

# Review on IOT based Electrical Panel Monitoring System Utilizing Infrared Thermography Analysis

Amrapali Onkar ware<sup>1</sup>, Dr. S.P KODGIRE<sup>2</sup>

<sup>1</sup> Department of Electrical Engineering, Maharashtra Institute of Technology, Chh. Sambhajinagar-431028

<sup>2</sup> Departments of Electrical Engineering, Maharashtra Institute of Technology, Chh. Sambhajinagar-431028

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**Abstract** -The MLX90640 infrared thermal sensor performs non-contact thermo graphic analysis to detect abnormal temperature rise across electrical components such as bus bars, circuit breakers, and cable joints. Thermal imaging data are processed by the ESP32 to identify hotspots that may indicate loose connections, overloading, or insulation degradation. Simultaneously, the DHT11 sensor monitors ambient temperature and humidity levels inside the panel enclosure, which are critical factors affecting insulation performance and condensation risks. The flame and smoke sensors provide additional safety layers by detecting early signs of fire or combustion, enabling rapid response to hazardous conditions.

The ESP32 microcontroller serves as the central processing and communication unit, acquiring multi-sensor data, performing threshold-based analysis, and transmitting real-time information to an IoT platform via Wi-Fi connectivity. This enables remote monitoring, data logging, and alert generation through web or mobile interfaces. When abnormal conditions such as excessive temperature, smoke presence, or flame detection are identified, the system triggers instant notifications to maintenance personnel, thereby reducing response time and preventing catastrophic failures.

Overall, the developed IoT-based Electrical Panel Monitoring System provides a smart, automated, and preventive approach to electrical safety management by combining real-time thermo graphic analysis, environmental monitoring, and intelligent communication technologies. This approach contributes to improved operational reliability, reduced maintenance costs, and enhanced protection against electrical fire hazards.

**Key Words:** IOT, Esp32, Control Panel, Thermal Image, Temperature

## 1. INTRODUCTION

The rapid evolution of industrial automation and smart infrastructure has intensified the need for intelligent monitoring systems capable of ensuring operational safety, reliability, and energy efficiency. Electrical distribution panels form the backbone of industrial and commercial power systems, regulating and distributing electrical energy to various loads. However, electrical panels are highly susceptible to faults such as loose connections, insulation degradation, overload conditions, short circuits, and component aging. These faults often manifest as localized overheating, abnormal humidity accumulation, smoke generation, or flame formation. If undetected, such anomalies can escalate into severe hazards including equipment damage, fire outbreaks, unplanned downtime, and significant economic losses.

Conventional electrical panel inspection methods typically rely on periodic manual maintenance and handheld thermal cameras. While effective, these approaches are labor-intensive, time-consuming, and incapable of providing continuous real-time monitoring. Moreover, intermittent inspections may fail to detect early-stage thermal abnormalities that develop between maintenance intervals. To address these limitations, an Internet of Things (IoT)-based Electrical Panel Monitoring System utilizing infrared thermography analysis offers a proactive and automated solution.

This project proposes a smart monitoring framework built around the ESP32 microcontroller, integrating environmental sensing, fire detection mechanisms, and advanced thermal imaging capabilities. The ESP32 serves as the central processing unit due to its high computational efficiency, built-in Wi-Fi connectivity,

dual-core architecture, and low power consumption, making it suitable for real-time industrial IoT applications.



Fig.1: Thermo graphic Testing & Infrared Electrical Inspections

A key component of the proposed system is the MLX90640 infrared thermal camera sensor, which enables non-contact temperature measurement and two-dimensional thermal mapping of electrical panel components. Infrared thermography plays a crucial role in predictive maintenance by identifying hotspots, uneven heat distribution, and abnormal temperature gradients that indicate potential electrical faults. Unlike conventional point-based temperature sensors, the MLX90640 provides a thermal image array, allowing comprehensive surface temperature profiling and early anomaly detection.

In addition to thermo graphic monitoring, the system incorporates a DHT11 sensor to measure ambient temperature and relative humidity within the panel enclosure. Elevated humidity levels inside electrical panels can lead to condensation, corrosion, and insulation failure, increasing the risk of electrical short circuits. Monitoring these environmental parameters ensures better assessment of operating conditions and supports preventive action.

For enhanced safety and fire hazard detection, the system integrates both flame and smoke sensors. The flame sensor detects infrared light emitted during combustion, providing rapid identification of open flames. Meanwhile, the smoke sensor identifies the presence of combustion by-products or particulate matter, offering an additional layer of protection against electrical fires. The combination of thermal imaging

with smoke and flame detection ensures multi-level safety monitoring, significantly improving fault detection accuracy and response time.

The IoT functionality of the ESP32 enables real-time data transmission to cloud platforms or remote dashboards for continuous supervision and data logging. This connectivity facilitates remote diagnostics, automated alerts, and data-driven decision-making. Industrial operators can access temperature trends, thermal images, and environmental conditions from any location, thereby minimizing downtime and enhancing maintenance planning strategies.

The proposed IoT-based Electrical Panel Monitoring System represents a shift from reactive maintenance to predictive and condition-based monitoring. By combining infrared thermography, environmental sensing, and intelligent connectivity, the system enhances operational safety, reduces maintenance costs, and improves overall reliability of electrical distribution infrastructure. This approach aligns with Industry 4.0 principles, promoting smart monitoring, automation, and data-centric industrial management.

## 2. Literature Review

### 1. Suryanto & Ammar — IOP Conference Series: Earth and Environmental Science

Agus Suryanto and Sa'id Ammar presented a comprehensive IoT-based electrical panel monitoring system that integrates sensor data (current, voltage, power, and temperature) with infrared thermography for heat distribution analysis. The system used an ESP32 microcontroller and DHT22 temperature sensor for environmental data acquisition, using a real-time IoT interface (Blynk) for remote monitoring. Infrared thermography was successfully used to visualize heat profiles of electrical panel components, offering early detection of hotspots and abnormal behavior before escalation. This work demonstrates the feasibility of combining IoT with thermal imaging for proactive electrical safety assessment.

### 2. Pekşen et al. — Alexandria Engineering Journal (Elsevier)

Pekşen and colleagues investigated electrical panel anomaly detection under an IoT framework enhanced with machine learning (ML) techniques. Although not

centered on thermography, their work is significant in predictive maintenance, using IoT sensors (temperature, humidity, gas) to detect potential fire hazards within panels. They applied classifiers (SVM, GNB, GPC) to sensor datasets and achieved high detection accuracy, illustrating the importance of IoT data analytics for electrical panel safety.

### **3. Firmansyah et al. — POSITRON Journal**

Heri Firmansyah et al. developed an IoT real-time thermal monitoring system using the affordable MLX90640 thermal camera with thermocouples (MAX6675) to validate temperature imaging. The research evaluated measurement accuracy, optimal sensor distance, and integration with IoT technologies (MQTT, Grafana dashboards) for real-time temperature insight. This work is directly relevant to MLX90640 deployment in embedded IoT platforms for continuous temperature surveillance.

### **4. Suryanto & Ammar — Earth and Environmental Science (Full Paper)**

The same authors' work in conference proceedings outlines performance metrics of infrared thermography in electrical panel monitoring. It provides quantitative results and highlights how ML algorithms can integrate sensor data with imaging for high-precision analysis. This supports the argument for using array thermal imaging (like MLX90640) for condition assessment.

### **5. MDPI Open Access — Thermo-Powered IoT Fire Detection System**

This study integrates IR flame sensors with an ESP32 for fire detection and data upload to cloud platforms. Although focusing on fire safety in industrial scenarios, it underscores the practical use of ESP32 with real-time IoT monitoring and alerting, and explains sensor interface and cloud integration relevant to electrical panel hazard detection.

### **6. SAINSTECH NUSANTARA — Fire Detection on Electrical Panels**

Hendra Aji Bimansyah et al. designed an IoT-based fire detection system on electrical panels using NodeMCU, DHT11, and MQ-2 gas sensor. This research reinforces the need for multi-parameter sensing (temperature + gas) to detect early signs of electrical faults. Although it uses

a different microcontroller, its methodology aligns with IoT monitoring goals in your project.

### **7. Journal of Industrial Automation and Electrical Engineering**

Zikri Kurnia M Fauzi and colleagues proposed a fire alarm monitoring system for industrial electrical panels using ESP32 integrated with flame, gas, and temperature sensors. This approach is crucial for hazard detection in electrical panels and supports the rationale for multi-sensor integration including flame and gas detection for safety.

### **8. IOSR Journal of Electronics and Communication Engineering**

This work analyzed the effect of distance on temperature measurement using the MLX90640 thermal imaging camera with an ESP32 microcontroller. It discussed calibration, sensor characteristics, and image interpretation. The study offers empirical insights on using MLX90640 hardware, necessary for reliable thermal profiling in electrical panels.

### **9. MDPI — Review of Infrared Thermography**

Balakrishnan's review on infrared thermography provided theoretical foundations and experimental methodologies relevant to condition-based monitoring, including instrumentation, temperature calibration, and thermal anomaly detection. Although broad in scope, it contextualizes thermographic analysis techniques which can be adapted for electrical panel inspection.

### **10. SSRN Open Access (Application of IoT + MLX90640)**

This exploration focused on a low-cost IoT thermal camera prototype using an ESP32 and MLX90640 to monitor electrical and environmental data for health prognosis and equipment failure prediction. It establishes a direct precedent for combining IoT, thermal imaging and embedded processing for safeguard applications.

### **3. Proposed System**

The proposed system presents an IoT-based Electrical Panel Monitoring System integrating Infrared Thermography Analysis for predictive maintenance and

real-time fault detection. The system is designed to continuously monitor thermal behavior and environmental conditions inside electrical panels using an ESP32 microcontroller as the central processing and communication unit. By combining contactless thermal imaging with conventional environmental and safety sensors, the system ensures early detection of overheating components, fire hazards, and abnormal operating conditions.

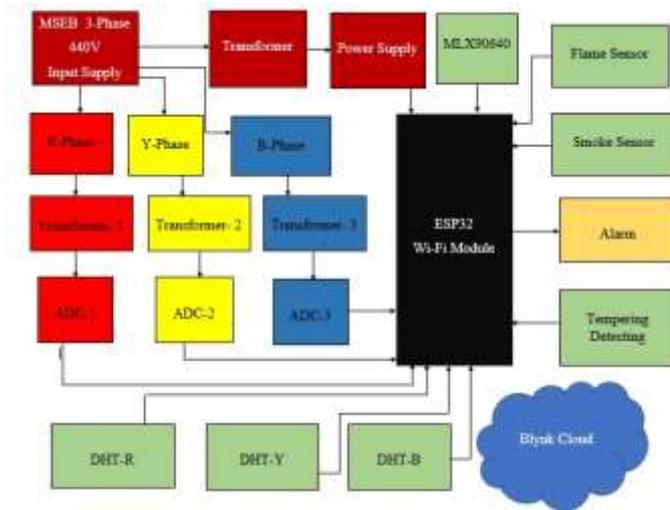


Fig.2: Block Diagram For Proposed System

### 3.1. System Architecture

The proposed architecture consists of four primary functional layers:

1. **Sensing Layer** – Responsible for acquiring electrical panel condition data.
2. **Processing Layer** – Performs data acquisition, preprocessing, and threshold-based analysis.
3. **Communication Layer** – Enables IoT-based remote monitoring.
4. **Alert and Visualization Layer** – Provides local display and remote notifications.

The ESP32 microcontroller acts as the core controller, interfacing with all sensors and handling Wi-Fi-based IoT communication.

### 3.2. Sensing and Data Acquisition

#### (a) Infrared Thermography – MLX90640

The MLX90640 is a 32×24 pixel thermal imaging sensor that performs non-contact temperature measurement

across the electrical panel surface. Unlike conventional point temperature sensors, the MLX90640 captures a complete thermal profile of components such as circuit breakers, busbars, contactors, and cable terminals.

The ESP32 reads thermal frame data via I2C communication and performs:

- Real-time thermal mapping
- Hotspot detection
- Maximum temperature extraction
- Temperature gradient analysis

Abnormal temperature rise beyond predefined safe operating limits indicates loose connections, overload conditions, insulation degradation, or potential short circuits. Early detection through infrared thermography significantly reduces the risk of catastrophic failure.

#### (b) DHT11 Sensor (Temperature and Humidity Monitoring)

The DHT11 sensor measures ambient temperature and relative humidity inside the electrical panel enclosure. Elevated humidity levels may cause condensation, corrosion, insulation breakdown, and tracking faults.

The ESP32 continuously monitors these parameters and compares them against safety thresholds. If abnormal environmental conditions are detected, alerts are generated to initiate preventive action.

#### (c) Smoke Sensor

The smoke sensor detects particulate concentration within the panel enclosure, indicating early-stage insulation burning or wire overheating. It serves as an early fire detection mechanism before visible flames appear.

Analog output from the sensor is read by the ESP32 ADC and calibrated against predefined concentration thresholds.

#### (d) Flame Sensor

The flame sensor detects infrared light emitted by open flames within a specific wavelength range. This provides immediate confirmation of fire presence in critical situations.

Upon flame detection, the system triggers emergency alerts and may activate protective mechanisms such as relay-based power cutoff (optional extension).

### 3.3. Data Processing and Fault Detection

The ESP32 performs the following operations:

- Continuous multi-sensor data acquisition
- Digital filtering to remove noise
- Threshold comparison and event classification
- Hotspot identification using MLX90640 matrix analysis
- Real-time risk assessment

Fault conditions are categorized into levels such as:

- Warning (temperature approaching threshold)
- Critical (overheating detected)
- Emergency (smoke or flame detected)

This layered fault classification improves maintenance planning and response prioritization.

### 3.4. IoT-Based Remote Monitoring

Using the built-in Wi-Fi capability of ESP32, sensor data is transmitted to a cloud platform or IoT dashboard. The system enables:

- Real-time visualization of panel temperature maps
- Historical data logging
- Trend analysis
- Remote alarm notifications via email/SMS/app alerts

Data transmission may use MQTT or HTTP protocols depending on system design requirements. Cloud integration enables predictive maintenance by analyzing thermal trends over time.

### 3.5. Local Monitoring and Alerts

For on-site monitoring, the system may include:

- LCD or OLED display for real-time temperature and humidity values

- Buzzer for emergency alerts
- LED indicators for system status

When abnormal conditions are detected, the ESP32 immediately activates visual and audible alarms.

### 3.6. Working Principle

1. Sensors continuously monitor thermal and environmental conditions.
2. ESP32 processes and analyzes sensor data.
3. Thermal imaging detects hotspots across panel components.
4. If abnormal conditions are detected:
  - Local alert is triggered
  - Data is uploaded to IoT server
  - Notification is sent to maintenance personnel
5. Preventive action is taken before equipment failure occurs.

The proposed IoT-based Electrical Panel Monitoring System utilizing Infrared Thermography Analysis provides a comprehensive and intelligent solution for industrial electrical safety. By integrating MLX90640 thermal imaging with environmental, smoke, and flame detection sensors under ESP32 control, the system ensures early fault detection, real-time monitoring, and preventive maintenance capability. This approach significantly enhances operational reliability, minimizes fire risk, and supports smart industrial infrastructure development.

The ESP32 microcontroller served as the central processing unit, facilitating high-speed data acquisition, sensor fusion, and wireless communication. Through IoT connectivity, the system enables remote monitoring and real-time data transmission to cloud platforms or supervisory dashboards. This ensures that maintenance personnel can access thermal patterns, environmental conditions, and safety alerts from any location, enhancing decision-making efficiency and enabling condition-based maintenance strategies.

However, certain limitations exist. Thermal image resolution constraints of the MLX90640 sensor may limit fine-grained detection in highly compact panel layouts. Environmental interference, sensor calibration drift, and network reliability may also affect long-term performance. Future research can focus on enhancing

thermal image processing through edge computing, integrating AI-based anomaly detection models, improving cyber security for IoT communication, and implementing automated shutdown mechanisms for critical fault scenarios.

#### 4. CONCLUSIONS

The present work proposed and implemented an IoT-based Electrical Panel Monitoring System utilizing infrared thermography analysis for proactive fault detection and safety enhancement in electrical installations. The system integrates an ESP32 microcontroller with multiple sensing modules, including the MLX90640 thermal imaging sensor, flame sensor, smoke sensor, and DHT11 temperature–humidity sensor, to provide comprehensive real-time monitoring of electrical panel conditions.

The core innovation of this project lies in the application of infrared thermography using the MLX90640 sensor to continuously analyze temperature distribution across electrical components within the panel. Unlike conventional point-based temperature sensing, thermal imaging enables non-contact, area-wide temperature profiling, allowing early identification of localized hotspots caused by loose connections, overloading, insulation degradation, or component failure. This predictive capability significantly reduces the risk of unexpected breakdowns, fire hazards, and costly downtime.

In conclusion, the IoT-based Electrical Panel Monitoring System utilizing infrared thermography presents an intelligent, reliable, and preventive approach to electrical safety management. By combining real-time thermal imaging with environmental and fire hazard detection, the system significantly enhances fault prediction capability, operational safety, and maintenance efficiency. This work contributes to the advancement of smart electrical infrastructure aligned with Industry 4.0 principles and modern predictive maintenance strategies.

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