A Review on IoT-Based Industrial SCADA System for Speed Control of Induction Motor

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Abstract—**The convergence of Supervisory Control and Data Acquisition (SCADA) systems with the Internet of Things (IoT) has significantly enhanced the capacity for real-time monitoring and control of electrical loads. IoT-based SCADA systems enable decentralized data collection, automated control, and remote accessibility across power distribution networks. This paper reviews recent developments in IoT-based SCADA systems, emphasizing their applications in load management, microgrids, and power distribution. We also discuss key challenges such as cybersecurity, scalability, and the integration of machine learning algorithms. This review references over 10 key studies from recent literature to outline the current state and future directions of IoT-based SCADA systems in electrical load management.**

Keywords—IoT, SCADA, electrical load management, power distribution, smart grids, load control, automation.

I. Introduction

The increasing complexity and demands on electrical grids necessitate advanced control systems capable of real-time monitoring, analysis, and control of electrical loads. Supervisory Control and Data Acquisition (SCADA) systems have traditionally been central to industrial automation, allowing operators to manage large, distributed networks. In recent years, integrating IoT technologies with SCADA has unlocked new possibilities, particularly in smart grids and microgrids. This paper presents a comprehensive review of IoT-based SCADA systems, focusing on their application in electrical load management and highlighting current trends, technological frameworks, and challenges.

II. Objective

The objective of this paper is to provide a comprehensive review of IoT-based Supervisory Control and Data Acquisition (SCADA) systems for electrical load management. Specifically, it aims to:

1. Analyse and summarize the current state of IoT-integrated SCADA systems in power distribution and load management.
2. Explore the architectural advancements and technological components, such as sensors, microcontrollers, communication protocols, and cloud/fog computing, that contribute to the enhanced functionality of these systems.
3. Review the key applications of IoT-based SCADA systems in various domains, including microgrids, smart grids, photovoltaic systems, and domestic energy management.
4. Identify the benefits, such as scalability, cost efficiency, and real-time control, alongside challenges like cybersecurity risks and data management complexities.
5. Highlight future research directions, focusing on machine learning integration, enhanced cybersecurity, and optimizing system efficiency.

Through this review, the paper intends to offer insights into how IoT can revolutionize SCADA systems in electrical load management, providing direction for future developments and applications.

III. Literature Survey

The integration of IoT into SCADA systems has emerged as a vital technology for real-time monitoring and control in electrical load management. This section presents a literature survey based on the reference papers, outlining various advancements, applications, and challenges in the field.

1. IoT-Integrated SCADA Architecture: IoT-based SCADA systems represent an evolution from traditional SCADA architectures, which relied on centralized control systems, proprietary hardware, and limited scalability. In contrast, IoT integration offers decentralized control, allowing for real-time

data acquisition and control from distributed devices via the internet.

Kao et al. (2018) discuss the development of a web-based SCADA system integrated with IoT for remote electrical power monitoring. The system utilizes wireless sensor networks to transmit real-time data to remote terminals, significantly reducing labor and time costs in power management (Kao, Chieng, & Jeng, 2018).

Similarly, Aghenta and Iqbal (2019) emphasize the use of low-cost, open-source platforms for the development of IoT-based SCADA systems for photovoltaic (PV) monitoring, highlighting the efficiency and scalability of integrating IoT with conventional SCADA architectures (Aghenta & Iqbal, 2019).

2. Applications in Electrical Load Management: The literature reveals numerous applications of IoT-based SCADA systems in electrical load management across different domains, including microgrids, smart grids, and domestic energy management.

- Microgrids: In microgrids, IoT-enabled SCADA systems optimize the integration and management of renewable energy sources like solar PV and battery storage. Kermani et al. (2021) present a real-time SCADA-based energy management system for microgrids, where IoT components ensure load balancing between renewable sources and traditional power generators (Kermani et al., 2021).
- Photovoltaic Systems: Aghenta and Iqbal (2019) provide a case study of PV monitoring using an IoT-based SCADA system. Their research demonstrates the ability to collect real-time data from solar panels, analyze performance metrics, and remotely control the system. The system is scalable and cost-effective, making it applicable for small and large-scale PV installations (Aghenta & Iqbal, 2019).
- Smart Grids: IoT-based SCADA systems also play a crucial role in the development of smart grids. Tom and Sankaranarayanan (2017) propose an IoT-based SCADA system integrated with fog computing for real-time monitoring of power distribution. This system helps in managing power outages, optimizing load distribution, and ensuring efficient power quality control across large smart grid infrastructures (Tom & Sankaranarayanan, 2017).
- Domestic Energy Management: In domestic applications, Yong et al. (2021) describe a smart switchboard integrated with IoT-based SCADA that monitors energy consumption at the household level, providing real-time alerts and fault notifications to prevent overloads and optimize energy use (Yong, Hamid, & Chieng, 2021).

3. Key Technologies and Communication Protocols

A central feature of IoT-based SCADA systems is their reliance on a variety of sensors and communication protocols to ensure efficient data transfer and control.

- Microcontrollers and Sensors: IoT-based SCADA systems typically utilize microcontrollers like Arduino and ESP32 for real-time data collection. These controllers are connected to sensors that measure electrical parameters such as voltage, current, and power factor. Aghenta and Iqbal (2019) highlight the importance of these microcontrollers in providing low-cost, scalable solutions for power system monitoring (Aghenta & Iqbal, 2019).
- MQTT and Modbus Protocols: The literature also discusses the use of lightweight communication protocols like MQTT (Message Queuing Telemetry Transport) and Modbus in IoT-based SCADA systems. Sayed and Gabbar (2017) show how these protocols enable efficient communication between IoT devices and SCADA systems, facilitating real-time control and data transmission over constrained networks (Sayed & Gabbar, 2017).
- Cloud and Fog Computing: Several studies explore the integration of cloud and fog computing in IoT-based SCADA systems. Tom and Sankaranarayanan (2017) demonstrate how fog computing can reduce latency by processing data closer to the source, which improves the performance of real-time energy management systems in smart grids (Tom & Sankaranarayanan, 2017).

4. Benefits of IoT-Based SCADA Systems: Research into IoT-based SCADA systems highlights several key advantages over traditional SCADA architectures:

- Cost Efficiency: IoT-based systems significantly reduce the cost of installation and maintenance. By using inexpensive, off-the-shelf hardware and leveraging cloud infrastructure, these systems offer a low-cost alternative for large-scale deployments (Aghenta & Iqbal, 2019).
- Scalability: Due to their modular nature, IoT-based SCADA systems can be easily scaled to accommodate growing energy needs or expanded power grids without significant infrastructure changes (Duair et al., 2022).
- Real-Time Control: The use of IoT sensors and real-time communication protocols enables operators to monitor and control electrical loads with minimal latency. Sayed and Gabbar (2017) discuss the efficiency gains made possible by IoT-enabled SCADA systems, particularly in smart grids and renewable energy applications (Sayed & Gabbar, 2017).

5. Challenges in IoT-Based SCADA Systems: While IoT-based SCADA systems offer many benefits, they also face several challenges that need to be addressed for widespread adoption.

- Cybersecurity Risks: One of the primary concerns with IoT-based SCADA systems is the potential for cyber-attacks, as these systems are often connected to public networks. Sayed and Gabbar (2017) emphasize the need for robust security measures to protect against unauthorized access and ensure data integrity (Sayed & Gabbar, 2017).
- Data Management: The vast amounts of data generated by IoT devices present significant challenges for data storage, processing, and management. Myint et al. (2021) note the importance of efficient data management systems, such as cloud storage solutions, to handle the data generated by IoT-based SCADA systems in hydropower stations (Myint et al., 2021).

6. Future Directions: Looking ahead, research suggests that the integration of machine learning algorithms will be critical in improving the predictive capabilities of IoT-based SCADA systems. Risco et al. (2021) propose the use of machine learning models for grid stability monitoring, which can predict potential system failures and optimize load balancing in real-time (Risco et al., 2021).

IV. Proposed Methodology

This section outlines the proposed methodology for designing and implementing an IoT-based SCADA system to monitor, control, and manage electrical loads. The methodology consists of several key phases, including system architecture design, hardware and software integration, communication protocols, data management, and real-time control strategies. The goal is to enhance scalability, reduce costs, and improve the efficiency of electrical load management.

1. System Architecture Design: The architecture for the IoT-based SCADA system will follow a decentralized structure, integrating various IoT devices to facilitate real-time monitoring and control. The proposed system consists of three main layers:

1. Sensor Layer: This layer involves installing IoT sensors to monitor electrical parameters such as voltage, current, power consumption, and temperature. Sensors like current transformers (CT), voltage sensors, and power quality sensors will be deployed across different load points in the electrical grid.
2. Edge Computing Layer: This layer includes the microcontrollers (e.g., Arduino, ESP32, Raspberry Pi) that will act as remote terminal units (RTUs). These devices will gather real-time data from sensors and preprocess it before sending it to the master terminal unit (MTU). The RTUs will also send control signals to actuators, enabling the management of electrical loads (e.g., turning equipment on/off based on load conditions).
3. Cloud/Fog Computing Layer: Cloud and fog computing platforms will be used to store, analyze, and visualize data in real-time. Fog computing nodes, located closer to the data source, will process time-sensitive data, reducing latency and bandwidth consumption. The cloud platform will store historical data and provide a user-friendly interface for operators.

Diagram of Proposed System Architecture:

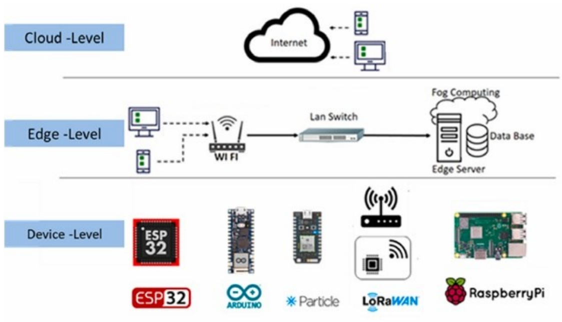

FIG SYSTEM ARCHITECTURE

2. Hardware and Software Integration: Sensors: Deploy sensors at strategic locations in the power distribution network to measure electrical parameters such as voltage, current, power factor, and energy consumption.

- RTUs: Microcontrollers like ESP32 or Arduino will be programmed to collect data from the sensors and act as gateways between the sensors and the cloud platform. These RTUs will support bidirectional communication, receiving commands from the central SCADA system and executing them to control electrical loads.
- MTU: A Raspberry Pi or similar device will serve as the Master Terminal Unit (MTU), managing communication between RTUs and the cloud. The MTU will also provide local storage for immediate backup and run monitoring applications (e.g., MQTT brokers) for real-time data flow.
- Cloud Platform: The system will leverage an IoT cloud platform like AWS IoT, Google Cloud, or ThingsBoard for data visualization and long-term data storage. These platforms will offer dashboards to monitor real-time and historical data.

3. Communication Protocols: Efficient and reliable communication between different layers is essential. The following protocols are proposed:

- MQTT (Message Queuing Telemetry Transport): A lightweight messaging protocol ideal for low-bandwidth and resource-constrained environments, MQTT will be used to enable communication between RTUs and the cloud platform.
- Modbus: Modbus will be utilized for communication between sensors and RTUs. Modbus is a proven protocol for industrial applications, supporting real-time data exchange.
- HTTP/HTTPS: For cloud communication, secure HTTP or HTTPS protocols will be used to transmit data from fog nodes to the cloud platform.

4. Data Management and Analytics: Real-time Data Processing: Data collected from sensors will be preprocessed

at the edge (RTU layer) to filter noise and ensure data quality. Critical data will be processed in real-time at the fog level to make quick decisions on load control.

- Data Storage and Analytics: All data will be stored on cloud servers for further analysis. Historical data will be used to generate reports on energy consumption patterns, identify trends, and support predictive maintenance.
- Machine Learning Integration: As an enhancement, machine learning algorithms can be applied to the historical data to predict load demand, identify faults, and optimize load distribution. Techniques like anomaly detection can alert operators to abnormal conditions in the power grid.

5. Real-Time Monitoring and Control: Monitoring: Real-time dashboards will be created to display key electrical parameters (voltage, current, power) on both mobile and desktop devices. Operators will be able to monitor load conditions remotely and receive alerts for any anomalies, such as overloads or power outages.

- Control Mechanisms: The IoT-based SCADA system will allow for remote control of electrical loads through the RTUs. For example, if the system detects an overload condition, the SCADA system can automatically shut down non-essential loads to prevent system failure.
- Automation: Based on predefined thresholds and conditions, the system will autonomously manage the power distribution and load balancing by activating or deactivating specific equipment.

6. Cybersecurity Considerations: Given the open nature of IoT-based systems, security protocols will be critical. The following security measures are proposed:

- Encryption: Secure data transmission using SSL/TLS for all communication between devices and the cloud.
- Authentication: Multi-factor authentication (MFA) and role-based access control (RBAC) will be implemented to ensure that only authorized users can access the system.
- Intrusion Detection: Network monitoring tools will be deployed to detect and respond to potential intrusions or cyberattacks.

7. Testing and Validation:

- Prototype Development: A prototype system will be built using the proposed methodology, including sensors, RTUs, and a cloud-based SCADA platform.
- Simulations: The system will be tested in a simulated environment before being deployed in the field. Various scenarios (e.g., load fluctuations, overload conditions, power failures) will be simulated to validate the performance of the system.
- Field Testing: After the prototype passes simulation tests, the system will be deployed in a real-world electrical grid (e.g., microgrid or industrial load) to verify its scalability, reliability, and effectiveness.

8. Performance Evaluation: The system will be evaluated based on several performance metrics:

- Response Time: Time taken for the system to detect a fault and execute control actions.
- Data Accuracy: Accuracy of the data collected and transmitted through the IoT sensors.
- Scalability: The ability of the system to handle increasing loads and integrate additional sensors or RTUs.
- Cost Efficiency: A comparative analysis of the cost of implementing this IoT-based SCADA system versus traditional SCADA systems.

V. Conclusion

The proposed IoT-based SCADA system is designed to provide a scalable, cost-effective, and efficient solution for real-time electrical load management. By integrating edge and fog computing, real-time data analytics, and robust communication protocols, the system will enable better monitoring, control, and automation of electrical loads. Future enhancements could involve integrating machine learning for predictive analytics and further improving system security.

References

[1] K. C. Kao, W. Chieng, and S. Jeng, "Design and development of an IoT-based web application for an intelligent remote SCADA system," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 323, 2018.

[2] L. O. Aghenta and M. Iqbal, "Development of an IoT-based open-source SCADA system for PV system monitoring," in *2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)*, 2019, pp. 1–4.

[3] S. Katkar and S. Umredkar, "Intelligent SCADA for load control," *Int. J. Power Syst. Oper. Energy Manage.*, vol. 2, no. 1, 2012.

[4] C. Y. Yong, K. Hamid, and J. H. Chieng, "Domestic electrical energy monitoring and alerting using SCADA and IoT," in *2020 8th International Conference on Intelligent and Advanced Systems (ICIAS)*, 2021, pp. 1–6.

[5] M. Kermani, B. Adelmanesh, E. Shirdare, C. Sima, D. Carní, and L. Martirano, "Intelligent energy management based on SCADA system in a real microgrid for smart building applications," *Renew. Energy*, vol. 173, 2021.

[6] J. J. Duair, A. I. Majeed, and G. M. Ali, "Design and implementation of IoT-based SCADA for a multi-microgrid system," *ECS Trans.*, 2022.

[7] R. J. Tom and S. Sankaranarayanan, "IoT based SCADA integrated with fog for power distribution automation," in *2017 12th Iberian Conference on Information Systems and Technologies (CISTI)*, 2017, pp. 1–4.

[8] K. Sayed and H. Gabbar, "SCADA and smart energy grid control automation," in *Smart Energy Grid Engineering*, Academic Press, 2017, pp. 481–514.

[9] A. Myint, K. Latt, T. Hla, and N. M. Tun, "IoT-based SCADA system design and generation forecasting for hydropower station," *Int. J. Electr. Electron. Eng. Telecommun.*, vol. 10, no. 4, pp. 251–260, 2021.

[10] A. Babilonia Risco, R. I. González Salinas, A. O. Guerrero, and D. L. Barrera Esparta, "IoT-based SCADA system for smart grid stability monitoring using machine learning algorithms," in *2021 IEEE XXVIII International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, 2021, pp. 1–4.

[11] F. Enescu and N. Bizon, "SCADA applications for electric power system," in *Energy Management of Distributed Generation Systems*, Springer, 2017, pp. 561–609.