Power Transformer Monitoring and Notification System Using IoT Technique

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***Abstract*—Power transformers are critical assets in electrical transmission and distribution networks, and their unexpected failure can result in service interruption, equipment damage, economic losses, and safety hazards. Conventional transformer inspection methods generally depend on periodic manual measurements, which may not provide continuous information about developing abnormal conditions. This paper presents the design and development of a low-cost, multi-parameter** Power Transformer Monitoring and Notification System **based on an ESP32 38-pin controller. The proposed system continuously monitors transformer-related electrical and environmental parameters using a 0–25 V DC voltage sensor, ACS712 current sensor, DHT11 temperature and humidity sensor, ultrasonic sensor for oil-level estimation, gas leakage sensor, and fire detection sensor. A 20×4 I²C LCD provides local real-time information, while the ESP32 transmits measured parameters to the ThingSpeak IoT platform for remote visualization and historical analysis. A SIM800L GSM module provides SMS-based fault notifications when predefined threshold conditions are exceeded. A GPS module provides the geographical coordinates of the monitored transformer so that maintenance personnel can identify the affected installation. In addition, a relay interface is incorporated to disconnect or reconnect the associated load according to locally detected faults or authorized GSM commands. The proposed architecture combines local sensing, edge-level fault detection, cloud-based monitoring, GSM notification, geographical identification, and remote load control in a single system. The resulting prototype is intended as a cost-effective supplementary monitoring and notification layer for distribution-transformer applications.**

***Index Terms*—Power transformer, ESP32, Internet of Things, IoT, GSM, SIM800L, ThingSpeak, GPS, ACS712, oil level monitoring, DHT11, fault detection, transformer monitoring.**

I. INTRODUCTION

Power transformers are among the most important and expensive components in electrical power systems. They provide voltage transformation between different sections of the grid and therefore have a direct influence on the reliability and continuity of electricity supply. Transformer failures can arise from electrical, thermal, mechanical, insulation, environmental, and operational stresses. Important condition variables include load current, voltage, temperature, oil condition and level, dissolved gases, moisture, and cooling-system status [1]– [5]. Continuous condition monitoring is therefore increasingly important for improving transformer reliability and enabling maintenance before severe failure occurs.

Traditional transformer maintenance is often based on scheduled inspection and periodic testing. Although these methods are useful, a fault developing between two inspection intervals may remain undetected. Online monitoring addresses this limitation by acquiring measurements continuously and presenting abnormal conditions to operators. Previous studies have demonstrated the use of sensor-based and IoT-based systems for monitoring voltage, current, temperature, oil level, and other transformer parameters [6]– [10]. In particular, IoT technologies enable measurements to be transmitted to a remote server where operators can visualize historical and real-time data.

Dissolved Gas Analysis (DGA) is an established technique for detecting incipient transformer faults because thermal and electrical stresses can cause decomposition of transformer oil and cellulose insulation, producing characteristic gases. However, online DGA systems can be considerably more complex and expensive than simple sensor-based monitoring systems [3], [4].

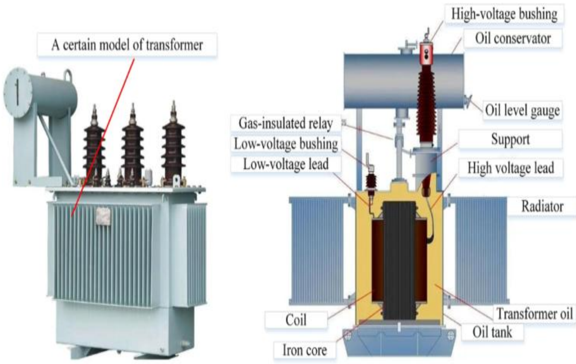

Figure 1. Basic Structure of a Transformer.

The objective of this research is therefore not to replace laboratory DGA or utility-grade transformer protection equipment, but to develop an economical multi-parameter monitoring and notification platform suitable for prototype and distribution-level monitoring applications.

The proposed system integrates electrical measurements with oil-level, environmental, gas, and fire detection. It additionally introduces two practical features: geographical identification using GPS and remote load control using GSM commands.

The main contributions of the proposed work are:

1. Development of an ESP32-based transformer monitoring controller.
2. Simultaneous measurement of voltage and load current.
3. Monitoring of temperature and humidity using DHT11.
4. Non-contact oil-level estimation using an ultrasonic sensor.
5. Detection of abnormal gas conditions and fire-related conditions.
6. Local real-time display through a 20×4 I²C LCD.
7. Cloud-based data logging through ThingSpeak.
8. SMS-based fault notification using SIM800L.
9. GPS-based transformer location identification.
10. Relay-based load ON/OFF control using authorized GSM commands.
11. Local threshold-based fault decision making to reduce dependence on cloud connectivity.

II. LITERATURE REVIEW

A. Conventional Transformer Condition Monitoring

Transformer condition monitoring has evolved from periodic inspection toward continuous online monitoring. De Faria et al. reviewed predictive-maintenance techniques based on dissolved-gas analysis and emphasized the importance of monitoring transformer condition to improve reliability and reduce unexpected failures [1].

Samimi presented a detailed survey of sensors used for transformer monitoring and identified electrical, thermal, mechanical, optical, chemical, and acoustic parameters that can be monitored depending on the transformer subsystem [2]. The study emphasizes that load current, voltage, winding temperature, top-oil temperature, oil level, and gas content are among the important parameters for transformer condition assessment.

Soni and Mehta reviewed transformer condition monitoring with particular attention to mineral oil and alternative dielectric fluids. Their study highlights the importance of thermal behavior, oil characteristics, and dielectric properties in transformer condition assessment [5].

Chandran *et al.* reviewed transformer status-monitoring techniques and discussed failure mechanisms including inter-winding faults, overcurrent, oil leakage, temperature rise, and electrical faults [11].

B. Dissolved Gas and Oil Monitoring

DGA is widely used for transformer fault diagnosis because gases produced by insulation and oil decomposition provide information about developing thermal and electrical faults. Abu Bakar *et al.* reviewed DGA measurement and interpretation techniques, including key-gas, ratio, and chromatographic approaches [3].

Duval and other DGA-based diagnostic methods have subsequently become important techniques for transformer fault interpretation. Ali *et al.* reviewed conventional DGA methods and showed the relationship between fault gases and transformer fault categories [4].

Gasser *et al.* reviewed online DGA equipment and reported the increasing use of online monitoring for energized transformers [12].

Although DGA provides valuable diagnostic information, a complete online DGA system is significantly more complex than the low-cost sensor arrangement proposed in this work. Therefore, the gas sensor in the proposed system is treated as an external abnormal-gas/fire-warning sensor, rather than as a replacement for laboratory or online dissolved-gas analysis.

C. GSM-Based Transformer Monitoring

One of the early approaches to remote transformer monitoring used GSM communication. Al-Ali *et al.* developed a GSM-based distribution transformer monitoring system for recording parameters including load current and transformer temperatures and transmitting information through a GSM modem [13]. GSM communication remains useful for installations where cellular coverage is available but continuous Internet connectivity cannot be guaranteed. SMS notification can therefore act as an independent emergency communication path.

D. IoT-Based Transformer Monitoring

Recent research has increasingly incorporated IoT into transformer monitoring. A 2022 IEEE conference study demonstrated IoT-based distribution-transformer monitoring using sensors for temperature, voltage, current, and oil level, with data made remotely accessible through an Internet-connected platform [6].

More recent systems have integrated ESP32 or similar controllers with cloud platforms. An IoT-driven distribution-transformer health-monitoring system reported the use of voltage, current, and temperature sensors together with ESP32 and a cloud/mobile interface [7].
IoT-based systems can provide continuous visualization and historical records. Public ThingSpeak implementations also demonstrate the feasibility of logging transformer voltage, current, temperature, oil level, and calculated power using ESP32-based systems [14].

E. Multi-Parameter Monitoring

Recent systematic reviews indicate that IoT transformer-monitoring systems increasingly combine electrical and non-electrical parameters. A 2024 systematic literature review specifically identified current, voltage, oil/winding temperature, and other sensors as common components in IoT-based transformer monitoring architectures [8].
A 2024 review of sensor technologies further emphasized that modern transformer monitoring is moving toward online and distributed sensing for early fault detection and asset-health assessment [9].

Recent work has also investigated integrated IoT architectures capable of monitoring transformer voltage, current, temperature, oil level, humidity, and related parameters [10], [15].

F. Research Gap

The literature demonstrates that transformer monitoring systems can successfully measure individual or combinations of electrical, thermal, oil, and environmental parameters. However, many low-cost prototypes concentrate mainly on voltage, current, temperature, and oil level. GSM notification has also been demonstrated independently, while IoT systems generally focus on cloud visualization.

The proposed work combines the following functions in a single ESP32-based platform:

- Electrical parameter monitoring;
- Environmental monitoring;
- Oil-level detection;
- Abnormal gas detection;
- Fire detection;
- Local lcd visualization;
- Thingspeak cloud logging;
- Gsm sms notification;
- Gps location reporting; and
- Gsm-command-based relay load control.

III. SYSTEM DESIGN AND METHODOLOGY

A. Proposed System Architecture

The proposed system consists of six major layers:

1. Sensor layer
2. ESP32 edge-processing layer
3. Local display and alarm layer
4. GSM communication layer
5. IoT/cloud layer
6. Load-control layer

The overall architecture is represented by Fig. 1.

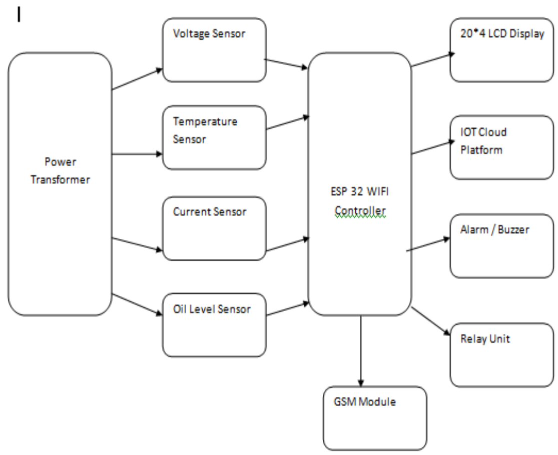

Figure 2. Proposed Block Diagram of The System

B. ESP32 Controller

An ESP32 38-pin development board is used as the main controller. The ESP32 is responsible for sensor acquisition, threshold comparison, LCD updating, relay control, GSM communication, GPS data acquisition, and ThingSpeak communication.

The controller performs local fault processing before transmitting data to the cloud. This approach ensures that an important fault can trigger a local relay/buzzer response even when Internet connectivity is unavailable.

C. Voltage Measurement

A 0–25 V DC voltage sensor is used to measure the low-voltage representation of the transformer electrical parameter in the prototype.

The sensor output is connected to an ESP32 ADC input.

The measured voltage can be represented as

[

V_{ADC}=\frac{ADC_{value}}{ADC_{max}}V_{ref}

]

and

[

V_{measured}=V_{ADC}\times K_v

]

where (K_v) is the voltage-sensor calibration factor.

The voltage sensor must be appropriately isolated and scaled for the actual transformer measurement point. A 0–25 V DC sensor must not be connected directly to a high-voltage AC transformer terminal. For a real AC transformer installation, an appropriately rated isolated AC voltage transducer such as a suitable PT/voltage-sensing module is required.

D. Current Measurement

An ACS712 current sensor is used for load-current measurement.

The ACS712 produces an analog output corresponding to current flowing through its conductor. After calibration, the controller calculates current as

[

I=\frac{V_{out}-V_{offset}}{S}

]

where:

- (V_{out}) = measured sensor output,
- (V_{offset}) = zero-current output voltage,
- (S) = calibrated sensor sensitivity.

The current value is compared against the configured threshold:

[

I>I_{max}\Rightarrow \text{Overcurrent Fault}

]

The threshold should be determined from the transformer and connected-load ratings rather than using an arbitrary value.

E. Temperature and Humidity Monitoring

A DHT11 sensor is used to monitor ambient temperature and humidity around the transformer monitoring enclosure.

The measured values are transmitted to the ESP32 and displayed on the LCD.

The temperature condition can be classified as:

NORMAL

WARNING

HIGH TEMPERATURE

The exact threshold should be selected according to the transformer rating, installation conditions, and applicable thermal requirements.

Transformer temperature is an important condition variable because excessive thermal stress accelerates insulation aging. IEEE transformer thermal models are commonly used for more rigorous temperature and loss-of-life calculations [16].

F. Oil-Level Detection

An ultrasonic sensor is mounted above the oil surface in the prototype tank.

The sensor measures the distance between the sensor and oil surface.

[
$$d=\frac{v_s t}{2}$$
]

where:

- (d) = distance to oil surface,
- (v_s) = speed of sound,
- (t) = measured echo time.

If the tank height is (H), an approximate oil height is

[
$$H_{oil}=H-d$$
]

and the percentage oil level can be estimated as

[
$$Oil\ Level(\%)=\frac{H_{oil}}{H}\times100$$
]

The controller generates a low-oil-level warning when the calculated level falls below the configured threshold.

The ultrasonic arrangement is intended for prototype oil-level estimation. Industrial transformer tanks require appropriate intrinsically safe/compatible sensing arrangements and mechanical installation practices.

G. Gas Leakage Detection

A gas sensor is included to detect abnormal gas conditions around the transformer enclosure.

The sensor output is continuously sampled by the ESP32.

A simplified decision condition is:

[
$$G>G_{limit}\Rightarrow Gas\ Alert$$
]

When a gas alert occurs, the system:

1. Activates The Buzzer;
2. Displays The Fault on The Lcd;
3. Sends An SMS Through Sim800l;
4. Uploads The Abnormal Condition to Thingspeak; And
5. Can Disconnect the load through the relay according to the configured protection logic.

The gas sensor in this prototype should be described as an external gas/leakage warning sensor. It does not perform dissolved-gas analysis of transformer oil.

H. Fire Detection

A flame/fire detection sensor is installed near the monitored transformer enclosure.

When a fire condition is detected:

Fire Sensor
↓
ESP32
↓
Fault Confirmation
↓
Buzzer ON
↓
Relay OFF
↓
SMS Alert
↓
GPS Location
↓
ThingSpeak Update

The fire-detection path is designed as an additional warning and load-isolation layer, not as a replacement for certified transformer fire-protection systems.

I. GPS Location Monitoring

The GPS module provides:

- latitude;
- longitude;
- UTC time;
- satellite information.

When a critical fault occurs, the ESP32 obtains the latest valid coordinates and includes them in the GSM notification.

Example SMS:

TRANSFORMER ALERT

Fault: HIGH TEMPERATURE
Voltage: XX V
Current: XX A
Temperature: XX °C
Oil Level: XX %

Location:
Lat: XX.XXXX
Lon: XX.XXXX

Load: OFF
This feature is particularly useful when multiple transformers are installed at geographically separated locations.

J. GSM Notification Using SIM800L
The SIM800L module is used for SMS-based communication.
The ESP32 communicates with the SIM800L using serial AT commands.

The notification sequence is:
Sensor Fault
↓
ESP32 Fault Detection
↓
Fault Confirmation
↓
SIM800L
↓
SMS
↓
Maintenance Personnel

SMS notifications can be generated for:
- Overcurrent;
- Abnormal voltage;
- High temperature;
- Low oil level;
- Gas alert;
- Fire detection;
- Communication failure;
- Load trip;
- Recovery/load restoration.

IV. RESULTS AND DISCUSSION

A. Experimental Evaluation
The prototype should be evaluated under normal and abnormal operating conditions. The principal objective is to verify whether the system correctly detects each abnormal condition, displays the information locally, uploads it to ThingSpeak, generates the appropriate SMS, and changes the relay state according to the programmed protection logic.
The following table provides the recommended result format. The numerical values marked as examples must be replaced with the actual measurements obtained from the developed hardware before journal submission.
*Thresholds must be replaced with values selected from the actual transformer rating and experimental design.

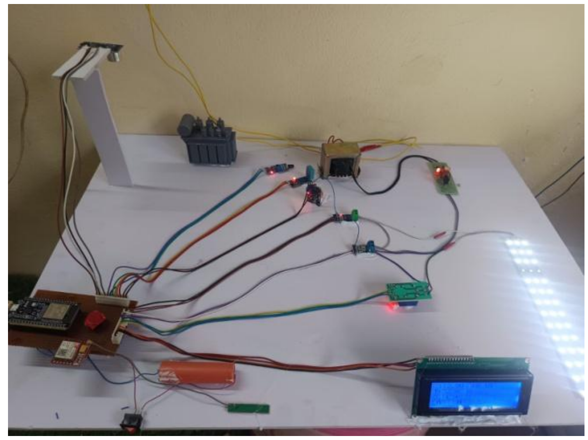

Figure 3. Hardware Structure

B. Voltage Measurement Result
The voltage-sensing subsystem should be calibrated against a reference voltmeter.
The percentage error is calculated using
[
Error(%)= \frac{|V_{sensor}-V_{reference}|}{V_{reference}}\times100
]
The results should be recorded at several test points.

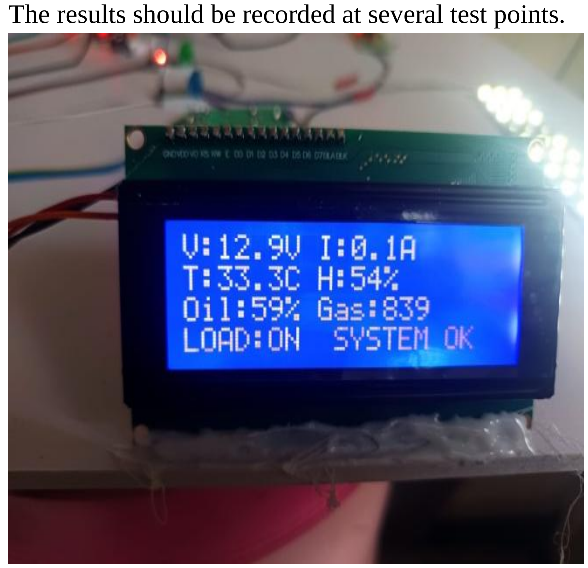

Figure 4. Display Shows Real Time Data

C. Current Sensor Result
The ACS712 should similarly be calibrated using a reference ammeter.

ACS712 CURRENT MEASUREMENT
The system should demonstrate that the measured current increases consistently with load and that an overcurrent threshold results in an appropriate warning or trip.

D. Oil-Level Detection Result
The ultrasonic sensor should be evaluated by changing the oil-level height in a controlled prototype tank.

OIL-LEVEL MEASUREMENT
The result should demonstrate that the measured distance changes inversely with oil height.

Figure 5. Display Shows Real Time Data

E. Fault Detection Results
The most important result of the proposed system is the ability to identify abnormal conditions and generate appropriate responses.

FAULT DETECTION AND NOTIFICATION
*Remote load restoration should be allowed only when protection conditions are satisfied.

F. Notification Performance
The GSM notification function is evaluated by measuring the time between fault confirmation and SMS transmission.

GSM NOTIFICATION TEST
The exact communication delay depends on cellular network availability, SIM registration, signal quality, and the GSM module's response time.

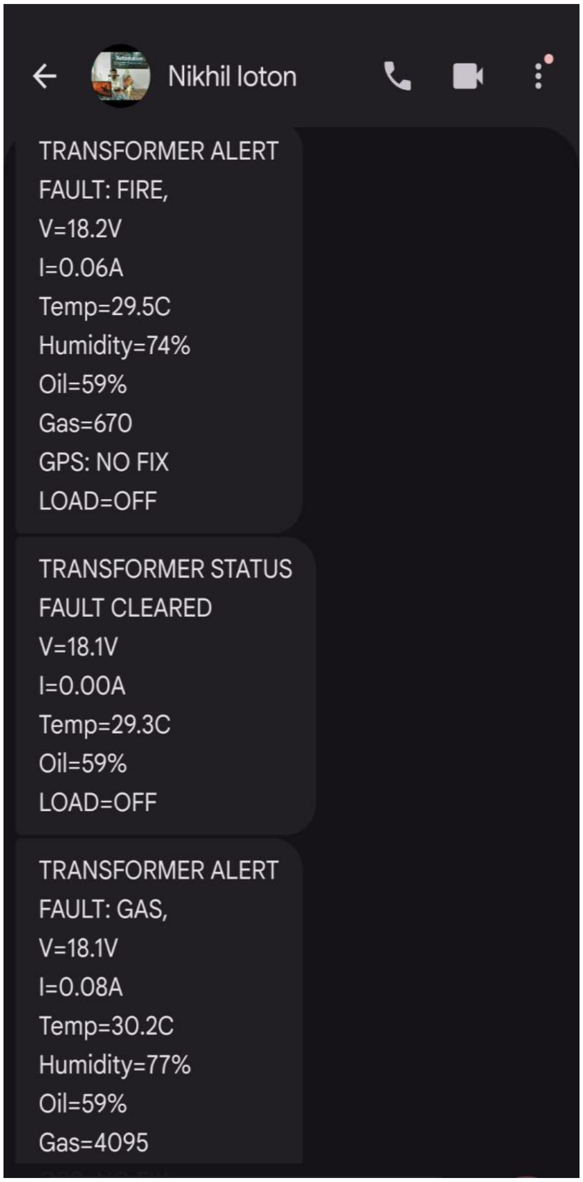

Figure 6. GSM Fault Notification to User

G. THINGSPEAK MONITORING RESULT
The ThingSpeak dashboard provides a graphical representation of the measured parameters.

Typical plots include:
1. Voltage versus time.
2. Current versus time.
3. Temperature versus time.
4. Humidity versus time.
5. Oil level versus time.
6. Gas level versus time.
7. Fire/fault status.
8. Load status.

Figure 7. Real Time Data Uploaded to Thinkspeak Web server

A normal operating condition should produce relatively stable trends. An abnormal event should appear as a corresponding change in the relevant field.

H. DISCUSSION

The proposed system provides several layers of fault awareness. First, the ESP32 acquires electrical and environmental data at the transformer site. Second, threshold-based logic performs immediate local assessment. Third, the LCD and buzzer provide local indication. Fourth, GSM communication provides remote notification independent of the cloud platform. Fifth, ThingSpeak provides historical visualization. Finally, GPS identifies the physical location associated with the alarm.

The architecture therefore addresses an important limitation of monitoring systems that depend solely on cloud connectivity. If Wi-Fi is unavailable, the local fault logic, LCD, buzzer, and GSM notification can continue to provide essential functionality.

The proposed architecture is also more comprehensive than systems that monitor only voltage, current, temperature, and oil level. Previous IoT transformer-monitoring work has demonstrated the value of these electrical and thermal parameters [6], [7], while transformer sensor surveys identify a much broader set of physical and chemical quantities for condition assessment [2], [9].

The inclusion of gas and fire sensors adds an additional safety-monitoring layer. However, these sensors should be considered auxiliary indicators. They should not be interpreted as substitutes for certified transformer protection, fire-protection equipment, or laboratory DGA. DGA remains an important diagnostic technology for identifying incipient internal transformer faults [3], [4].

The GSM-controlled relay provides a practical control function but must be implemented with authorization and electrical interlocking. A remote "LOAD ON" command should not be accepted if a critical transformer fault remains active. This prevents the communication layer from defeating the protection layer.

I.ADVANTAGES OF THE PROPOSED SYSTEM

The main advantages are:

1. Real-time transformer parameter monitoring.
2. Low-cost embedded implementation.
3. Local fault detection.
4. Local LCD visualization.
5. Audible fault indication.
6. GSM-based remote notification.
7. IoT-based historical data storage.
8. GPS-based transformer identification.
9. Remote load control.
10. Multiple sensor integration.
11. Reduced dependence on manual inspection.
12. Possibility of future predictive-maintenance development.

J. LIMITATIONS

The proposed prototype has several limitations.

First, the 0–25 V DC voltage sensor is appropriate only for a suitably scaled and isolated low-voltage measurement point. It cannot be directly connected to a high-voltage AC transformer terminal.

Second, the DHT11 measures ambient temperature/humidity and should not be interpreted as a direct measurement of transformer oil or winding hot-spot temperature.

Third, a generic gas sensor does not provide the detailed dissolved-gas composition required for formal DGA-based transformer diagnosis.

Fourth, the ultrasonic oil-level sensor is appropriate for prototype-level oil-height estimation, while industrial transformer tanks require suitably engineered and rated oil-level instrumentation.

Finally, ACS712 is suitable for low-cost prototype measurement, but utility-grade transformer protection requires appropriately rated current transformers, protection relays, and coordinated protection systems.

V. CONCLUSION

This paper presented the design and development of an ESP32-based Power Transformer Monitoring and Notification System integrating electrical, thermal, oil-level, gas, fire, communication, location, and load-control functions. The proposed system uses a 38-pin ESP32 controller to acquire voltage and current measurements, temperature and humidity data, oil-level information, gas-condition information, and fire status.

A 20×4 I²C LCD provides local real-time information, while ThingSpeak enables remote visualization and historical recording. The SIM800L module provides SMS-based fault notification, allowing maintenance personnel to receive information about abnormal operating conditions even when the cloud platform is unavailable. The GPS module adds geographical identification to the alarm message, which is useful for transformer installations distributed over large areas.

The relay-based load-control mechanism further extends the system from passive monitoring to supervisory protection and control. Critical faults can result in load disconnection, while authorized GSM commands can control the load subject to safety conditions.

The proposed system should be regarded as a low-cost supplementary monitoring and notification platform, rather than a replacement for certified transformer protection, DGA equipment, or utility protection relays. Future work can incorporate transformer oil temperature, winding temperature, vibration, moisture, pressure, dissolved-gas sensors, energy metering, machine-learning-based fault classification, and predictive remaining-useful-life estimation. Recent research is moving toward edge-cloud transformer monitoring, adaptive data transmission, and cloud-based lifetime prediction, providing a clear direction for extending this prototype into an advanced predictive-maintenance platform [17].

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