Determination of the Impact of Sensor Technology on 33/11kV Substation Transformers

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Abstract- The growing need for reliable and cost-effective monitoring in electrical power systems has brought sensor-based technologies to the forefront of substation management. This paper presents the design, simulation, and analysis of a remote transformer monitoring system using Arduino-based sensor modules at a 33/11kV substation. Conventional supervisory systems like SCADA, though effective, are cost-intensive and limited in real-time adaptability. The proposed system integrates temperature, current, and ultrasonic sensors, interfaced with an Arduino UNO microcontroller, to achieve real-time monitoring and detection of transformer overloads, temperature anomalies, and oil level fluctuations. This model enhances operational transparency and fault detection without significant infrastructural overhaul. Performance evaluation using simulation data from the Egbu Injection Substation revealed that sensor integration can pre-emptively identify hazardous conditions, reduce failure rates, and optimize transformer lifespan. Findings suggest that the proposed system is a scalable and economical alternative to traditional SCADA frameworks, capable of increasing the resilience and intelligence of modern substations.

I. INTRODUCTION

The reliability of electrical power systems hinges significantly on the effective management of substation components, especially power transformers. Substations operating at the 33/11kV voltage level serve as critical nodes in electricity distribution, bridging high-voltage transmission with medium-voltage local supply. Historically, the maintenance and fault detection strategies for such substations have revolved around periodic manual inspections or costly SCADA-based solutions. However, these approaches are limited in their capacity for continuous, real-time monitoring and proactive fault detection, often resulting in delayed responses and equipment degradation [1], [2].

Sensor technologies have emerged as transformative tools in this domain, enabling the continuous acquisition of electrical, thermal, and mechanical data from critical substation assets. These sensors, when deployed on transformers, measure parameters such as load current, winding and oil temperature, vibration, and oil level, thereby facilitating early anomaly detection and condition-based maintenance [3], [4]. With advancements in embedded systems, microcontrollers such as the Arduino UNO can serve as cost-efficient processing units for sensor networks. These systems are programmable, flexible, and capable of interfacing with communication modules such as GSM for remote data transmission.

In this study, we simulate an intelligent transformer monitoring system that integrates multiple sensors with an Arduino platform. This research aims to demonstrate how sensor technology can mitigate the challenges of conventional monitoring by offering real-time visibility into transformer health. The proposed solution is tested using empirical data from Egbu Injection Substation in Owerri, Nigeria, to assess its ability to detect overloading and thermal stress on the transformer.

This paper is structured as follows:
Section 2 presents a comprehensive review of literature on substation sensors and related works. Section 3 describes the methodology, including the materials and simulation setup. Section 4 presents the results and their analysis, while Section 5 concludes the study and outlines future recommendations.

II. LITERATURE REVIEW

The integration of sensor technology into substation infrastructure represents a significant milestone in the evolution of power system monitoring and automation. In a 33/11kV substation, numerous components such as transformers, circuit breakers, busbars, and isolators play pivotal roles in managing power flow and ensuring grid stability. These components, particularly power transformers, are vulnerable to faults arising from thermal stresses, insulation degradation, and overload conditions. The deployment of sensors on such components facilitates real-time health diagnostics, preventive maintenance, and data-driven operations [1], [3].

Power transformers, being among the most valuable and failure-prone elements in substations, require stringent monitoring protocols. Typically, sensors such as Resistance Temperature Detectors (RTDs), thermocouples, optical fibre temperature sensors, current transformers, and ultrasonic probes are used to detect abnormalities [5], [6]. For instance, temperature sensors enable detection of overheating due to excessive load, while current sensors reveal load imbalance and potential short circuits. Figure 2.2 illustrates the strategic positioning of sensors within a transformer for optimal data acquisition.

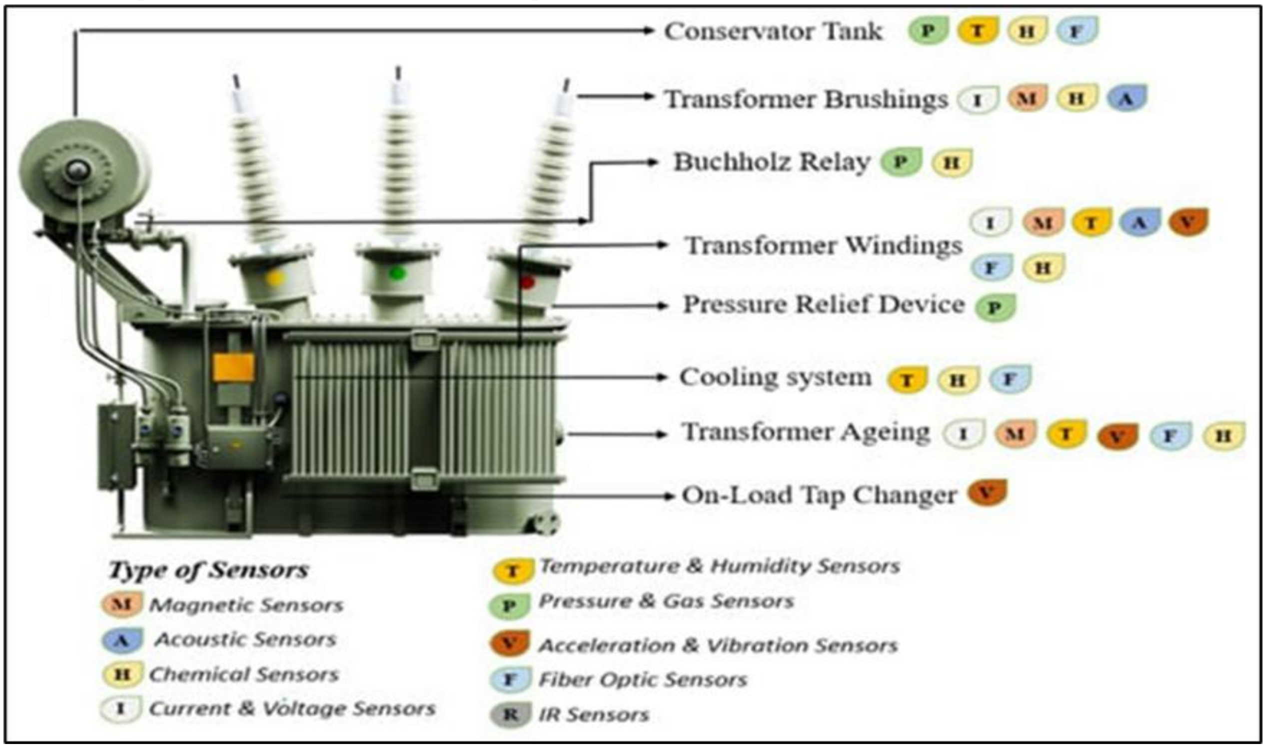

Fig. 1: Key sensing areas of a power distribution transformer

The necessity for sensors in transmission and distribution systems stems from the increasing demand for real-time condition monitoring, especially in contexts where manual inspections are impractical or economically unfeasible. Remote Terminal Units (RTUs), Phase Measurement Units (PMUs), and SCADA systems rely heavily on sensor inputs for precise operation. However, SCADA systems, although sophisticated, suffer limitations in flexibility and economic scalability, especially in developing regions [6].

Several researchers have explored alternatives to SCADA by integrating low-cost microcontrollers and sensors. Chopra et al. [8] introduced a transformer overload protection system using thermal modelling, emphasizing the importance of real-time temperature tracking for system protection. Patil [9] and Ojo [10] proposed GSM-based distribution transformer monitoring solutions capable of remote fault communication via SMS. These systems measured voltage, current, and temperature to detect faults. Hashemzadeh et al. [11] developed a SCADA-based diagnostic model leveraging neural networks for transformer health assessment, though the cost and complexity of such models remain a concern.

The existing literature reveals a critical research gap: the lack of affordable, flexible, and scalable systems capable of providing near-SCADA performance in resource-constrained settings. The use of Arduino-based platforms integrated with sensors has emerged as a promising alternative. Arduino boards are open-source, highly customizable, and support real-time processing of sensor data. Table 2.2 highlights a comparison between conventional SCADA systems and Arduino-based projects in terms of cost, customization, security, and simulation capabilities.

Table 1: Comparison between a SCADA system and an Arduino-Based Project

	SCADA	Arduino based project
Customization	Limited	Highly Customizable
Cost-Effectiveness	High Installation Costs	Cost-Effective
Data Analytics	Limited	Advanced Data Analytics
Flexibility	Limited	Highly Flexible
Cyber Security	Vulnerable	Enhanced Security
Simulation Capabilities	Limited	Advanced Simulation Capabilities

Additionally, Figure 2.1 offers a system-wide view of the roles of sensors in transmission and distribution networks.

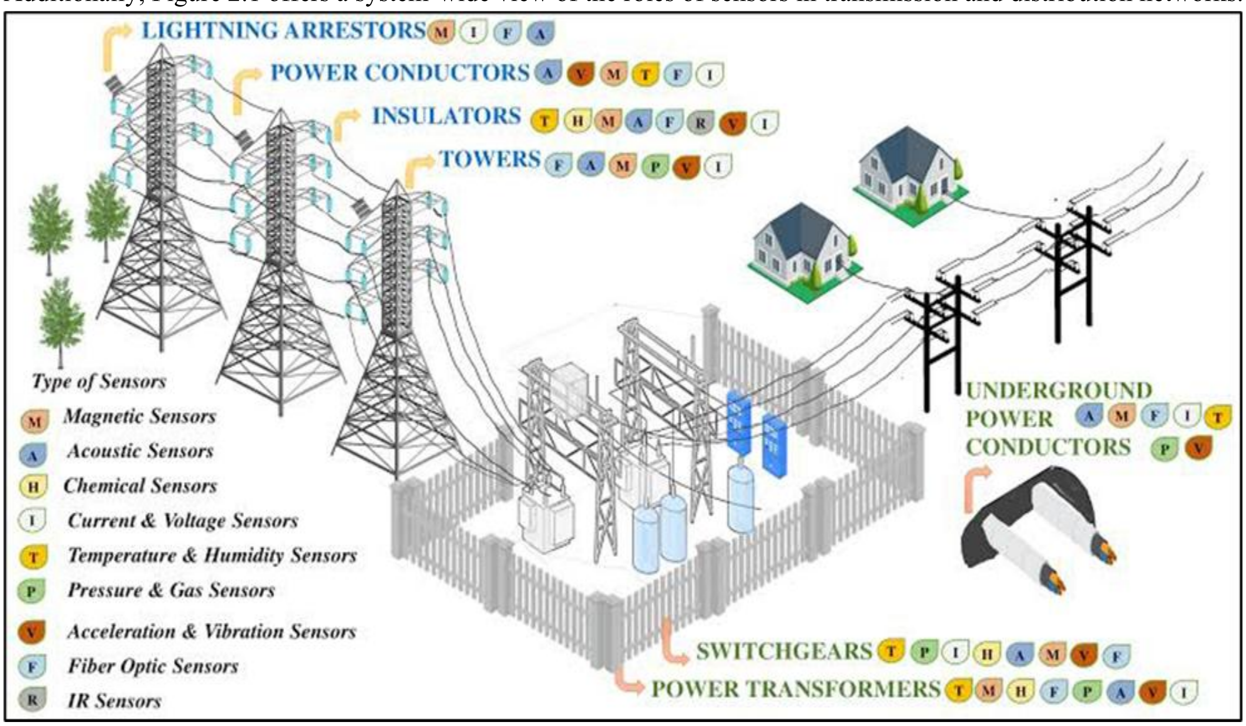

Fig. 2: Key sensing areas in a transmission and distribution system

These findings collectively suggest that Arduino-sensor integration can provide a robust framework for real-time substation monitoring. By leveraging such a system, operators can achieve improved fault detection accuracy, optimize transformer lifespan, and ensure enhanced system reliability at a fraction of the SCADA cost.

III. METHODOLOGY

The methodology adopted for this research involved the simulation of a remote transformer monitoring system using Arduino hardware architecture in conjunction with a suite of analogue and digital sensors. The core aim was to evaluate the efficacy of real-time data acquisition and monitoring of critical transformer parameters namely: current, temperature, and oil level - under varying load conditions. The implementation was executed using Proteus simulation software, which enabled precise modelling of sensor behaviour and transformer load conditions.

3.1 System Architecture

The simulated system was structured into three main subsystems:

Sensing Unit: This included temperature sensors (LM35), current sensors (ACS712), and an ultrasonic sensor to capture oil level and vibration. Each sensor was strategically deployed to measure specific transformer conditions in real-time.

Processing Unit: An Arduino UNO served as the data acquisition and control core. It interfaced with all sensors and processed their analogue signals using its internal Analog-to-Digital Converter (ADC).

Transmitter and Receiver Units: A GSM module (SIM900D) and a 20x4 LCD display were used for remote data transmission and local visualization, respectively.

3.2 Sensor Configuration

Temperature Sensor

The LM35 sensor was used for monitoring oil temperature. This sensor offers high linearity and operates directly from the 5V DC supply of the Arduino. It outputs 10 mV/°C and connects to analog pin A3.

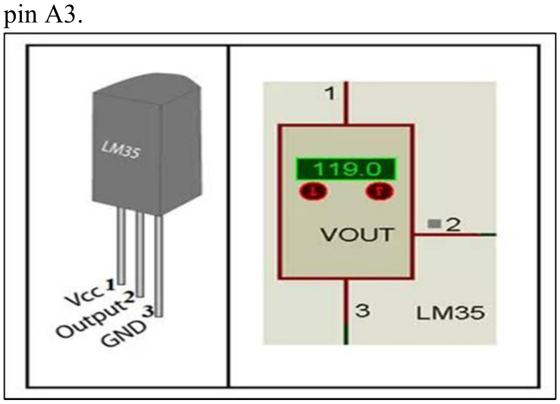

Fig. 3: Temperature sensor (LM35)

Current Sensors

Four ACS712 sensors (20A and 58A rated) were deployed. Three sensors monitored line currents, while one measured eddy current from the transformer. These sensors convert the sensed current into a voltage that is read by the Arduino via analog pins A0, A1, and A2.

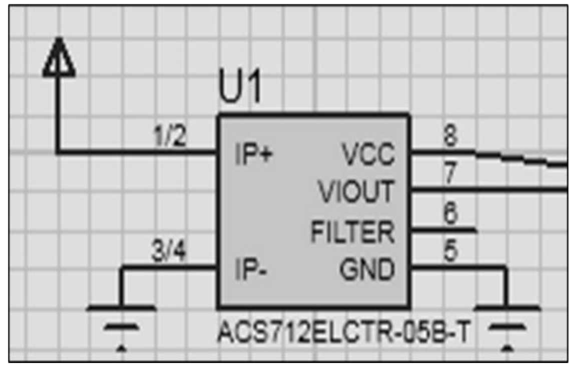

Fig. 4: Current sensor (ACS712)

Ultrasonic Sensor

This sensor was deployed to assess oil tank level and mechanical vibration. It uses the trigger-echo method for distance measurement and connects to digital pins 8 (trigger) and 7 (echo) of the Arduino.

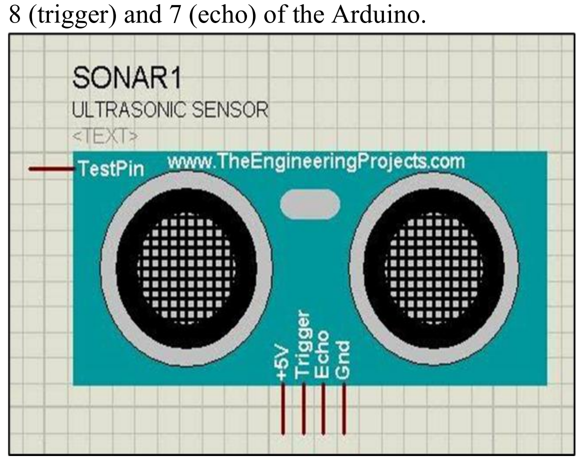

Fig. 5: Ultrasonic sensor

3.3 Arduino and Power Interface

Arduino UNO

The Arduino UNO controlled all sensor operations, read analog signals, and sent processed data to the LCD and GSM module. It was programmed using C++-based Arduino IDE code.

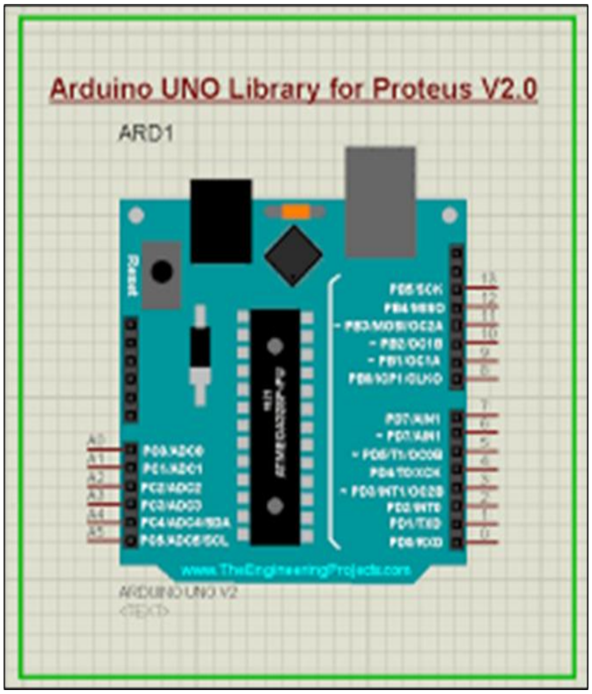

Fig. 6: Arduino UNO

GSM Module (SIM900D)
This module was responsible for sending SMS alerts in the event of abnormal readings such as transformer overheating, line overcurrent, or oil depletion.

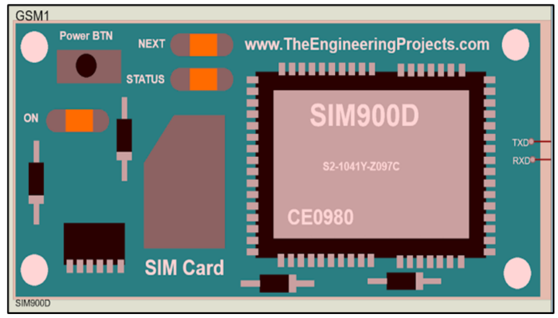

Fig. 7: GSM Module

LCD Display (20x4)
A liquid crystal display was used to show live readings from all three phases, oil level, and temperature for user reference.

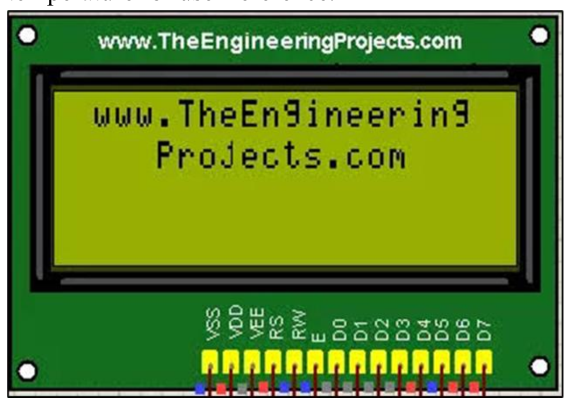

Fig. 8: LCD Display

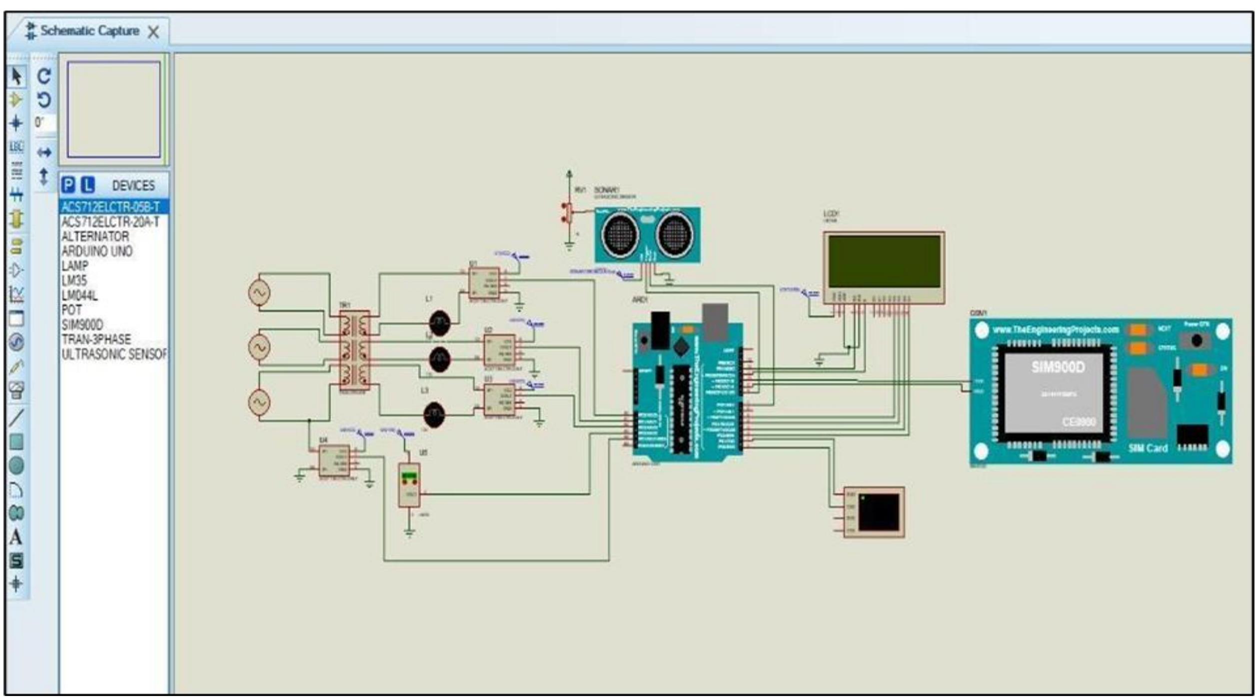

Fig. 9: Assembly of the components

3.4 Simulation Approach

The Proteus simulation connected the sensors to the Arduino via analogue/digital pins. Variable loads were simulated to model current surges and evaluate overload detection thresholds. The system was powered using a simulated DC generator, with 5V VCC to mirror real transformer conditions.

Sensor outputs were validated by simulating abnormal conditions:

High temperature: simulated by increasing LM35 input

Overcurrent: simulated by increasing line load

Oil depletion: simulated by reducing echo response from the ultrasonic sensor

Alarm conditions were displayed on the LCD and sent via SMS using GSM as shown from Fig 10 to Fig 13.

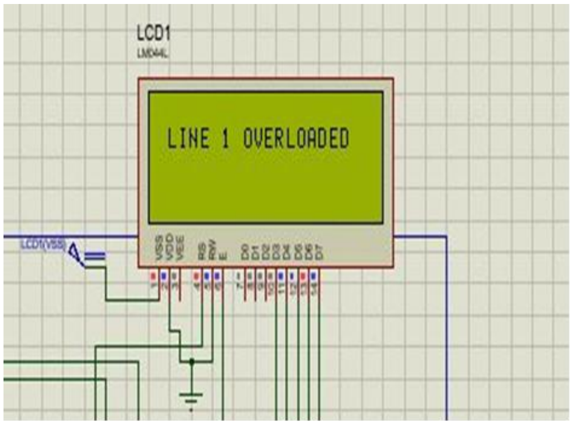

Fig 10: LCD showing when line 1 is overloaded

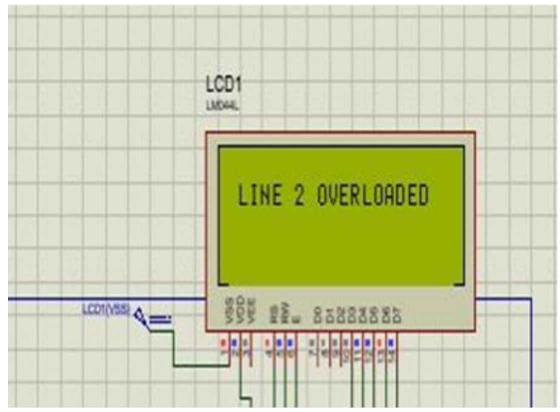

Fig 11: LCD showing when line 2 is overloaded

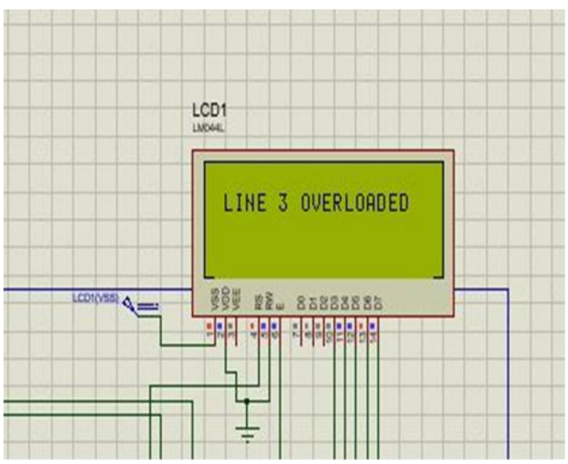

Fig 12: LCD showing when line 3 is overloaded

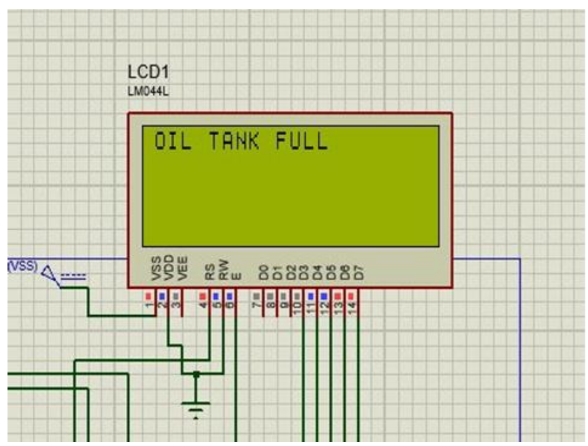

Fig 13: LCD indicating the level of the transformer oil tank

3.5 Field Data Integration

To validate the simulation, real-world load data was collected from the 11kV feeder at Egbu Injection Substation in Owerri. This included hourly current and usage data for three feeder zones: Township, N/OWERRI, and NAZE as shown in Tables 2 and 3.

Table 2: 11kV feeder at Egbu Injection Substation for January 2023

DATE	TOWNSHIP (hrs)	TOWNSHIP (A)	N/OWERRI (hrs)	N/OWERRI (A)	NAZE (hrs)	NAZE (A)
1	10.97	227	7.12	247	11.75	350

2	4.38	240	0	0	0.15	400
3	12.37	267	5.82	235	5.82	315
4	13.03	269	6.52	272	6.81	257
5	7.55	238	8.71	251	6.84	424
6	5.24	302	3.18	169	8.45	358
7	2.53	304	4.02	268	0.1	400
8	6.9	288	4.51	285	0	0
9	6.35	281	9.56	298	0.03	0
10	5.95	321	6.07	90	7.63	398
11	10.15	336	14.44	231	7.61	411
12	9.2	289	11.72	309	9.23	383
13	9.93	307	4.93	300	6.1	267
14	2.75	320	3.48	267	8.33	355
15	4.05	304	5.65	78	13.73	378
16	14.97	313	16.38	290	0.38	0
17	3.3	282	0.34	309	3.27	354
18	11.85	271	8.1	289	12.4	409
19	11.42	267	8.83	258	7.07	410
20	7.7	274	5.87	298	10.02	321
21	11.23	322	6.68	258	5.16	435
22	10.65	300	9.52	278	7.38	400
23	17.63	309	9.64	284	0	0
24	15.38	293	4.51	273	8.24	298
25	5.37	294	10.6	314	11.95	400
26	4.03	308	11.9	294	3.07	402
27	7.83	290	4.15	281	5.2	376
28	6.63	340	9.8	300	10.58	395
29	10.05	280	10.33	314	12.25	379
30	9.59	252	14.17	307	9.01	404
31	10.88	277				

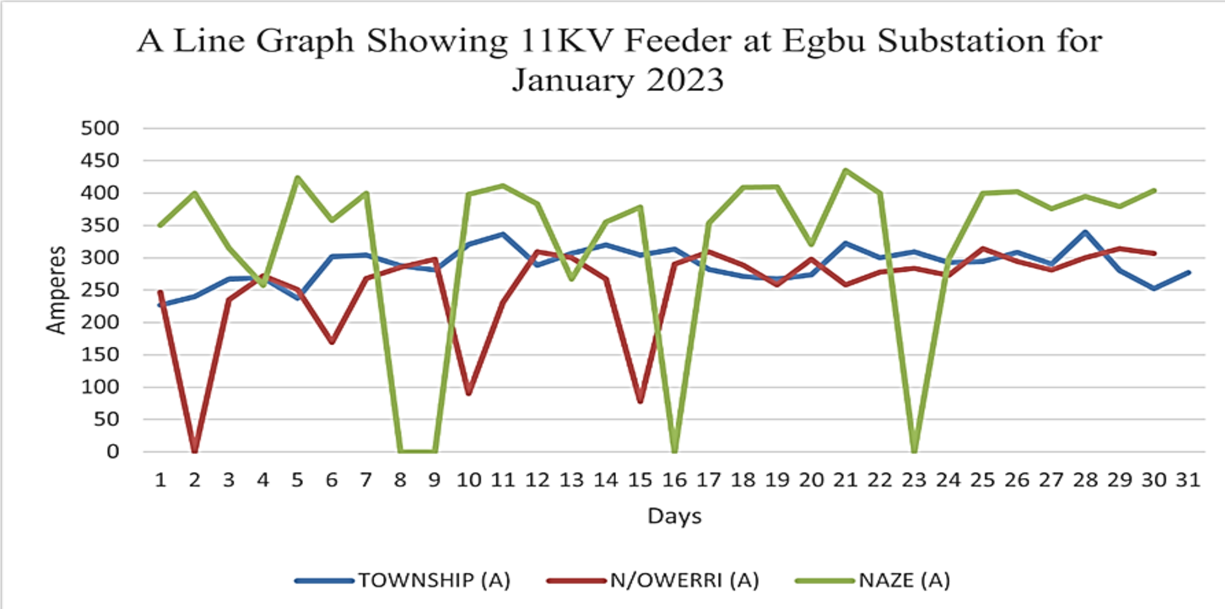

Fig. 14: Line Graph Showing 11kV Feeder at Egbu Substation for January 2023

Table 3: 11kV feeder at Egbu Injection Substation for February 2023

DATE	TOWNSHIP (hrs)	TOWNSHIP (A)	N/OWERRI (hrs)	N/OWERRI (A)	NAZE (hrs)	NAZE (A)
1	14.28	292	12.06	282	2.85	412
2	7.32	258	8.72	327	4.77	379
3	9.53	289	14	314	8.83	365
4	3.85	218	3.85	304	12.62	350
5	14.38	251	15.9	310	3.12	352
6	8.63	285	5.5	310	13.07	388
7	7.78	283	4.18	372	5.7	370
8	7.3	284	10.94	356	8.28	356
9	9.73	317	11.18	340	11.42	380
10	11.12	310	12.6	305	11.15	416
11	13.25	298	13.19	304	4.61	404
12	6.07	270	11.33	303	2.13	390
13	19.7	280	7.23	300	9.18	390
14	4.44	246	8.74	286	6.31	345
15	8.38	278	8.38	315	12.45	376
16	12.3	290	12.92	345	5.48	289

17	11.13	281	10.87	251	6.09	375
18	13.58	262	9.98	277	8.85	390
19	9.55	243	13.05	295	7.27	315
20	10.63	266	14.47	308	4.85	306
21	12.05	260	13.68	269	9.95	400
22	8.25	280	8.08	265	11.32	380
23	7.86	282	13.47	334	9.88	403
24	5.25	287	10.12	296	5.57	360
25	9.61	263	0	0	0	0
26	15.13	233	6.77	284	4.6	400
27	11.63	261	13.97	281	8.2	310
28	16.38	288	14.43	292	6.63	300

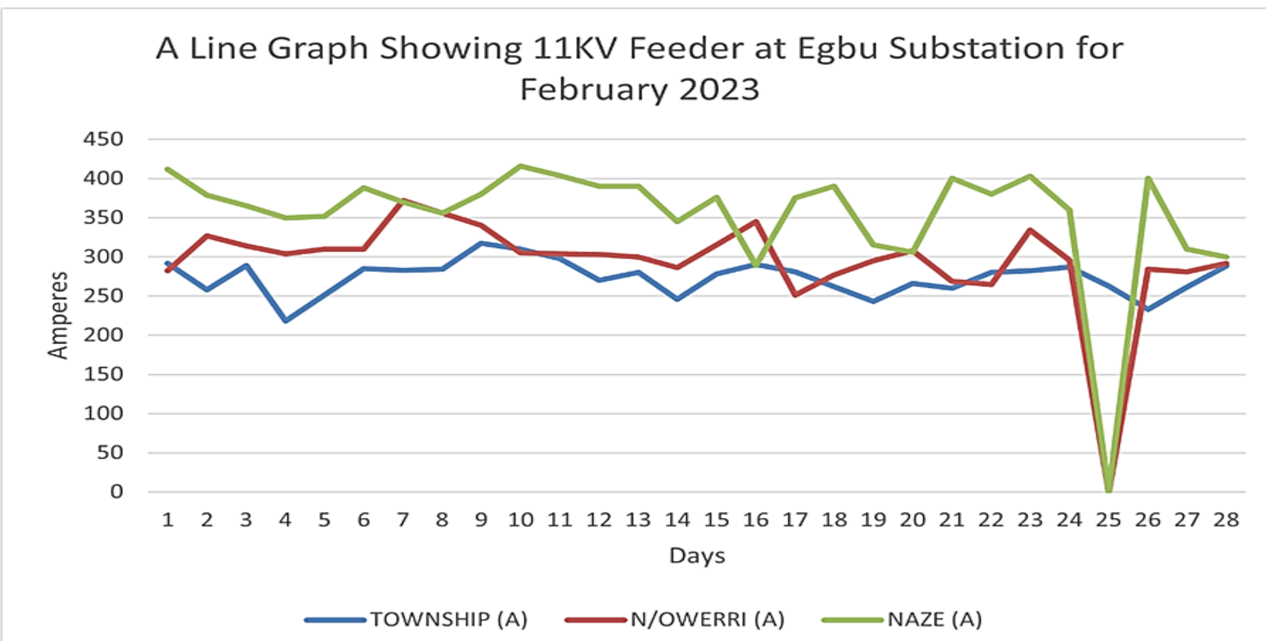

Fig. 15: Line Graph Showing 11KV Feeder at Egbu Substation for February 2023

These datasets were used to simulate realistic transformer loading scenarios in Proteus and validate the system's responsiveness to actual substation stress conditions.

IV. RESULTS

This section presents the outcomes of the Proteus-based simulation of the Arduino-driven monitoring system, integrated with multiple sensors, and validated using real-world load data from the Egbu Injection Substation. The simulation was configured to observe the system's ability to monitor temperature, current, and oil levels under various operational conditions and to detect potential transformer faults, particularly overloads.

4.1 Sensor Load Configuration and Measurement

The transformer parameters were monitored over time using three current sensors connected to analogue pins A0, A1, and A2. The load conditions, in terms of voltage and current levels, were simulated with varying intensities to represent real substation stress.

Table 4: Loads Details

SENSOR ID	1	2	3
PIN	A0	A1	A2
VOLTAGE (KV)	9	8	10
CURRENT (A)	20	30	10
VPP (KV)	4	6	2
PLP (KV)	2	3	1

The current and voltage configurations across the three sensors were as follows:

Sensor 1: 9 kV, 20 A

Sensor 2: 8 kV, 30 A

Sensor 3: 10 kV, 10 A

Peak-to-peak voltage (VPP) and peak load potential (PLP) were derived using the following formulae:

Voltage Drop = V_{IN} -V_{LOAD}

VPP = 2 x Voltage Drop

PLP = VPP/2

Current = Voltage Drop/Load Resistance

4.2 Time-Variant Current Simulation Results

The current values for each sensor were observed over a 15-second simulation window. As time progressed, each sensor registered increased current levels, indicating overload development on respective transformer lines.

Table 5: Results Obtained from Current Sensors

Time	Sensor 1(A)	Sensor 2 (A)	Sensor 3 (A)
0	0	0	0
1	0.5	0.9	0.2
2	1.6	2	1.3
3	2.3	2.9	1.7
4	3.1	4.7	2.6
5	4.7	5.9	2.7
6	5.4	7.6	4.3
7	7.3	8.6	5.7
8	7.8	9.2	6.1
9	8.4	10.4	6.4
10	9.2	13.7	6.9
11	10.2	14.5	7.3
12	10.7	16.4	7.8
13	11.4	18.4	8.4
14	11.9	19.8	9.2
15	13.4	21	9.8

This data reveals that:

Sensor 1: Rose from 0 A at 0 sec to 13.4 A at 15 sec

Sensor 2: Rose from 0 A to 21 A

Sensor 3: Rose from 0 A to 9.8 A

This upward trend reflects increasing load demand on the transformer lines, eventually triggering overload flags in the system.

4.3 Temperature and Oil Monitoring Results

As load-induced current increased, the transformer temperature, detected via the LM35 sensor, also rose. When the temperature exceeded a predefined threshold of 75°C, the system triggered a warning message on the LCD and transmitted an SMS alert via the GSM module.

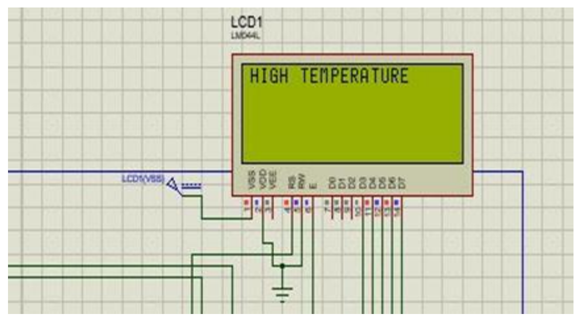

Fig. 16: LCD Indicating High Temperature of the Transformer

Simultaneously, the ultrasonic sensor monitored transformer oil level. A simulated drop in oil below the threshold level was successfully captured and displayed. Conversely, a 73% oil tank level was also detected and recorded as shown in Fig 17.

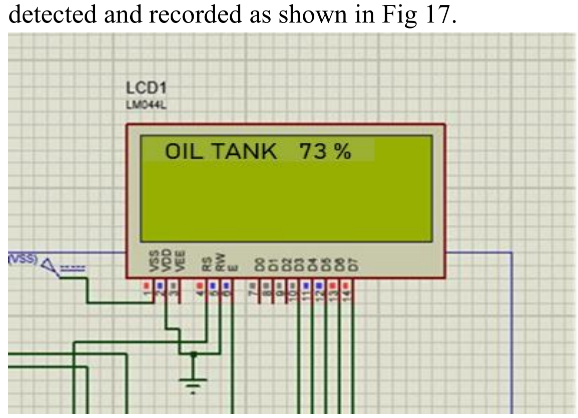

Fig. 17: LCD Indicating 73% Oil Level of the Transformer Tank

These results confirm the system's capability to detect:
Transformer overheating
Oil depletion
Line overloads
All events were simultaneously reported via LCD and GSM interface, providing both local and remote operator alerts.

4.4 Field Data Simulation Outcome
Using historical load data from Egbu Injection Substation (Tables 2 and 3), the simulation modelled actual load patterns. The plotted graphs for January and February 2023 showed load surges that matched with the overload patterns seen in the simulation.
This confirmed the real-world applicability of the system, reinforcing that Arduino-based sensor platforms can serve as reliable substitutes for expensive SCADA installations in detecting and managing transformer faults.

V. DISCUSSION

The integration of sensor technology in monitoring 33/11kV substation transformers presents a compelling alternative to conventional supervisory systems, offering real-time responsiveness, cost-efficiency, and modular scalability. The results obtained from the simulation strongly support the argument that Arduino-based systems can deliver effective and proactive transformer condition monitoring. These outcomes are aligned with global research trends advocating for the decentralization of power infrastructure diagnostics using embedded systems and wireless technologies [2], [6], [10].
The current sensors demonstrated consistent and reliable tracking of real-time current flow across all three transformer phases. As evidenced in Table 4.2, current levels progressively rose under simulated load stress, and the system correctly responded with LCD notifications and GSM-based alerts. This behaviour mimics real transformer overload events, wherein delay in intervention could lead to insulation breakdown, overheating, or even catastrophic transformer failure. The detection system's ability to promptly identify such overloads within a 15-second window highlights the viability of Arduino-controlled protection relays as referenced in Chopra et al. [8].
Temperature monitoring using the LM35 sensor also proved highly effective. When the transformer exceeded the 75°C thermal threshold, the sensor-triggered alert successfully activated visual and remote warnings. This feature mirrors the approach proposed in Patil's GSM-based transformer control model [9], which emphasized thermal protection as a key preventive strategy. Similarly, the ultrasonic sensor measuring oil level helped detect potential cooling failures, validating its application in non-invasive maintenance monitoring.
The comparative analysis between SCADA systems and Arduino-based models (Table 2.2) underscores several key advantages of the latter. Unlike SCADA systems which are typically hard-coded, cost-intensive, and vulnerable to cybersecurity threats, Arduino-based systems offer enhanced flexibility, low installation costs, and customizable firmware features. Moreover, the addition of GSM modules improves scalability, allowing field units to communicate with central control rooms or mobile devices without reliance on internet-based cloud infrastructure — a crucial factor in developing regions with limited connectivity [11].
Furthermore, the application of real feeder data from the Egbu Injection Substation adds real-world credibility to the simulation. The January and February 2023 data revealed significant current variability and load spikes across Township, N/OWERRI, and NAZE zones. These patterns matched the simulation results in terms of system stress and overcurrent detection, confirming the Arduino-sensor platform's applicability in live environments.
Despite the system's promising performance, limitations remain. The Proteus environment, although comprehensive, does not replicate high-voltage power system dynamics in full fidelity. Environmental conditions such as temperature fluctuations, electromagnetic interference, and component aging were not simulated. These factors may affect sensor accuracy and signal integrity in live deployments. Additionally, the Arduino UNO has limited processing power and memory, which could constrain performance if scaled to monitor multiple transformers simultaneously.
Nevertheless, the research highlights the transformative potential of sensor-based remote monitoring systems. Future iterations can incorporate Internet of Things (IoT) architectures for cloud-based analytics, wireless mesh communication, and machine

learning-based fault prediction algorithms, as suggested in [2] and [4].

VI. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study has successfully demonstrated the potential of sensor technology in enhancing the monitoring, protection, and operational efficiency of 33/11kV substation transformers. The Arduino-based simulation system was designed to observe and respond to three critical parameters: load current, temperature, and oil level. The results validated the platform's capacity to provide real-time status updates and fault alerts using a cost-effective, scalable framework. Unlike traditional SCADA systems, the proposed solution is not only affordable but also highly adaptable, which makes it particularly attractive for deployment in underserved or developing regions.

The system's responses to simulated transformer overload, excessive heating, and oil depletion were timely and accurate, as evidenced by the sensor outputs and LCD/GSM notifications. Moreover, the integration of real-world feeder data from Egbu Injection Substation reinforced the relevance and reliability of the model under typical distribution system conditions. These findings align with similar implementations of GSM-based transformer monitoring [9], SCADA diagnostic systems [11], and IoT-based sensor platforms [2], demonstrating the universality of the sensor-driven approach in substation automation.

Ultimately, this paper supports the notion that transitioning toward intelligent, sensor-enabled substations is a critical step in modernizing power infrastructure. By leveraging simple, open-source microcontrollers such as Arduino and combining them with widely available sensor technologies, power utilities can achieve significant gains in fault detection, system reliability, and data-driven decision-making, all while reducing operational costs.

6.2 Recommendations

Based on the findings of this study, the following recommendations are proposed for future work and practical deployment:

1. Adoption of IoT Architecture: Future versions of this system should incorporate cloud-based IoT platforms to allow centralized data aggregation, advanced analytics, and remote dashboard access. This would support long-term trend analysis and fault forecasting.

2. Wireless Communication Enhancement: Integration of Wi-Fi or LoRa modules alongside GSM would improve redundancy in communication and provide broader network coverage for remote installations.

3. Real-World Deployment and Calibration: Field trials in actual substations are essential to validate sensor accuracy under high-voltage, real-world environmental conditions, including electromagnetic interference and component aging.

4. Energy Autonomy: Incorporating renewable energy sources such as solar panels can ensure continuous operation of the monitoring system, especially in off-grid or outage-prone locations.

5. Advanced Analytics: Implementing machine learning algorithms for pattern recognition and fault classification could significantly enhance the predictive capabilities of the system.

6. Security Layer Integration: As the system is remotely accessible, adding encryption protocols and secure authentication mechanisms is vital to mitigate cybersecurity threats.

6.3 Challenges Encountered

During simulation, several limitations were identified:

The Proteus software was unable to accurately emulate real-world voltage levels such as 33kV or 11kV.

Environmental effects such as humidity and temperature fluctuations were not modelled.

The lack of high-fidelity component libraries constrained the realism of certain transformer behaviours.

These challenges, though not critical to the simulation outcome, highlight areas for enhancement in future studies or live implementations.

REFERENCES

[1] V. Sharma, "Sensor Technology in 33/11kV Substation," Vellore Institute of Technology, Vellore, India, 2023.

[2] K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi, and M. Mustaqim, "Internet of Things (IoT) for next-generation smart systems: A review of current challenges, future trends, and prospects for emerging 5G-IoT scenarios," IEEE Access, vol. 8, pp. 23022–23040, 2020.

[3] Electric Power Research Institute, Sensor Technologies for a Smart Transmission System, EPRI Technical Reports NSAC, Palo Alto, CA, USA, 2009.

[4] D. Srivastava and M. M. Tripathi, "Transformer Health Monitoring System Using Internet of Things," in Proc. 2018 2nd IEEE Int. Conf. Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 2018, pp. 903–908.

[5] N. Haque, J. V. Ittiarah, T. K. Gangopadhyay, and S. Chakravorti, "Temperature Monitoring of Power Transformer Using Fiber-optic Sensor," in Proc. 1st Conf. Power, Dielectric and Energy Management at NERIST (ICPDEN), Arunachal Pradesh, India, Jan. 2015, pp. 1–5.

[6] J. Liu, Z. Zhao, J. Ji, and M. Hu, "Research and application of wireless sensor network technology in power transmission and distribution system," Intell. Converg. Netw., vol. 1, pp. 199–220, 2020.

[7] D. Srivastava and M. M. Tripathi, "Transformer Health Monitoring System Using IoT," in Proc. 2018 2nd IEEE Int. Conf. Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 2018, pp. 903–908.

[8] D. Chopra, K. Kalia, and A. K. Narula, "Transformer Overload Protection Relay Design Using Transformer Thermal Modeling," IEEE Trans. Power Syst., vol. 18, no. 2, pp. 847–855, 2003.

[9] V. Patil, "Distribution Transformer Monitoring and Controlling using GSM Modem," Int. J. Innov. Res. Sci. Eng. Technol., vol. 10, no. 6, pp. 7065–7068, 2021.

[10] T. P. Ojo, "Design and Implementation of a GSM-based Monitoring System for a Distribution Transformer," Eur. J. Eng. Technol. Res., vol. 7, no. 2, pp. 22–28, 2022.

[11] S. Hashemzadeh, A. S. Khoda, M. Saremzadeh, and M. Vossoughi, "SCADA-based Monitoring and Diagnostic System for Transformer Health Condition Assessment," IET Electr. Power Appl., vol. 7, no. 2, pp. 127–134, 2013.

[12] "LM35 Current Sensor," Bing, [Online].Available:https://www.bing.com/Lm35+current+sensor. [Accessed Apr. 2025].