Nusantara Journal of Multidisciplinary Science
Vol. 3, No. 9, April 2026
Hal 1278-1284
E-ISSN : 3024-8752
P-ISSN : 3024-8744
Site : https://jurnal.intekom.id/index.php/njms

Design And Implementation of Fire Protection Systems For Powerpole Transformers

Fenoria Putri[1], Muhamad Habib Abizar[2], Muhammad Asyraf bin Zulkipli[3]
[1]Department of Mechanical Engineering, Politeknik Negeri Sriwijaya, Palembang, Indonesia
[2]Politeknik Negeri Sriwijaya,Palembang,indonesia
[3] Management and Science, University Selangor, Malaysia

Article Info

Article history:

Received Maret 25, 2026
Revised April 1, 2026
Accepted April 3, 2026

Kata Kunci:

Transformator Tiang Listrik,
Proteksi Kebakaran

Keywords:

Power pole Transformers,
Fire Protection

ABSTRAK

Transformator tiang listrik, komponen penting dalam distribusi listrik, menghadapi risiko kebakaran yang signifikan akibat beban listrik yang tinggi, korsleting, dan faktor lingkungan. Pengembangan sistem proteksi kebakaran yang efektif untuk transformator ini sangat penting untuk mencegah pemadaman listrik dan meminimalkan bahaya kebakaran. Studi ini mengeksplorasi desain dan implementasi strategi proteksi kebakaran tingkat lanjut, termasuk penggunaan material tahan api, deteksi kebakaran otomatis, dan sistem pemadaman. Studi ini juga menekankan pentingnya perawatan rutin dan pemantauan waktu nyata untuk mengidentifikasi tanda-tanda awal panas berlebih atau kegagalan. Dengan mengintegrasikan sistem-sistem ini, risiko kebakaran transformator dapat dikurangi secara signifikan, sehingga memastikan keandalan dan keamanan yang lebih besar dalam jaringan distribusi listrik. Penelitian ini selanjutnya mengevaluasi dampak ekonomi dan lingkungan dari implementasi sistem tersebut, serta mendukung peningkatan standar keselamatan dalam infrastruktur utilitas.

ABSTRACT

Power pole transformers, essential components in electricity distribution, face significant fire risks due to high electrical loads, short circuits, and environmental factors. Developing effective fire protection systems for these transformers is critical to preventing power outages and minimizing fire hazards. This study explores the design and implementation of advanced fire protection strategies, including the use of fire-resistant materials, automated fire detection, and suppression systems. It also emphasizes the importance of regular maintenance and real-time monitoring to identify early signs of overheating or failure. By integrating these systems, the risk of transformer fires can be significantly reduced, ensuring greater reliability and safety in power distribution networks. This research further evaluates the economic and environmental impacts of implementing such systems, advocating for enhanced safety standards in utility infrastructure.

Corresponding Author:
Fenoria Putri
Department of Mechanical Engineering, State Polytechnic of Sriwijaya,
Palembang, Indonesia
Email: putripolsri@gmail.com

1. INTRODUCTION

Transformers serve as core equipment in power plants and distribution networks. Their operational safety directly affects grid reliability and service continuity. In the event of fire, transformers may experience catastrophic failure, causing power outages and infrastructure damage [1]. Historically, transformer fires have been recurring incidents in distribution systems, particularly in oil-immersed transformers where combustible insulation materials are present [2].

As electricity demand continues to grow, the reliability and safety of distribution transformers have become increasingly important. Studies emphasize the need for early fault detection and fire mitigation technologies to prevent escalation of hazardous conditions [3]. Traditional fire protection approaches often rely on passive systems and manual inspection, which may not provide sufficient real-time response.

Recent advancements highlight the effectiveness of automated fire detection systems using temperature, gas, and flame monitoring sensors [4]. In addition, modern suppression technologies such as water mist and aerosol systems have demonstrated improved fire control performance in transformer environments [5]. Integration of smart grid technologies and IoT-based monitoring platforms further enhances predictive maintenance capabilities [6].

Therefore, this project aims to design and implement an automated fire protection system for power pole transformers incorporating real-time monitoring, early hazard detection, and automatic CO_2-based fire suppression. The system is developed to provide a cost-effective and scalable solution for residential distribution networks.

2. METHOD

Based on the identified risks, system requirements are established to guide the design of the fire protection system. These requirements specify essential capabilities, including Real-Time Monitoring,Response Speed and The system must function reliably under variable load and environmental conditions

The target of this project is to design and create a safety monitoring system that uses an ESP32 microcontroller and several sensors to detect hazardous conditions such as gas leaks, flames, high temperatures, and electrical overcurrent. The MQ2 gas sensor detects gas leaks, the flame sensor recognizes flames, the DS18B20 detects temperature, and the ACS712 monitors current. Each of these sensors delivers data to the ESP32, which interprets the inputs and takes relevant actions, such as triggering a siren for alarms and regulating relays to switch off the motor pump or other AC loads when a threat is detected. This type of devices is critical for areas prone to fires or electrical faults, as it provides early warnings to avoid accidents and equipment damage.

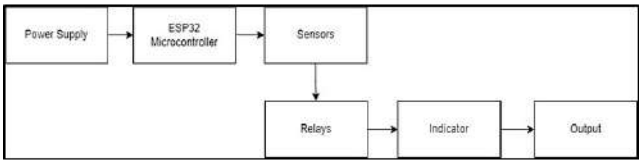


Figure 1. Block Diagram of Protection System

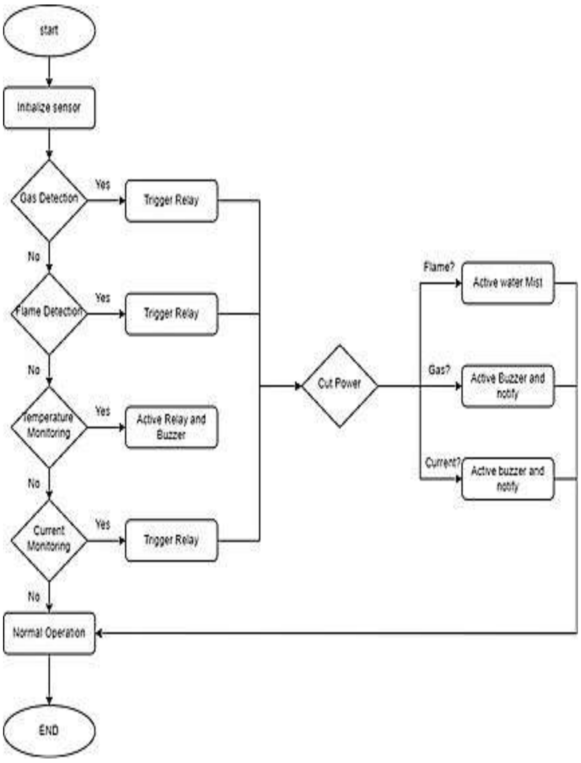


Figure 2. Flowchart of Fire Protection Systems

The flowchart for the transformer protection system depicts the actions taken by the system to monitor, identify, and respond to various dangers. It starts with the initialization phase, in which the system turns on and configures all sensors attached to the ESP32 microcontroller. The sensors continuously monitor important factors such as gas levels (MQ2 sensor), temperature (DS18B20 sensor), flame presence (flame sensor), and current flow (ACS712 sensor). The ESP32 evaluates each sensor reading to determine whether it violates predefined safety standards. If no threats are detected in any of the sensors, the system stays in normal operation, allowing the motor pump and AC load to run uninterrupted.

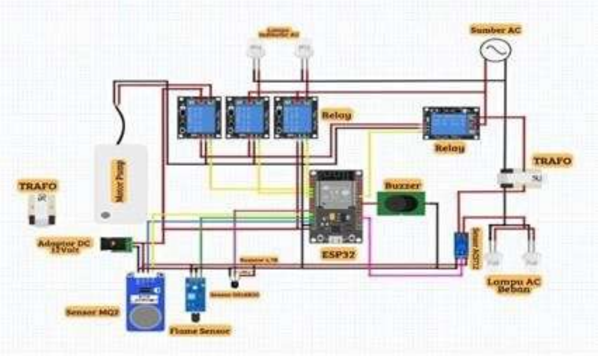


Figure 3. Block Diagram of Protection System

The ESP32 is coupled to three sensors: a MQ2 gas sensor, a flame sensor, and a temperature sensor (DS18B20). The MQ2 sensor detects gases such as methane, LPG, and smoke, whereas the flame sensor detects the presence of flames, which may indicate a fire risk. The DS18B20 is a digital temperature sensor that delivers realtime temperature data, which can be useful for monitoring environmental conditions. These sensors provide critical information to the ESP32 for decision-making.

The relay modules in the circuit regulate both AC and DC demands, such as the motor pump and indicator lighting. The ESP32 can reliably control high-power devices via relays, which behave as electrically powered switches. Each relay is connected to the ESP32 and receives signals to open or close the circuit based on the control logic. The motor pump, controlled by a relay, can be used to pump water or liquids, and the indicator lamps provide visual input on the system's status.

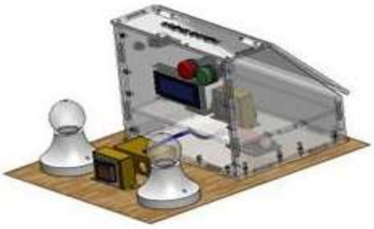
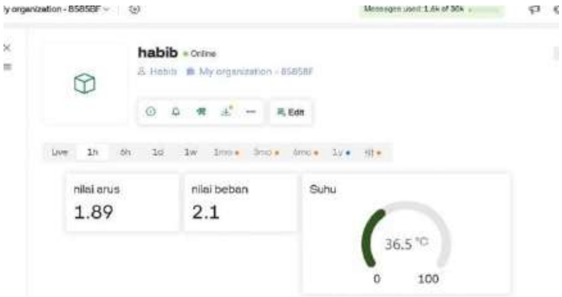


Figure 4. Assembly Part Design

The assembly design of the fire protection system for a power pole transformer consists of a compact, modular structure built on a sturdy wooden base, supporting both sensing and control units. A transparent acrylic enclosure protects the main control components, including a microcontroller, relay module, and power supply, while still allowing for visual inspection. Mounted on the front of the enclosure are two push buttons (emergency stop and reset) and an LCD display for real-time monitoring of system status and temperature data. Flame and heat sensors are strategically positioned near simulated transformer insulators to detect abnormal heat or fire conditions. All components are securely fastened to ensure durability in outdoor environments and ease of maintenance.



nilai arus
1.89

nilai beban
2.1

Suhu
36.5 °C
0
100

Figure. 5. Realtime monitoring via Blynk app

There are three parameters displayed on the LCD and Blynk app, namely temperature, current, and power.The values are updated in real-time and are always synchronized with the current conditions.Transformer Monitoring via Blynk.

App:Through the Blynk app, the transformer monitoring system can be done in real-time, with the following features: Current, Temperature, and Power Monitoring:DC current sensors measure the current used by the loads in the transformer system.The temperature sensor monitors the temperature around the transformer to detect potential overheating.

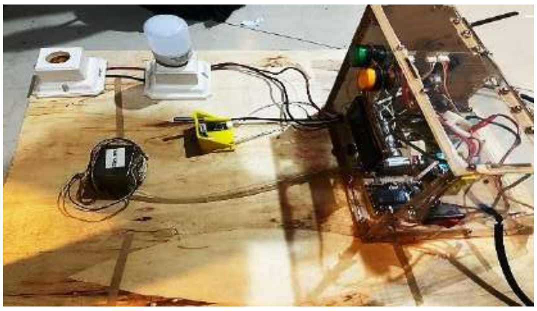


Figure 6. Overall Fire Protection System

The fire protection system is equipped with a smoke sensor and a light sensor. When both sensors detect the presence of smoke and light simultaneously, it will be considered a fire.The servo will move the CO gas cylinder inflator to spray extinguishing gas towards the fire.The alarm (buzzer) will sound and the indicator light will turn on.The Blynk application will send a notification to the user's email and application to notify that there has been a fire in the transformer.

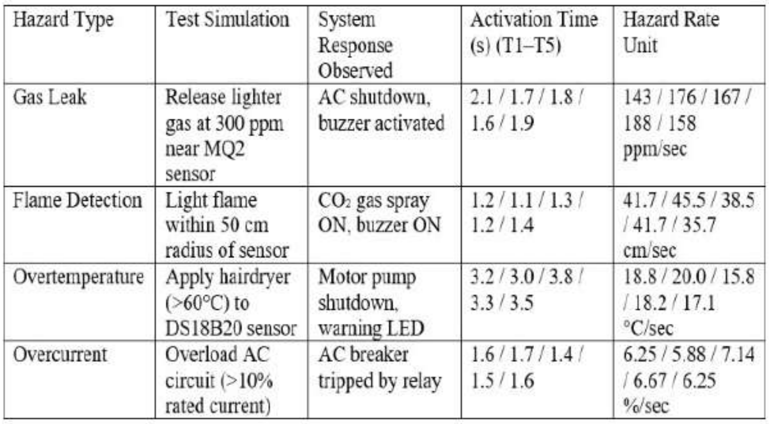
The AC power source will be downgraded using a stepdown transformer, then converted into DC current to power the DC lights.The system is equipped with a DC current sensor that monitors the current value in real-time.In this prototype, a condition is made that if the current exceeds 2.2A, it is considered an overload on the transformer.When the current exceeds 2.2A, the relay will disconnect from the power source so that the lights will go out.

Transformer fire protection design must comply with international safety standards. IEEE guidelines provide general requirements for transformer construction and fire safety considerations [8]. Additionally, NFPA 850 outlines recommended practices for fire protection in electric generating plants and high-voltage installations [9]. Compliance with IEC 60076 ensures transformer operational and thermal performance standards [10].

3. RESULT AND DISCUSSION

The objective of this chapter is to validate the functionality, performance, and effectiveness of the proposed system, which integrates multi-sensor modules for the early detection of hazardous conditions, including gas leaks, flames, high temperatures, and overcurrent events.

Table 1. Hazard Detection Test Result



Hazard Type	Test Simulation	System Response Observed	Activation Time (s) (T1–T5)	Hazard Rate Unit
Gas Leak	Release lighter gas at 300 ppm near MQ2 sensor	AC shutdown, buzzer activated	2.1 / 1.7 / 1.8 / 1.6 / 1.9	143 / 176 / 167 / 188 / 158 ppm/sec
Flame Detection	Light flame within 50 cm radius of sensor	CO_2 gas spray ON, buzzer ON	1.2 / 1.1 / 1.3 / 1.2 / 1.4	41.7 / 45.5 / 38.5 / 41.7 / 35.7 cm/sec
Overtemperature	Apply hairdryer (>60°C) to DS18B20 sensor	Motor pump shutdown, warning LED	3.2 / 3.0 / 3.8 / 3.3 / 3.5	18.8 / 20.0 / 15.8 / 18.2 / 17.1 °C/sec
Overcurrent	Overload AC circuit (>10% rated current)	AC breaker tripped by relay	1.6 / 1.7 / 1.4 / 1.5 / 1.6	6.25 / 5.88 / 7.14 / 6.67 / 6.25 %/sec

The table serves as a benchmark for evaluating the responsiveness, accuracy, and reliability of the sensor-based safety system. It provides both quantitative (activation time, hazard rate) and qualitative (system behavior) data, making it valuable for performance validation and improvement planning.

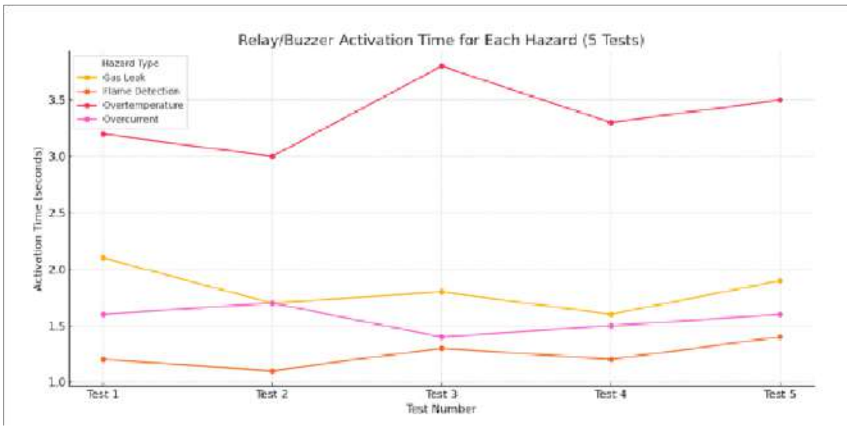


Figure 7. Activation Time Chart

Table 2. Sensors Respond Time

Sensor	Monitored Condition	Test 1 (s)	Test 2 (s)	Test 3 (s)	Test 4–5 Avg (s)	Remarks
MQ2 Gas Sensor	Lighter Gas Leak	2.1	1.7	1.8	1.75	Consistent and within expected range
Flame Sensor	Direct Flame Exposure	1.2	1.1	1.3	1.3	Fast and reliable detection
DS18B20 Temperature	Temperature > 60°C	3.2	3.0	3.8	3.4	Matches expected behaviour
ACS712 Current Sensor	Load > Rated Capacity	1.6	1.7	1.4	1.55	Fast response within expectations

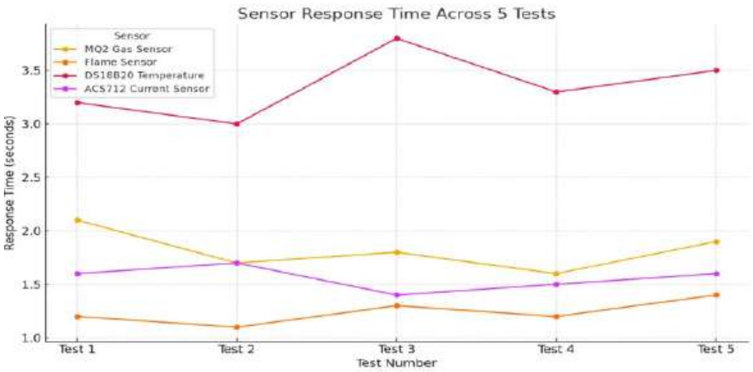


Figure 9. Chart Sensors Respond Time

The hazard detection system underwent rigorous testing across four key hazard types: gas leaks, flames, overtemperature, and overcurrent. Each hazard scenario was simulated under controlled conditions, and sensor responses were measured in five trials to evaluate accuracy, reliability, and consistency. The overall system response including alarms, shutdowns, and safety mechanisms was also assessed.

The MQ2 gas sensor successfully detected butane gas leaks in all trials with activation times between 1.6 and 2.1 seconds. The system responded by shutting off the air conditioning and activating an alarm buzzer, which indicates a fast and consistent performance. The sensor proved effective in identifying gas presence quickly, crucial for preventing potential explosions or suffocation hazards.

The flame sensor exhibited the fastest response, detecting flames within 1.1 to 1.4 seconds. Upon detection, the system immediately triggered a CO_2 gas discharge and alarm. This rapid and dependable response ensures early fire detection and suppression, minimizing damage and injury risk. The uniform results across tests highlight the flame sensor's high sensitivity and operational reliability. The results align with previous research advocating sensor-based predictive systems and automated suppression technologies [4], [5], [7].

4. CONCLUSION

The hazard detection system demonstrated effective realtime response across all tested scenarios. Sensors consistently detected their respective hazards within acceptable timeframes, and the system activated appropriate safety mechanisms such as alarms, shutdowns, and suppression actions. The MQ2 and flame sensors provided especially rapid responses, while the DS18B20 and ACS712 sensors delivered reliable results within expected performance ranges.Despite minor challenges related to test conditions and sensor calibration, the system proved to be a viable and efficient solution for hazard monitoring. Continued development can further enhance its adaptability and reduce response delays in dynamic environments. Overall, the results support the deployment of such a system in environments requiring constant safety surveillance and early hazard mitigation.

REFERENCE

[1] W. Chen, X. Yang, dan L. Li, "Research review on Transformer Fire Protection Technology," *IOP Conference Series: Earth and Environmental Science*, vol. 242, no. 6, pp. 1–8, 2019, doi: 10.1088/1755-1315/242/6/062005.

[2] H.-P. Berg dan N. Fritze, "Reliability of Main Transformers," *International Journal of Performability Engineering*, vol. 7, no. 5, pp. 475–484, 2011.

[3] H. Zhou et al., "Fault simulation platform for transformer and on-load tap changer," *Energy Reports*, vol. 8, pp. 1027–1035, 2022, doi: 10.1016/j.egyr.2022.01.145.

[4] M. Rohilla, R. Tripathi, S. Mishra, dan A. Kumar, "Condensed Aerosol Based Fire Extinguishing System Covering Versatile Applications: A Review," *Fire Technology*, vol. 58, pp. 633–657, 2022, doi: 10.1007/s10694-021-01184-2.

[5] H. Song, Y. Li, Z. Wang, dan Q. Liu, "Experimental Study on Fire Suppression of the Outdoor Oil-Immersed Transformer by High-Pressure Water Mist System," *Fire*, vol. 6, no. 1, pp. 1–16, 2023, doi: 10.3390/fire6010018.

[6] L. Ardito, G. Procaccianti, M. Menga, dan M. Morisio, "Smart Grid Technologies in Europe: An Overview," *Energies*, vol. 6, no. 1, pp. 251–281, 2013, doi: 10.3390/en6010251.

[7] Q. Li, S. Zhang, dan J. Wang, "Comparative study on machine learning models for predictive analysis," *Engineering Structures*, vol. 284, pp. 115–234, 2023, doi: 10.1016/j.engstruct.2023.115234.

[8] IEEE Power & Energy Society, *IEEE Standard C57.12.00-2015: Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers*, IEEE, New York, NY, USA, 2015.

[9] National Fire Protection Association (NFPA), *NFPA 850: Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations*, Quincy, MA, USA, 2020.

[10] International Electrotechnical Commission (IEC), *IEC 60076 Power Transformers – Part 1: General*, 2018.