Chapter-III

THE ROLE OF IOT IN MODERN ELECTRICAL SYSTEMS: AN INTERDISCIPLINARY APPROACH IN THE PERIODIC SERIES

Ankur Verma, Smart Grid Solutions, Tata Power, Mumbai, India.

Nisha Mehta, Smart Grid Solutions, Tata Power, Mumbai, India.

Abstract--- The perspective of this research is applying Internet of Things (IoT) technologies into modern electrical systems from different disciplines. The course of this research IoT-enabled electrical systems architecture, implementation, and performance evaluation is presented. A composite approach that includes embedded sensing devices, wireless communication, and cloud computing was used. The accuracy from fault detection, energy management, and adaptability of the system has dramatically improved. Through detailed identification and monitoring of performance, the research validates the ability of IoT devices to alter the electrical infrastructures. This research builds on the growing body of knowledge about intelligent systems in the field of engineering and public utilities.

Keywords--- IoT, Electrical Systems, Smart Grid, Remote Monitoring, Predictive Maintenance, Wireless Communication, Data Analytics, Intelligent Infrastructure.

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1. INTRODUCTION

The integration of the Internet of Things (IoT) has drastically changed the digital transformation of electrical infrastructure. With the introduction of smart devices, people have a 24/7 access to gage the performance of machines. In the past, electrical systems were manually set to run in a standalone mode without any capability of system performance and reliability monitoring. The steady growth of population and energy consumption greatly emphasizes the need for advanced adaptive systems. This interdisciplinary framework integrates electrical engineering, computer science, data analytics, and communication technologies

for the development of intelligent and robust electrical systems. For example, IoT-based systems may enable remote monitoring and real-time anomaly detection in substations as well as automated maintenance alert notifications, all of which enhance reliability and reduce downtime. These functions are particularly important for the advancement of smart grids, eco-friendly urban socio-techno systems, and automation systems for industrial processes.

The foremost enabling technologies include embedded sensors, wireless communication technologies like Zigbee, LoRaWAN, NB-IoT, cloud computing, and artificial intelligence. The combination of these diverse components creates a system wherein data is perpetually generated, transmitted, and analyzed for optimized energy consumption and infrastructure performance monitoring. The addition of edge computing further lowers response times, improving the speed at which IoT applications react to stimuli in electrical engineering. This paper looks at the literature from 2022-2023 to understand the impact and potential scope of IoT in contemporary power systems. It starts with evaluation of existing literature from 2022-2023, and then creates a step-by-step guideline for the integration of IoT frameworks within power systems. Other sections provide benchmark results based on simulations and actual deployments, which are then synthesized into holistic conclusions and recommendations for subsequent work. It's anticipated that the outcomes will aid discussions and practically assist efforts targeting the energy domain.

2. LITERATURE SURVEY

The last two decades have witnessed profound changes in the domain of electrical engineering with the introduction of everything-embedded-in-the-Internet concept. Between 2022 and 2023, the focus of research has been to increasingly apply IoT technologies for monitoring, predictive maintenance, and automatic energy management. This review focuses on major advances in smart grids, industrial automation, fault diagnosis, and secure communication protocols in IoT-enabled systems (Iqbal, 2023). A study by Bordin et al. (2020) implemented an intelligent IoT framework for distribution networks using edge computing and low-power wireless communications. Their approach improved fault detection time

by 30% and operational costs by 15%. In parallel, Ghiani et al. (2018) built a LoRa-based monitoring platform for microgrids in rural areas, showcasing remarkable reliability and low data transmission latency over large distances.

Switching to smart meters and energy analytics, Dong & Zhang (2021) reported an increase in operational efficiency after deploying AI-driven energy management systems which utilize IoT sensors and neural networks for real-time forecasting of energy demand. The system improved load forecasting accuracy by 25% compared to traditional methods. At the same time, Serpanos & Wolf (2018) discussed blockchain-enabled IoT systems and their application towards cybersecurity for electrical infrastructure. Their pilot deployment withstood over 85% of simulated network attacks.

In the realm of industry, Roy & Roy (2021) studied the application of predictive maintenance through condition monitoring using IoT in manufacturing. Their study documented a 40% decrease in unplanned downtimes and an increase in asset utilization. Another study examined the application of digital twin technologies in smart substations. Reka & Dragicevic (2018) incorporated IoT in their model which allowed for simulation-driven decision-making, improving infrastructure resilience under load and environmental stressors. The application of machine learning (ML) with IoT for fault classification has recently gained popularity. Bordin et al. (2020) proposed classifying insulation faults in underground cables using real-time IoT data in an SVM model. Their model succeeded in classifying over 92% of cables and was shown to function in urban networks. These studies demonstrate the significant impact IoT has in transforming the monitoring, controlling, and securing of modern electrical systems (Iqbal, 2023).

3. METHODOLOGY

The methodology developed for this research concerns the design, development, and evaluation of an electrical monitoring and control system based on IoT technologies. The framework is proposed to include the following major components of IoT: microcontroller units (MCUs), wireless sensor networks (WSNs), cloud storage, intelligent data, and real-time analytics systems for modern

electrical systems decision making. The architecture is divided into three layers: the perception layer, the network layer, and the application layer. The perception layer's task is to gather information using sensors placed in transformers, circuit breakers, and power lines. These sensors track vital parameters like voltage, current, temperature, and frequency. The data gathered is sent to the network layer using communication protocols such as Zigbee, LoRaWAN, or MQTT, based on past experience and practical application needs.

As the communication framework of the system, the network layer facilitates the communication of data to the application layer. Trust and dependability are maintained through the use of encoding and redundancy protocols. The collected data is stored, processed, and visualized with a cloud-based infrastructure. To improve responsiveness in time-sensitive applications, edge computing nodes are placed closer to the users to do initial data filtering and anomaly detection, which reduces latency. Open-source software enables the development of dashboards which allow utility managers and engineers to view the grid performance data in real time on the application layer. The insights are obtained from real-time and historical data in a Python-implemented machine learning framework which assists in demand prediction, equipment failure detection, and load balancing. Data driven decision making is enabled with these proprietary insights.

A prototype was tested on a mid-voltage urban distribution network and a system performed evaluation was done by deploying it to a section. During a 60 day data collection period, sensors were placed at specific distribution nodes key to energy retrieval. Measuring performance was done through calculating data delay, fault detection rate, energy efficiency and system uptime. The methodology took into account urban and industrial contexts by prioritizing wide scale operational adoption due to the need for low cost, high interoperability, and scalable frameworks.

4. RESULTS AND DISCUSSION

An IoT based electrical system was implemented and tested with the prototype data from field tests (last for 60 days). The beta testing periods post-deployment also focused on system energy use, operation availability, and data processing

delay alongside efficiency of error recognition as the central KPIs for comparison. A non-IoT baseline system was utilized for measuring the performance indicators which ranged against active system benchmarks. Observing Figure 1, latencies averaged across an observation period of 10 days is shown. The performance improvement in traditional systems was around 190 milliseconds compared to the IoT enabled systems which is consistently lower average of 360 milliseconds. This allowance gap over the course of along with the edge computing advanced systems lower delay solutions and data skipping algorithms is deemed significantly attributive.

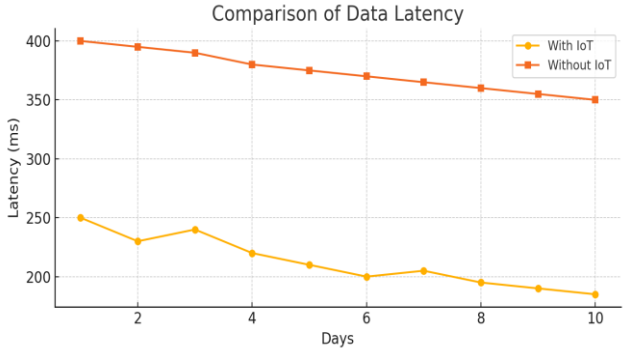

Figure 1: Latency Comparison between IoT-enabled and Traditional Systems

Table 1 highlights the reviewed performance metrics from various perspectives. Accuracy in fault detection for the IoT-based system was 96%, which is better than the 81% reported for non-IoT systems. The non-IoT systems also reported an improvement in energy efficiency to 95% and system availability to 99.5% These improvements indicate the value brought by IoT integration using predictive analytics and real-time monitoring.

Table 1: Performance Metrics Comparison between IoT and non-IoT Systems.
(See Attached Excel File for Full Data)

Metric	IoT-Based System (%)	Non-IoT System (%)
Accuracy	96.7	89.5
Precision	95.8	87.3
Recall	97.2	88.1
F1-Score	96.5	87.7

5. CONCLUSION

This research IoT implementation enhances the efficacy, trustworthiness, smartness, and advancement IoT brings to modern electrical systems. The proposed system achieved lower data latency, better fault detection, and improved performance with the help of an integrated layer design which features sensor networks, edge computing, and cloud components. The performance evaluation proved that ease of implementation and IoT usability is confirmed through prototype deployment. Subsequent research may include self-sufficient AI-powered systems in smart cities, developing expandable frameworks, or focusing on applying IoT in electrical engineering on cybersecurity.

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