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A Comparative Study of IoT-Based Acquisition and Protection Systems for Power System Equipment

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Abstract: *The proliferation of Internet of Things (IoT) technology has catalysed a significant transformation in power system protection and monitoring methodologies. Conventional circuit breaker and transformer protection systems rely on manual inspection and hard-wired relay logic, offering limited real-time observability and no remote intervention capability. This paper presents a structured comparative analysis of four landmark IoT-based acquisition and monitoring architectures proposed between 2017 and 2024 — spanning current overload detection, automated circuit breaker systems, Thing Speak-based monitoring, and advanced smart-environment protection. The comparison spans seven dimensions: sensing modality, processing platform, communication protocol, cloud/IoT platform, monitored parameters, fault response mechanism, and scalability. Analysis reveals a clear evolutionary trajectory from simple threshold-alert systems toward multi-parameter, cloud-integrated, remotely configurable protection platforms. Based on this comparison, a synthesis of best-practice architectural decisions is presented, informing the design of the authors' proposed IoT-based acquisition system for transformer monitoring and circuit breaker protection (Group G9, PCE Nagpur, Session 2025-26)..*

Keywords: IoT; circuit breaker; transformer monitoring; acquisition system; Arduino Nano; ESP8266; comparative study; power system protection; remote monitoring

I. INTRODUCTION

Electric power systems rely on protection devices — circuit breakers, relays, and fuses — to isolate faulty equipment and prevent cascading failures. Transformers, as central assets in distribution networks, are particularly vulnerable to overcurrent, overvoltage, overheating, and dielectric fluid (oil) degradation. Failures in these assets are costly: a single 132/33 kV transformer may represent a capital investment exceeding ₹5 crore, and unplanned outages impose significant economic and social burden [1].

Traditional protection relies on electromechanical relays with fixed thresholds and manual oil-level inspection routines. This approach is reactive and offers no visibility into parameter trends, no remote notification, and no data logging for post-fault analysis. The advent of low-cost microcontrollers (Arduino platform), miniaturised sensors (CT, PT, NTC, optical), and Wi-Fi SoC modules (ESP8266) has made intelligent, connected monitoring economically viable even for distribution-level assets [2].

This paper surveys and comparatively analyses the principal IoT-based protection architectures documented in the literature from 2017 to 2024. Four representative systems are selected for detailed comparison. The goal is to identify architectural strengths, limitations, and design patterns that inform the specification of an optimised system — the proposed IoT-based acquisition system for circuit breaker (CB) monitoring developed by Group G9 at Priyadarshini College of Engineering, Nagpur.

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II. BACKGROUND AND MOTIVATION

Power system equipment failures incur direct costs (equipment damage, replacement) and indirect costs (outage duration, revenue loss, safety incidents). Real-time condition monitoring addresses these costs through three mechanisms: (i) early fault detection before failure thresholds are crossed; (ii) remote alerting enabling rapid dispatch of field crews; and (iii) historical trend logging enabling predictive maintenance scheduling [3].

The IoT paradigm adds three capabilities absent from conventional SCADA: (a) wireless connectivity without dedicated communication infrastructure; (b) cloud-based analytics accessible from any internet-connected device; and (c) edge intelligence enabling local autonomous protection decisions independently of network availability [4].

The parameters critical for transformer and circuit breaker health are: (1) Primary and secondary current (for overcurrent and overload detection); (2) Primary and secondary voltage (for over/under-voltage); (3) Winding and oil temperature (for thermal overload and fire risk); and (4) Oil level (for dielectric integrity and cooling capacity). Monitoring all four simultaneously with coordinated fault response defines a comprehensive acquisition system.

III. REVIEW OF COMPARED SYSTEMS

A. System 1 — IoT-Based Current Overload Monitoring [Patil et al., 2024]

Patil et al. [1] developed a system targeting current overload detection in low-voltage distribution feeders. The architecture employs a current transformer (CT) sensor feeding an analogue front-end, processed by a microcontroller that applies pulse-width modulation (PWM)-based threshold comparison. When current exceeds the set limit, an IoT alert is generated via an HTTP GET request to a cloud endpoint. The system is notable for its simplicity and low cost (< ₹800 component cost) but is limited to single-parameter monitoring (current only) and does not support voltage, thermal, or oil-level supervision.

B. System 2 — IoT-Based Automated Circuit Breaker [Agbese et al., 2024]

Agbese et al. [2] presented a more comprehensive automated circuit breaker system integrating IoT connectivity. Their design employs a dedicated microcontroller with Wi-Fi capability to monitor circuit breaker state (open/closed), trip count, and supply current. A key contribution is the remote trip/close command capability — an operator can actuate the circuit breaker from a smartphone application, bridging the gap between monitoring and control. However, the system does not address transformer-specific parameters (temperature, oil level) and targets industrial circuit breakers rather than distribution transformers.

C. System 3 — Arduino Mega + ThingSpeak Monitoring [Das et al., 2018]

Das, Kalimuthu, and Biswas [3] proposed an IoT-based circuit breaker monitoring system using an Arduino Mega 2560 as the processing platform and ThingSpeak as the IoT cloud service. Current and voltage parameters from the circuit breaker are sampled, uploaded to ThingSpeak channels, and visualised through the ThingSpeak web dashboard. The work established the viability of open-source IoT platforms for electrical monitoring and demonstrated near-real-time data visualisation (update interval: 15 s). Its limitation is the higher cost of the Arduino Mega platform and absence of local display or autonomous protection logic.

D. System 4 — IoT Power-System Protection Device [Machidon, 2018]

Machidon [4] described a more architecturally complete power-system protection device with IoT support designed for smart building environments. The system integrates multiple sensor types (current, voltage, temperature), uses a Raspberry Pi as the processing core, and implements both local protection logic and cloud reporting. The dual-layer protection architecture (local autonomous + remote supervisory) represents the state of the art in the reviewed literature. Limitations include the relatively high cost of the Raspberry Pi platform (vs. Arduino) and the complexity of the software stack.

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IV. COMPARATIVE ANALYSIS

TABLE I. COMPARATIVE ANALYSIS OF REVIEWED IoT PROTECTION SYSTEMS

Feature	Patil et al. [1] 2024	Agbese et al. [2] 2024	Das et al. [3] 2018	Machidon [4] 2018
Processing Platform	Microcontroller (NR)	Dedicated MCU + Wi-Fi	Arduino Mega 2560	Raspberry Pi
Monitored Parameters	Current only	CB state, trip count, current	Current, Voltage	Current, Voltage, Temp.
Communication	HTTP / IoT cloud	Wi-Fi / App	Wi-Fi / ThingSpeak	Wi-Fi / Cloud
IoT/Cloud Platform	Generic HTTP	Custom App	ThingSpeak	Custom Cloud
Local Display	No	No	No	No
Autonomous Protection	Yes (PWM threshold)	Yes (remote trip)	No	Yes (local logic)
Remote Control	Alert only	Trip/Close command	Monitor only	Monitor + Alert
Fault Types Covered	Overcurrent	Overcurrent	Over/Under-voltage	Multi-fault
Temperature Monitoring	No	No	No	Yes
Oil/Fluid Level	No	No	No	No
Scalability	Low	Medium	Medium	High
Approx. Cost	Low	Medium	Medium	High

Table I reveals several critical observations. First, no single reviewed system monitors all four parameters (current, voltage, temperature, oil level) simultaneously — a gap directly addressed by the proposed Group G9 system. Second, local display capability is absent in all reviewed designs; a 16×2 LCD for on-site parameter readout is a practical addition for field personnel. Third, only Machidon's system implements multi-fault detection; the 2024 systems are more narrowly focused despite being six years newer, reflecting different target application contexts.

V. MULTI-DIMENSIONAL COMPARISON

A. Sensing Architecture

Systems 1–3 rely on a single sensing modality (current). System 4 extends to multi-parameter sensing but omits oil level — a critical indicator of transformer health. The trend toward sensor fusion (combining electrical, thermal, and fluid sensors) is clearly the architecturally superior approach for comprehensive transformer protection, as confirmed by industry standards including IEC 60076-7 (transformer thermal modelling).

B. Processing Platform

Arduino Mega (System 3) and Raspberry Pi (System 4) represent the two ends of the embedded processing spectrum. For a student prototype targeting distribution-level monitoring, the Arduino Nano (ATmega328P) platform chosen by Group G9 occupies an optimal cost-performance point: sufficient computational resources for multi-sensor sampling, relay control, and UART communication with the ESP8266 Wi-Fi module, at a component cost below ₹250.

C. Communication and Cloud Platform

ThingSpeak (System 3) and custom HTTP endpoints (System 1) represent contrasting cloud strategies. ThingSpeak provides free, structured IoT data channels with built-in MATLAB analytics, making it the preferred platform for academic prototypes. The ESP8266 AT command set enables straightforward ThingSpeak HTTP API calls, making the Nano + ESP8266 + ThingSpeak stack the most well-documented and reproducible architecture in the comparative field.

D. Protection Response

Systems 1 and 2 implement hardware-level fault response (relay actuation). Systems 3 and 4 differ: System 3 monitors only (no hardware protection), while System 4 implements dual-layer protection. For distribution transformer applications where fault response time is safety-critical (typically < 500 ms for overcurrent), hardware relay actuation controlled directly by the microcontroller is mandatory. Cloud-based alerting serves as a supplementary notification channel, not a primary protection mechanism.

E. Scalability and Deployment

Raspberry Pi (System 4) offers the highest scalability due to its Linux OS, enabling complex analytics and multi-device management. For single-transformer deployments typical of 11 kV/433 V distribution transformers in Indian utilities, the Arduino Nano architecture is adequately scalable and far simpler to commission and maintain by field engineers unfamiliar with embedded Linux.

VI. ARCHITECTURAL SYNTHESIS AND DESIGN RECOMMENDATIONS

Based on the comparative analysis, the following architectural decisions are recommended for a complete, cost-effective IoT-based acquisition system for distribution transformer and circuit breaker monitoring:

1) Sensor Suite: Deploy four sensor types — CT (current), potential divider/ZMPT101B (voltage), NTC thermistor (temperature), and optical/float sensor (oil level) — to achieve full-parameter coverage absent in all reviewed systems.

2) Processing: Arduino Nano (ATmega328P) for edge processing; provides adequate speed for 10-bit ADC sampling at 100 Hz across four channels while keeping BOM cost minimal.

3) Local Display: 16×2 character LCD (I2C interface) for on-site real-time readout — absent in all four reviewed systems; essential for field technician usability.

4) Connectivity: ESP8266 Wi-Fi module (AT command firmware) for wireless data upload to ThingSpeak IoT platform at configurable intervals (recommended: 30 s for normal, 5 s on alarm).

5) Protection Actuation: Relay module (5 V coil, 10 A / 250 V AC contacts) driven directly by Arduino digital output for hardware-speed fault isolation (< 100 ms from threshold crossing to relay trip).

6) Alert Mechanism: Active buzzer for audible local alarm plus ThingSpeak webhook for remote SMS/email notification — combining local and remote alert modalities.

This synthesis directly informs the hardware specification of the Group G9 prototype system, described in detail in the companion Paper 2.

VII. CONCLUSION

This paper presented a structured comparative analysis of four significant IoT-based protection and monitoring systems for power equipment, published between 2017 and 2024. The analysis across seven architectural dimensions — sensing, processing, communication, cloud platform, protection response, local display, and scalability — revealed that: (i) no existing reviewed system achieves comprehensive four-parameter monitoring simultaneously; (ii) local display for field usability is universally absent; and (iii) the Arduino Nano + ESP8266 + ThingSpeak architecture represents the optimal cost-performance-reproducibility point for a student prototype targeting distribution transformer monitoring.

These findings directly shaped the hardware and software design of the proposed IoT-based acquisition system for circuit breaker monitoring developed as the Group G9 final year project at PCE Nagpur. The full hardware implementation, component specifications, test results, and performance analysis are reported in the companion paper (Paper 2: Final Implementation Paper).

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