state

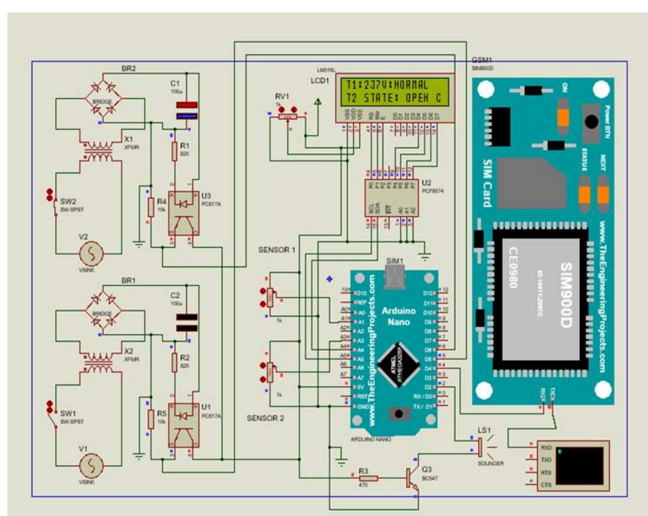

Fig. 8 Transformer 2 at its open circuit state

In contrast, Transformer 1 continues to operate smoothly, maintaining a stable and uninterrupted current flow. This contrast between the two transformers highlights the vulnerability of Transformer 2, where its fault stands in stark relief against the steady performance of Transformer 1, which remains unaffected. Figure 9 shows the status of Transformers 1 and 2. Transformer 1 has experienced a fault due to high voltage, while Transformer 2 remains in its normal operating state. Figure 10 illustrates the status of Transformers 1 and 2.

Transformer 2 has experienced a fault due to high voltage, while Transformer 1 continues operating normally. The status of Transformers 1 and 2, as shown in Figure 11, indicates that Transformer 1 operates at a lower voltage, while Transformer 2 functions normally. The status of Transformers 1 and 2, as shown in Figure 12, indicates that Transformer 2 operates at a lower voltage while Transformer 1 remains in its normal condition.

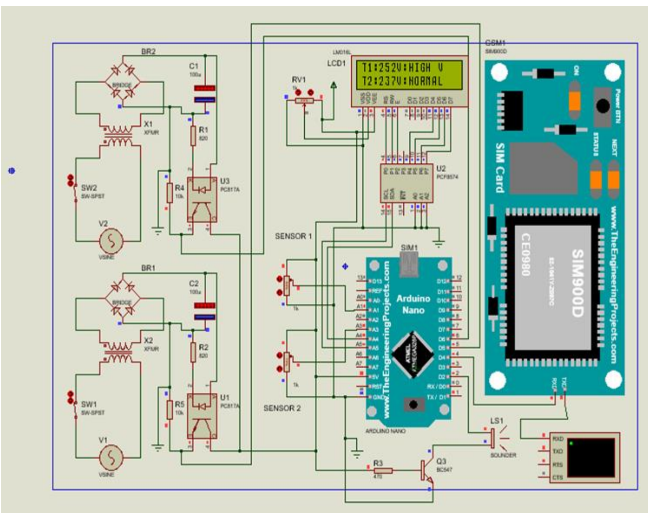

Fig. 9 Transformer 1 at its high voltage state

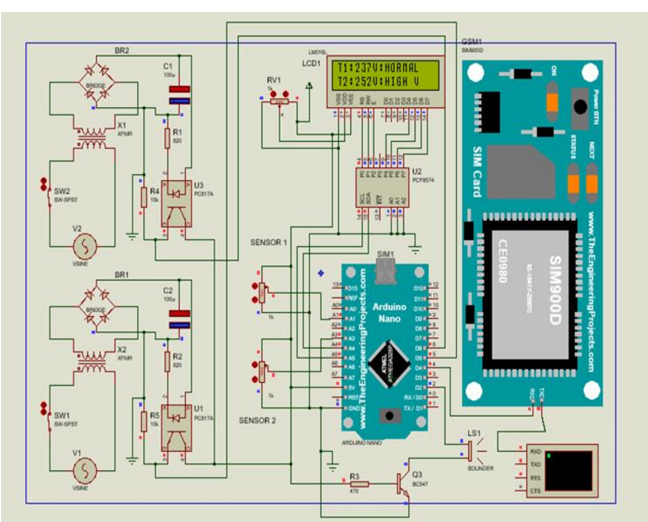

Fig. 10 Transformer 2 at its high voltage state

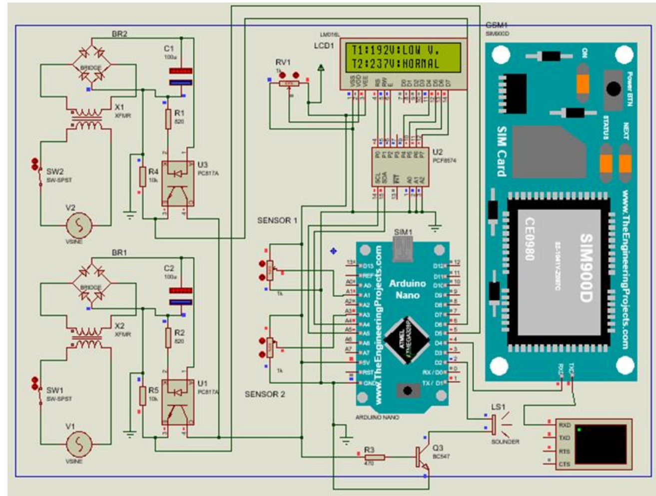

Fig. 11 Transformer 1 at its low voltage state

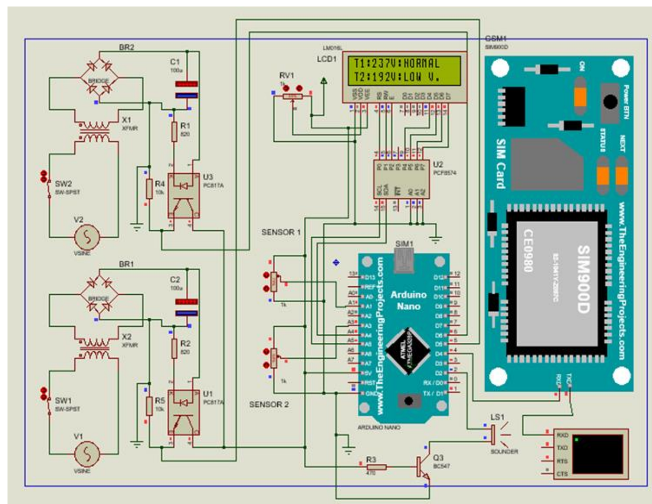

Fig. 12 Transformer 2 at its low voltage state

3.2. Experimented Results

As shown in the figures below, the practical tests of the circuits confirm the simulation results in prototype form. Figure 13 illustrates explicitly the normal operating states of both Transformer 1 and Transformer 2. Figure 14 shows that Transformer 1 operates with no voltage, indicating an open circuit, while Transformer 2 remains in its normal operating state. Figure 15 shows that Transformer 2 operates with no voltage, indicating an open circuit, while Transformer 1 remains in its normal operating state. Figure 16 shows that Transformer 1 operates at a low voltage while Transformer 2 remains in its normal operating condition. Figure 17 shows that Transformer 2 operates at a low voltage while Transformer 1 remains in its normal operating condition. Figure 18 indicates that Transformer 1 operates at a high voltage while Transformer 2 remains in its normal operating condition. Finally, Figure 19 indicates that Transformer 2 operates at a high voltage while Transformer 1 remains in its normal operating condition

Fig. 13 The picture of the implemented system (transformer 1 and transformer 2) at its normal state

Fig. 16 The picture of the implemented system of transformer 1 at a low voltage state

Fig. 14 The picture of the implemented system of transformer 1 in an open circuit state

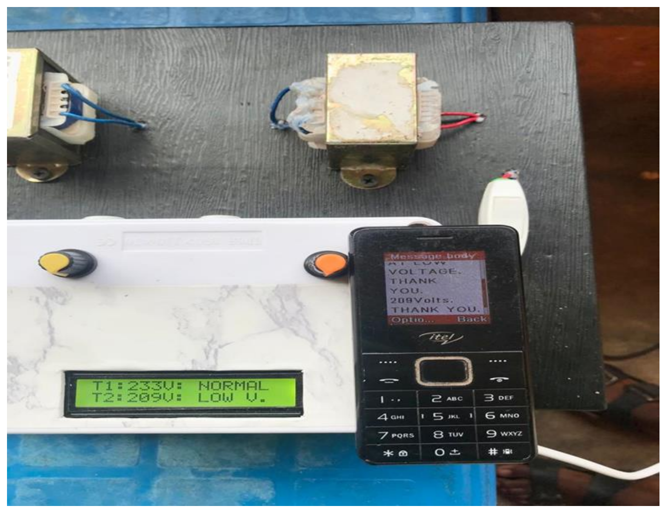

Fig. 17 The picture of the implemented system of transformer 2 at a low voltage state

Fig. 15 The picture of the implemented system of transformer 2 in an open circuit state

Fig. 18 The picture of the implemented system of transformer 1 at a high-voltage State

Table 1. Comparison of the simulation readings (volts) and the experimental findings

Number of Faults	Simulated Fault Detected (volts)	Experimented Fault Detected (volts)	LCD Display	State of Buzzer
Normal	237	234	Normal	Off
Open Circuit	0	0	Fault Detected	ON
High Voltage	252	251	Fault Detected	ON
Low Voltage	192	209	Fault Detected	ON

Fig. 19 The picture of the implemented system of transformer 2 at a high voltage state

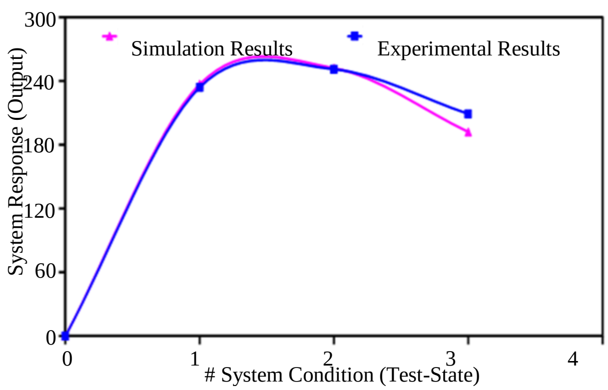

Fig. 20 The graph of the design and implementation of a distribution transformer monitoring system using GSM technology

Figure 20 illustrates the graph depicting the results of designing and implementing the distribution transformer monitoring system utilizing GSM technology.

4. Discussion

Based on the design results, when a fault occurs, the microcontroller detects the issue and triggers the GSM module to send a notification. Simultaneously, the buzzer alerts the maintenance team. Both the simulation and experimental tests closely aligned, confirming the system's effectiveness. Four tests were conducted to validate the design, with Figures 5 to 12 showing simulated results. Figures 5 and 6 represent the system's initialization and normal states. Figures 7 to 10 illustrate various faults: open circuits in transformers 1 and 2 and high voltage conditions for both transformers. Figures 11 and 12 depict low voltage conditions. The experimental results are shown in Figures 13 to 19, confirming similar findings. The simulations and experiments displayed fault details on the LCD and sent corresponding messages via GSM. Table 1 summarizes the simulation (237V normal, 0V open circuit, 252V high voltage, and 192V low voltage) and experimental results (234V normal, 0V open circuit, 251V high voltage, and 209V low voltage). Figure 20 compares these results visually. The system performed as expected in both cases, with faults detected and communicated via GSM.

5. Conclusion

This research demonstrates the integration of GSM technology with Arduino to improve the monitoring of distribution transformers. Compared to manual methods, the GSM-based system offers a more reliable solution for tracking key parameters like high and low voltage and open circuits. GSM is favored for its affordability and widespread availability, especially in developing countries, making it superior to older technologies such as Radio Frequency (RF) for long-distance communication. The system, tested and validated using Proteus software and an experimental prototype, displays results on an LCD and sends alerts to mobile phones. Despite occasional delays due to GSM network traffic, the system enhances transformer monitoring efficiency, safety, and convenience over traditional manual methods.

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