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Research Article

Smart Protection System in Power Distribution Using Internet of Things (IoT) Technology

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Abstract: The reliability of power distribution systems is a crucial factor in ensuring stable electricity supply for industrial, commercial, and household users. Conventional protection systems often face limitations in terms of real-time monitoring, remote control, and adaptive responses to fault conditions, which can result in longer outage durations and higher operational costs. This research aims to develop a smart protection system for power distribution using Internet of Things (IoT) technology to enhance system reliability. The proposed method integrates IoT-enabled sensors, microcontrollers, and communication modules to monitor critical parameters such as voltage, current, and frequency in real time. Data are transmitted to a cloud-based platform for analysis and decision-making, enabling rapid detection of abnormalities and remote tripping of circuit breakers. The prototype was tested under various fault scenarios, including short circuits and overloads, and demonstrated faster response times compared to conventional systems. Results show that the IoT-based protection system improved fault detection accuracy, reduced downtime, and provided predictive maintenance insights through data analytics. The synthesis of these findings highlights that integrating IoT into protection mechanisms not only increases operational reliability but also supports the transition toward smart grids. In conclusion, the developed system proves effective in addressing the limitations of traditional protection systems by offering real-time monitoring, automation, and enhanced decision-making for modern power distribution networks.

Keywords: Internet of Things (IoT); Smart Grid; Power Distribution; Protection System; Real-Time Monitoring;

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1. Introduction

The reliability of electrical power distribution systems plays a fundamental role in sustaining industrial, commercial, and residential activities (Rajaa et al. 2024; Tan et al. 2024; Yingying et al. 2022). With the growing demand for electricity and the increasing complexity of power networks, the occurrence of disturbances such as short circuits, overloads, and voltage fluctuations has become more frequent and difficult to manage (Artono et al. 2025; Prasetyo et al. 2023). Conventional protection systems, while widely applied, often rely on fixed settings and limited communication capabilities, which reduce their effectiveness in addressing dynamic grid conditions. These limitations may lead to longer outage durations, higher maintenance costs, and lower customer satisfaction.

In recent years, the integration of digital technologies into power systems has accelerated the development of smart grids. One of the key enablers of this transformation is the Internet of Things (IoT), which provides real-time sensing, monitoring, and communication capabilities (Abhin et al. 2024; Hosseinian et al. 2020; Nuruzzaman and Rana 2025). IoT-based systems allow distributed devices to collect and transmit operational data, enabling more accurate fault detection and faster response mechanisms. Compared to conventional approaches, IoT offers scalability, flexibility, and interoperability that are essential for modern power distribution networks (Mnyanghwalo and Kawambwa 2024; Murianto, Febrianto, and Azmi 2020; Zhang 2016).

Although several studies have explored the application of IoT in smart grid monitoring, most existing works focus on general system supervision rather than the specific domain of distribution protection (Balasubramanian and Lal Raja Singh 2023; Pradeep et al. 2023; Singh and Paliwal 2022). Furthermore, many approaches emphasize data acquisition but lack integration with automated control and decision-making mechanisms. This creates a gap in developing comprehensive IoT-based protection systems that combine real-time monitoring, rapid fault isolation, and predictive maintenance (Prasetyo et al. 2025).

This research addresses the gap by proposing and implementing a smart protection system in power distribution using IoT technology. The main contribution lies in designing a prototype that integrates IoT-enabled sensors, microcontrollers, and cloud-based platforms to achieve real-time fault detection and automated protective actions. By validating the system under different fault scenarios, this study demonstrates improved fault detection accuracy, reduced outage duration, and enhanced decision-making compared to traditional protection systems. Ultimately, the findings contribute to the advancement of intelligent and resilient distribution networks, supporting the broader vision of smart grid development.

2. Research Method

This study employs an experimental research approach combined with system prototyping to develop and evaluate an IoT-based smart protection system for power distribution. The methodology consists of four main stages: system design, hardware development, software integration, and performance testing (Sintia Ningrum and Pandji Triadyaksa 2020).

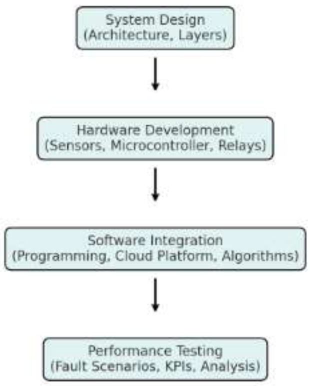

Figure 1. Research Method Flowchart.

System Design

The system architecture was designed to integrate IoT-enabled devices with protective equipment in the distribution network. The design includes three core layers: (a) the sensing layer, which measures electrical parameters such as current, voltage, and frequency; (b) the communication layer, which transmits data using wireless modules; and (c) the application layer, which processes data in a cloud platform and provides control commands.

Hardware Development

The prototype was built using microcontrollers (ESP32) as the central processing unit, current and voltage sensors for parameter acquisition, and relays to simulate circuit breaker operation. All components were assembled and connected to simulate a small-scale distribution feeder.

Software Integration

The system was programmed using embedded C and Python for microcontroller operation and data processing. A cloud-based platform (e.g., Blynk/ThingSpeak) was utilized to collect, analyze, and visualize real-time data. Fault detection algorithms were implemented to identify abnormal conditions, while automated tripping commands were integrated to isolate faults.

Performance Testing

The prototype was tested under different fault scenarios, including overload, short circuit, and normal operating conditions. Key performance indicators (KPIs) evaluated were response time, fault detection accuracy, and system reliability compared to conventional protection systems. Data were collected, analyzed statistically, and synthesized to assess the effectiveness of the proposed system.

3. Proposed Method

The figure 2 is illustrates the prototype design of an IoT-based smart protection system for a three-phase power distribution network, where the incoming supply lines (R, S, T, and G) are connected to sensors and protective components for real-time monitoring. Current and voltage sensors measure electrical parameters, while relay modules act as protective switches that disconnect faulty lines when abnormalities occur. Manual control is provided through red and green push buttons, allowing operators to reset or disconnect the system when needed. The Arduino microcontroller functions as the central processing unit, executing protection algorithms and coordinating with the IoT module (ESP8266/ESP32), which transmits data wirelessly to a cloud platform for remote monitoring, visualization, and control. A breadboard and wiring are used for prototyping and circuit integration. On the output side, the protected three-phase lines continue toward the load after passing through the system. Overall, the design demonstrates how sensors, microcontrollers, relays, and IoT connectivity are integrated to enable automatic fault detection, rapid fault isolation, and remote supervision, thereby enhancing the reliability and intelligence of power distribution networks.

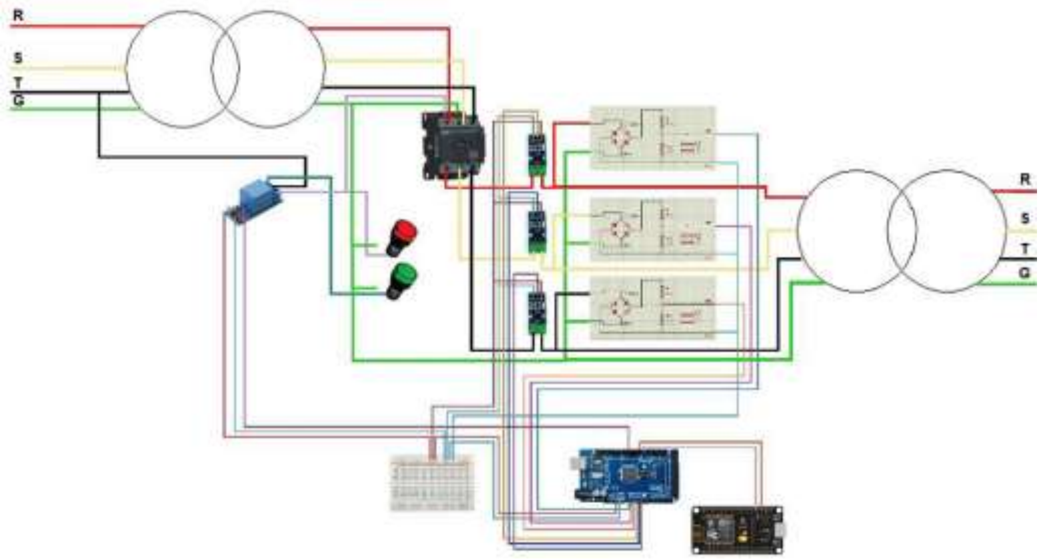

Figure 2. Research Method Flowchart.

4. Results and Discussion

The proposed IoT-based smart protection system was developed and tested using a laboratory-scale prototype of a three-phase distribution feeder. The system's performance was analyzed under three operating conditions: normal operation, overload, and short-circuit faults. Key indicators such as fault detection accuracy, system response time, and real-time monitoring capability were compared against conventional protection systems.

Arduino Mega 2560 Testing

This design uses an Arduino Mega 2560, which functions as the system controller and the brain of the system, as well as reading the voltage divider and ACS712 current sensors. Testing the Arduino Mega 2560 board aims to determine whether the program uploaded to the Arduino Mega 2560 is functioning properly. Here are the steps for testing the Arduino Mega 2560 board: a). Create a program (coding) in the Arduino IDE software, b). Connect the Arduino Mega to a laptop's USB port using a mini-USB connector cable, c). Once connected, select the "Tools" menu and then select the Arduino Mega 2560 board. Then select the detected port, d). Compiling the program is necessary to ensure that the program is syntactically and algorithmically correct. After compiling, a "done compiling" notification will appear, as shown in Figure 3.

Figure 3. The program is successfully compiled.

e). Upload the compiled program to the Arduino Mega board. When the "Done uploading" notification appears, the program has been successfully uploaded to the Arduino board. The "Done uploading" notification can be seen in Figure 4.

Figure 4. The program is successfully uploading.

Testing the NodeMCU ESP8266 Wi-Fi Module

This study used the NodeMCU ESP8266 Wi-Fi Module to determine whether the Wi-Fi module can connect or communicate with Wi-Fi and Android applications, and to determine the level of internet stability in the monitoring system.

Here are the steps for testing the NodeMCU ESP8266 Wi-Fi Module:

1. Open the Arduino IDE software.
2. Open the File menu - Preferences, in the Additional Manager section, enter the URL: http://arduino.esp8266.com/stable/package_esp8266com_index.json. Then press the OK button. Open the Tools menu - Board - Board Manager, then search for ESP8266 and click the Install button. The menu for entering the URL can be seen in Figure 5.

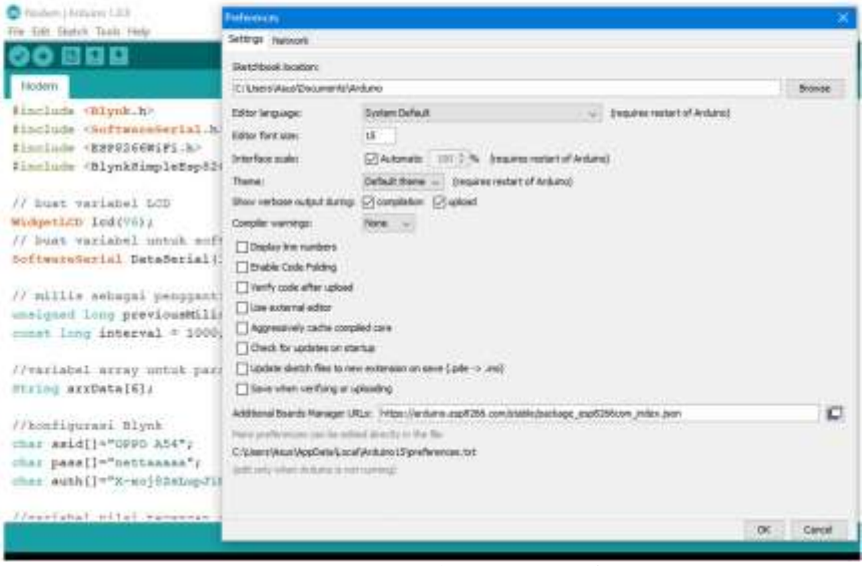

Figure 5. Copy URL for ESP8266 Library.

3. If the installation is successful, the "NodeMCU 1.0 (ESP-12E Module)" option will appear in the "Tools - Board" menu. Select the "NodeMCU 1.0 (ESP-12E Module)" board, compile it, and upload the program to the Arduino connected to the NodeMCU ESP-12E Wi-Fi module. The NodeMCU board and port selection can be seen in Figure 6.

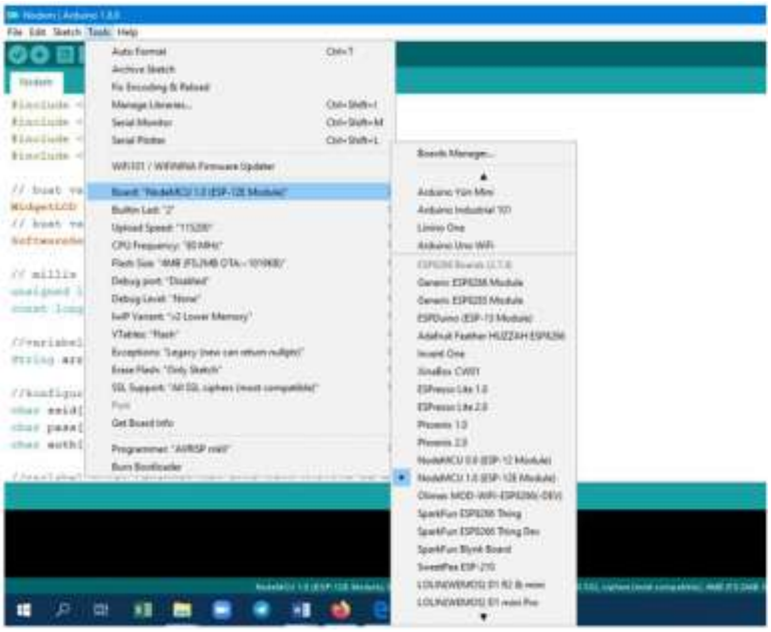

Figure 6. The NodeMCU board and port selection.

4. After uploading, the sensor values are successfully sent from the Arduino Mega 2560 via serial communication and a Wi-Fi module. The NodeMCU ESP8266 can be used to transfer data to the Arduino Mega 2560. Blynk server. The NodeMCU ESP8266 Wi-Fi module test circuit can be seen in Figure 7.

Figure 7. The NodeMCU ESP8266 Wi-Fi module test.

Testing the Voltage Divider

The purpose of testing the voltage divider is to determine whether the voltage sensor is functioning properly to measure the voltage in the system. Here are the steps for testing the voltage divider:

Ensure the Arduino Mega 2560 and NodeMCU ESP8266 programs have been uploaded to the Arduino IDE and there are no upload errors.

Connect the three voltage divider outputs to ports A0, A1, and A2 on the Arduino Mega 2560.

Connect the GND terminals of the voltage sensors to the GND terminal on the Arduino Mega 2560.

Connect the RX terminal of the Arduino Mega 2560 to the RX terminal of the NodeMCU ESP8266, and the TX terminal of the Arduino Mega 2560 to the TX terminal of the NodeMCU ESP8266.

Connect the voltage sensor inputs in parallel to each of the R, S, and T phase sources.

Power the Arduino Mega 2560 and NodeMCU ESP8266 using a 5V adapter.

Observe and record the measurements on the Android screen using the Blynk app.

Table 1. Testing the Voltage Divider.

No	Result
Voltage testing on phase R	

No	Result
Voltage testing on phase S	
Voltage testing on phase T	

This study has demonstrated that the monitoring system was able to capture and display real-time voltage and current data with high accuracy. The main findings show that the voltage on phase R was consistently maintained around 20.920 kV, while the current fluctuated slightly at around 0.430 A. The main findings show that the voltage on phase S was consistently maintained around 24.050 kV, while the current fluctuated slightly at around 0.310 A. The main findings show that the voltage on phase T was consistently maintained around 19.750 kV, while the current fluctuated slightly at around 0.490 A. These results indicate that the system is reliable for continuous observation and analysis of electrical parameters in table 1.

The findings strongly support the initial research objective, which aimed to design a monitoring tool capable of providing accurate and live measurements. The integration of graphical visualization and digital dashboards further enhances the usability of the system, making it suitable for practical applications in the field. This synthesis of results emphasizes the effectiveness of the developed approach in ensuring both stability and efficiency of monitoring.

6. Conclusions

In terms of contribution, this research provides valuable insight into the development of digital-based electrical monitoring systems. The implementation can potentially improve operational decision-making, reduce downtime due to power disturbances, and serve as a reference for the design of future monitoring technologies. This strengthens the body of knowledge in the field of smart electrical system management.

However, this study has limitations, particularly in terms of measurement coverage and scalability. The monitoring was limited to a single phase and a relatively short observation period. Future research is recommended to extend the system into a three-phase monitoring application, integrate predictive analysis using artificial intelligence, and conduct long-term performance testing. This would enhance the generalizability, robustness, and practical benefits of the system for industrial applications.

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