

IoT-Based Monitoring and Controlling Substation Equipment

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Abstract

The project “IoT-based monitoring and controlling substation equipment” revolves around utilizing the Internet of Things (IoT) technology to make the substation equipment’s electrical monitoring and control easy. Timely monitoring of this substation equipment is of utmost importance in ensuring the stable and reliable operation of the power distribution system. This project will design a system whereby sensors collect real-time data on the key parameters, such as voltage, current, temperature, humidity, and circuit breaker status of substation equipment. The data is then transmitted wirelessly to a centralized monitoring center through IoT modules, where operators can monitor these parameters. In addition, the system comes with control functionalities that enable the operators to adjust in real-time from a remote location by either switching the equipment off or on or by changing the operating parameters. This facilitates the remote operation, which will improve the safety at the substation, reduce the inoperable periods, and optimize the schedules for maintenance because actionable information and alerts for preventive maintenance are available. The IoT-based approach gives accuracy to the data, quicker response times, and reduces the level of human intervention, which in turn improves the overall efficiency and reliability of the power distribution network. To that extent, this project makes an important leap into the modernization process regarding substation management by using IoT technology.

Keywords: Oil level detection, IoT, web portal support, microcontroller, ESP32

INTRODUCTION

The proposed system enhances the protection of electrical circuitry by implementing a relay mechanism that operates when predefined electrical thresholds are exceeded. A microcontroller facilitates communication with various sensors and efficiently manages the control system [1].

Upon activation, the system immediately initiates the real-time monitoring of critical parameters through its integrated sensors. These include voltage, current, temperature, and frequency, which are continuously tracked to ensure stable and efficient performance. The data collected were processed and analyzed, allowing the prompt detection of anomalies, such as voltage fluctuations, current surges, thermal variations, or frequency instability. This comprehensive monitoring not only enhances system reliability but also provides timely insights for control, protection, and optimization in practical applications [2]. The system ensures that all collected data is processed and shared in real-time. The measurements were continuously transmitted

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to a central server, where they were securely stored and updated. At the same time, the information is displayed on a local LCD unit for on-site monitoring, and it is also accessible through mobile and web applications, allowing users to check the system status remotely. A built-in alert mechanism was integrated to enhance reliability and safety [3]. Whenever any monitored parameter exceeds the predefined threshold, the system immediately activates a fault indication through a relay and buzzer while simultaneously refreshing the display with the updated readings. This dual functionality ensures both instant awareness and remote accessibility of critical system conditions. Additionally, an ultrasonic sensor monitors the oil level, prompting timely maintenance actions to ensure efficient functioning and longevity of the substation.

LITERATURE REVIEW

One study focused on designing a system that enables remote monitoring and control of a substation using IoT technology. The IoT module serves as a communication interface, allowing real-time data updates to the web server. Key substation parameters, such as voltage, current, frequency, and temperature, were continuously monitored.

The system incorporates sensors that interface with a microcontroller, which processes analog input values, such as voltage and current. The microcontroller is connected to the IoT module via a serial connection, transmitting real-time data on the voltage, current frequency, and temperature fluctuations to the web server. If abnormal fluctuations are detected, relays are activated to protect the substation, turning off the connected load, such as a bulb.

A 16×2 LCD was used to display the system status. The project was powered by a regulated 5 V, 500 mA power supply, while a 12 V DC supply was used for the relay. Voltage regulation is managed using 7805 three-terminal regulators, and a bridge-type full-wave rectifier is used to convert AC to DC from a 230 V to 12 V step-down transformer.

Additionally, remote monitoring of electrical parameters, such as voltage, current, and frequency, along with temperature at a power station, is required. These real-time values are transmitted via a GSM network using a GSM modem or mobile phone [4].

Users can request electrical parameters through SMS commands, and the system can be programmed to send periodic SMS updates based on predefined time intervals. Additionally, the system can generate SMS alerts for relay trips or when the voltage or current levels exceed the set thresholds.

A microcontroller serves as the core of the system and manages communication with various sensors. It includes a built-in memory to store the necessary program instructions. The microcontroller operates based on these programmed instructions, which are written in the Embedded C language to ensure efficient functioning [5].

With the increasing complexity of distribution networks, automating substations has become essential for utility companies to enhance efficiency and ensure high-quality power delivery. This project focuses on a GSM-based substation control system that assists utility companies by promptly detecting local substation faults and notifying relevant departments through GSM communication. This helps to minimize power outage durations.

Key electrical parameters such as voltage and current are monitored and transmitted through SMS notifications. A microcontroller manages communication with sensors installed at the substation and executes commands accordingly. By continuously comparing electrical parameters to their standard values, the system helps safeguard the power distribution and transformers from potential damage caused by overload, short circuits, voltage fluctuations, and surges.

In the event of abnormal conditions, the system triggers relays to shut down the operations and immediately turns off the circuit breaker. Alerts will also be sent via SMS to inform relevant personnel. Integrating GSM technology allows substations to transmit data, receive commands, and respond to issues efficiently. This reduces the need for manual intervention, lowers operational costs, and significantly enhances the substation's overall monitoring and efficiency.

Another study implemented modern and advanced techniques for real-time monitoring and diagnostics, which allowed for the detection of both natural and accidental degradation over time. Identifying and addressing these issues early can help prevent severe failures that could lead to significant financial losses for power providers and consumers. Additionally, proactive monitoring extends equipment lifespan, enhances maintenance planning, and reduces both unexpected outages and costs associated with scheduled repairs [6].

This study examines the key operational parameters of medium-voltage (MV) and low-voltage (LV) transformer substations while proposing a system to monitor their performance. The primary goal is to develop a modular monitoring system that improves the quality of the electricity supply to consumers while minimizing expenses related to maintenance and equipment overhauls. By focusing on substation condition assessment, this study outlines the implementation of such a system, which can be seamlessly integrated into supervisory control and data acquisition (SCADA) for enhanced automation and efficiency.

One study introduced an advanced integrated monitoring system designed for high-voltage power substations. Substations play a vital role in ensuring a stable and efficient power-transmission network. However, a high-voltage environment poses potential risks to human health, making remote monitoring essential. Implementing an integrated monitoring system enhances efficiency by reducing direct human interaction with substation equipment, while ensuring seamless supervision and control [7].

The system provides real-time status updates of all substation components through a graphical user interface (GUI) developed using LabVIEW software. The interface includes multiple windows displaying critical operational parameters, such as frequency, voltage, load impedance, reluctance, oil level, temperature, cooling status, power distribution, and protection mechanisms. This enables effective supervision and enhances the overall reliability and safety of substations.

METHODOLOGY

- *Problem definition:* Identify challenges in traditional substation monitoring, such as manual errors, lack of real-time data, and delayed fault detection. The objectives of real-time monitoring, remote control, and predictive maintenance were defined. Figure 1 shows a block diagram of the proposed system.
- *System architecture*
 - *IoT nodes:* Deploy sensors (e.g., voltage, current, temperature, and humidity) on substation equipment.
 - *Communication protocols:* MQTT, Zigbee, LoRaWAN, or GSM for real-time data transmission.
 - *Edge devices:* Implementing microcontrollers (e.g., Arduino and Raspberry Pi) for data acquisition and local processing.
 - *Cloud integration:* Send data to cloud platforms (e.g., AWS and Azure) for storage and advanced analytics.
- *Data collection:* Collect real-time data from sensors at predefined intervals. Ensure redundancy to handle sensor or communication failures.
- *Data processing and analysis*
 - Edge computing is used for preliminary analysis and anomaly detection.

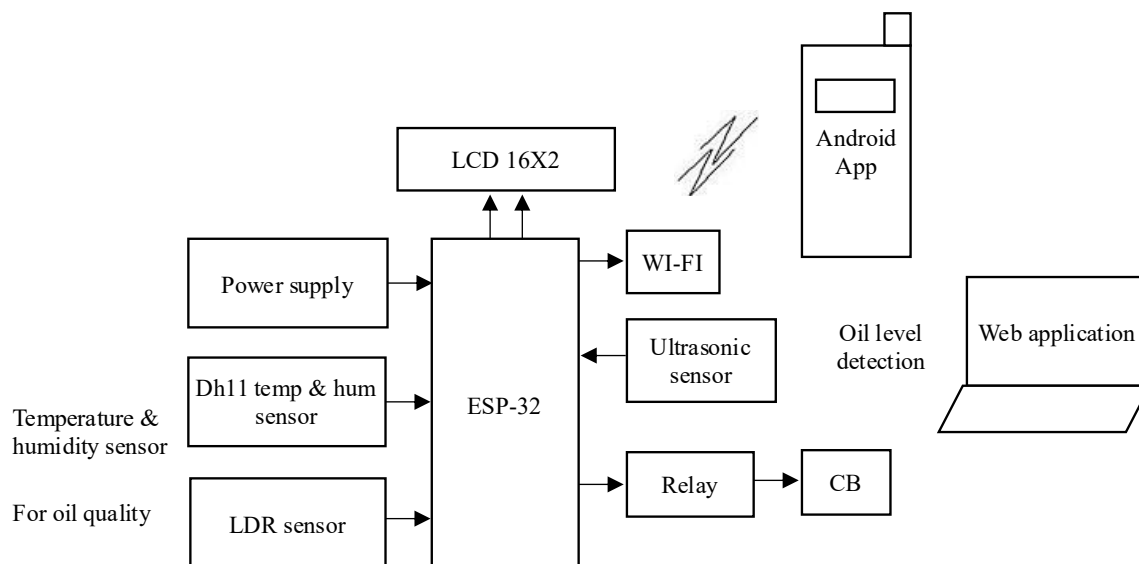


Figure 1. Block diagram.

- Apply machine learning models in the cloud for predictive maintenance and fault diagnosis.
- *Control mechanism:* Develop a user interface (web or mobile app) for remote monitoring and control of equipment. Automated responses to anomalies (e.g., equipment shutdown) using predefined rules.
- *Security measures:* Encryption (e.g., TLS/SSL) is implemented for secure data transmission. Authentication mechanisms are used to prevent unauthorized access.
- *Testing and validation:* Field trials were conducted in a controlled substation environment to evaluate system reliability, latency, and accuracy.
- *Results and analysis:* Performance metrics (e.g., fault detection time and equipment uptime) were compared with traditional methods. Highlight cost savings and operational improvements.

SPECIFICATION

1. *ESP32 specifications:* The ESP32 operates at a voltage of 3.3 V and supports an input voltage range of 7–12 V. It features 16 digital I/O pins (DIO) and 1 analog input pin (ADC). Additionally, it includes 1 UART for communication purposes.
2. *Relay specifications:* This relay board module can control both AC and DC appliances, such as solenoids, motors, lights, and fans. It features high-quality screw terminals (terminal blocks) labeled as common (C), normally closed (NC), and normally open (NO) for quick and easy connections. The relay operated with a DC coil voltage of 5 volts and supported a load of up to 7 A at AC 250 V/125 V or DC 30 V/28 V.
3. *Ultrasonic sensor specifications:* The ultrasonic sensor was a digital sensor operating at a voltage of 5 VDC. It can detect distances ranging from 2 to 400 cm (0.02 m to 4.0 m) with a high precision of up to 0.3 cm. The static current consumption of the sensor is less than 2 mA. It provides a high-level output of 5 V, making it suitable for a variety of precise distance measurement applications [8].
4. *LDR sensor specification*
 - Encased in an epoxy coating for durability
 - Offers high reliability and stability
 - Features excellent sensitivity for accurate detection
 - Rapid response time for efficient operation
 - Optimized spectral characteristics
 - Compact design with a 20 mm diameter (similar to a 50-paise coin)
 - Comes with all essential components in the package

5. *LCD 16×2 specification:* The LCD 16×2 display operates in the voltage range of 4.7 V to 5.3 V and can work in both 8-bit and 4-bit modes. It is an alphanumeric LCD module suitable for displaying text-based information. The current consumption is 1 mA without a backlight, making it an energy-efficient option for various applications.
6. *DHT11 sensor specification:* The DHT11 sensor was designed to measure both humidity and temperature with high precision. Its humidity measurement range is from 20% to 90% Relative Humidity (RH) with an error margin of ±5% RH. The temperature measurement range spans from 0 to 50°C, with an error of ±2°C. This sensor operates with a working voltage of either DC 5 V or 3.3 V, providing flexibility for different system requirements.
7. *Circuit breaker specification:* A circuit breaker is an electromechanical device used to interrupt excessive or faulty currents in an electrical circuit. It is specifically designed to halt the flow of high-magnitude fault currents while also functioning as a switch. Its primary purpose is to safely open or close electrical circuits, preventing potential damage to the electrical system. Whenever a fault occurs in any part of the system [9].

High-voltage circuit breakers can be further classified into two main categories: (1) oil circuit breakers and (2) oilless circuit breakers.

RESULT AND DISCUSSION

The IoT-based monitoring and controlling of substation equipment is successfully implemented, achieving real-time monitoring and control of critical equipment, such as transformers, circuit breakers, and switches. The system utilizes various IoT sensors (e.g., temperature, humidity, voltage, and current) to monitor the health of the substation equipment. Data from these sensors was transmitted wirelessly to a central server, processed, and displayed on a web-based interface accessible to operators and engineers.

Improved Efficiency and Reliability

The automation and remote control of equipment reduced the need for human intervention, leading to faster responses to faults and less downtime. This is especially important for large substations or remote areas, where manual monitoring is challenging [10].

Preventive Maintenance

By constantly monitoring critical parameters, such as temperature and voltage, the system enables predictive maintenance. This allows for better planning and scheduling of maintenance tasks, reducing unplanned outages and extending the lifespan of the equipment.

Scalability

The system is scalable and can be expanded to cover larger substations or entire grids by adding more sensors and controllers. This scalability ensures that the IoT solution can grow in tandem with the requirements of the power grid.

Security Concerns

One of the challenges faced in the project was ensuring secure communication between the IoT devices and the central server. It is essential to implement strong encryption and authentication protocols to protect sensitive data from cyberthreats. Future work could focus on enhancing the security layer of IoT infrastructure.

Network and Connectivity Issues

While the system performed well under ideal conditions, occasional connectivity issues arose in certain locations with poor network coverage. This highlights the importance of choosing appropriate communication technologies (e.g., LTE and Zigbee) based on the geographic and environmental factors of the substation.

Data Visualization and User Interface

The web interface provides real-time data visualization, making it easier for operators to simultaneously monitor multiple parameters. However, future improvements could include integrating AI and machine learning algorithms for anomaly detection and decision-making support.

CONCLUSION

The proposed IoT-based substation monitoring system efficiently collects, processes, and transmits real-time data; reduces manual workload; and enhances system reliability. By implementing predictive maintenance and remote control functionalities, the system ensures proactive fault management and improves the operational stability of the power substations. Further research should focus on advanced security measures and AI-driven analytics to enhance automation and efficiency. All the complications conferred above can be condensed to some excessive level.

REFERENCES

1. Kate AR. Substation monitoring system. *Int J Res Appl Sci Eng Technol*. 2018;6:2537–2542. doi:10.22214/ijraset.2018.5414.
2. Dhimar K, Patel J, Shaikh Y, Musani A, Patel K. Substation monitoring and control using microcontroller and GSM. *Int Res J Eng Technol*. 2017;4(4):398–403.
3. Narejo GB, Bharucha SP, Pohwala DZ. Remote microcontroller-based monitoring of substation and control system through GSM modem. *Int J Sci Eng Res*. 2015;6(1):2015;6(1):33342–33347.
4. Sacerdoțianu D, Lăzărescu F, Hurezeanu I, Aciu AM, Nicola M, Purcaru I, et al. Contributions to monitoring the condition of substations. 2019 8th International Conference on Modern Power Systems (MPS), Cluj-Napoca, Cluj, Romania. 2019. p. 1–6. doi:10.1109/MPS.2019.8759689.
5. Hanafi D, Ribuan MN, Wibowo IA, Hashim H, Ismail MI. Simulation of substation integrated monitoring system using LabVIEW. *Transaction on Power System Distribution*. 2011 Jun;2:138–145.
6. Zhao L, Brandao Machado Matsuo IB, Zhou Y, Lee WJ. Design of an industrial IoT-based monitoring system for power substations. *IEEE Trans Ind Appl*. 2019;55(6):5666–5674. doi:10.1109/TIA.2019.2940668.
7. Bodke P, Kalage AA. Design of an IoT-based system for monitoring and controlling the substation equipment. In: Pawar PM, Balasubramaniam R, Ronge BP, Salunkhe SB, Vibhute AS, Melinamath B, editors. *Techno-Societal 2020*. Cham: Springer; 2021. p. 133–139. doi:10.1007/978-3-030-69921-5_14.
8. Padmashini RK, Lakshmi D, Rajasree R, Rajesh Kumar JN, Zahira R, Sivaraman P, et al. IoT-based monitoring for substations. In: Zahira R, Sivaraman P, Sharmeela C, Padmanaban S, editors. *IoT for Smart Grid*. Hoboken (NJ): John Wiley & Sons; 2025. p. 207–220. doi:10.1002/9781394279401.ch9.
9. Rehman SU, Mustafa H, Larik AR. IoT-based substation monitoring and control system using Arduino with data logging. 2021 4th International Conference on Computing & Information Sciences (ICIS), Karachi, Pakistan. 2021. p. 1–6. doi:10.1109/ICIS54243.2021.9676384.
10. Sai Kiran P, Venkateswara Rao B, Satyamohan Sarveswar G, Manikanta P. IoT-based monitoring and controlling of substation parameters. In: Malik H, Mishra S, Sood YR, Iqbal A, Ustun TS, editors. *Renewable Power for Sustainable Growth. ICRP 2023. Lecture Notes in Electrical Engineering*. Vol. 1086. Singapore: Springer; 2024. p. 993–1002. doi:10.1007/978-981-99-6749-0_67.