Research Article

Design of Equipment for Detecting and Ensuring Reliability of The Substation

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Abstract: Substations are vital elements of electrical infrastructure that necessitate continuous monitoring and maintenance to ensure optimal performance. This research advocates for the deployment and design of devices based on the Raspberry Pi 3 Model B to enhance substation reliability. The project involves developing hardware and software capable of real-time monitoring of substation conditions, utilizing sensors to measure critical parameters such as temperature, current, voltage, and humidity. The monitoring software is designed to collect, analyze, and report data, employing detection algorithms, including the Fuzzy Mamdani method, to ensure accurate sensor and frequency measurements and to identify potential disturbances or anomalies. Additionally, the system integrates automatic mechanisms for maintaining substation conditions, encompassing preventive measures and rapid responses to emergencies. Testing under various fault scenarios and operational conditions demonstrated the device's effectiveness in detecting issues and providing swift responses, thereby enhancing substation performance. The results show an average error of 0.14% for voltage measurements, 0.31% for current measurements, and 0.02% for data transmission frequency. This implementation is expected to positively impact substation management and maintenance, reduce the risk of system failures, and improve overall operational efficiency. Leveraging Raspberry Pi technology ensures a cost-effective solution that can be seamlessly integrated with existing substation monitoring systems.

Keywords: Substation; Monitoring; Real-time; Fuzzy Mamdani; Raspberry Pi

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1. Introduction

Electricity has become an essential resource for daily life in both urban and rural areas. It is crucial for various sectors, including the economy, transportation, industry, education, and technological advancements. Consequently, PT. PLN (Persero), the leading provider and supplier of electrical energy in Indonesia, must operate efficiently to meet the electrical energy needs of the general populace. To achieve this, numerous power generation centers, main substations, transmission lines, and distribution networks have been established to facilitate the distribution of electrical energy to consumers. Substations play a vital role in the Electric Power Transmission system by regulating the flow of electric power and transforming the voltage from power generation centers to the required levels. This function is supported by various types of equipment, including primary and secondary devices [1-3]. The Raspberry Pi 3 Model B is utilized in designing and installing detection equipment to maintain the reliability of substations, focusing on the status indication of substation equipment, particularly Circuit Breakers (CB) and Disconnecting Switches (DS) [4-7].

The control circuits for this prototype incorporate Open or Close functions for DS and CB circuits using self-holding and Interlock methods, which are fundamental in control circuit design. The indication circuit employs a Selector switch and an Auxiliary relay, enhanced with a 220 VAC pilot lamp as an indicator. This circuit monitors specific conditions of equipment, showing the state of DS and CB (open or closed) and the Annunciator Indication during simulated disturbances [8-9]. The status design series serves as Digital Input data for the Raspberry Pi, aiding in software management. Equipment status retrieval utilizes the NO (Normally Open) contact on each auxiliary relay. The software setup includes configuring the Raspberry Pi 3 Model B, establishing a web server, and developing an application using Android Studio. Configuration and programming are performed on a computer within the same local network as the Raspberry Pi, using VNC viewer software [10-11].

This tool is installed in the control room panel, which connects the electrical power system of the Line to the opposing GI directly through the Programmable Logic Controller (PLC) system [12-13]. It functions as a status and indication tool for the Main Transmission Unit (MTU) and relays, linked to the signal provider within a single panel [14]. An additional MLX90614 infrared sensor is incorporated to measure the temperature of cables and terminals, ensuring system reliability within the substation.

The design and realization of installation equipment for the substation system or equipment must undergo a specification determination stage to ensure the system meets actual needs. The design process involves creating system block diagrams, and developing both hardware and software designs [15-17]. This tool offers high accuracy and reliability while consuming minimal power, ensuring the maintenance of the electrical system's integrity. It allows users to monitor and maintain substation equipment systems remotely and in real-time, addressing the limitations of human resources in substations. Additionally, it serves as an early warning system, enabling users to quickly analyze and respond to potential system issues [18-21].

Standard Operating Procedures, this tool maintains real-time reliability and high accuracy, thanks to its microprocessor and Solid State Drive. This ensures that the information relayed corresponds accurately to detected anomalies, with fast performance and low power consumption, making the tool both efficient and dependable.

The author will elucidate the outcomes of the contributions made:

- High Accuracy and Reliability: Ensures precise monitoring and maintenance of electrical systems.
- Remote Real-Time Monitoring: Enables convenient remote maintenance of substation equipment.
- Support for Limited Human Resources: Offers effective solutions to address staffing limitations at substations.
- Adherence to Standard Operating Procedures: Maintains reliability and accuracy during real-time operations.
- Fault and Failure Detection: Utilizes software on the Raspberry Pi to process sensor data, identify issues such as current spikes or voltage drops, and provide appropriate alerts.

2. Theory

In this chapter, the author details the components and resources utilized in the development of the tools designed to support the creation and functionality of the system.

2.1 Node-Red

Node-Red is a highly capable and adaptable flow-based development tool extensively utilized for integrating hardware devices, APIs, and online services in innovative ways. Here's a detailed overview of how Node-Red is employed for detecting wattage, power, and transmitting data: [1] Integration with Sensors for Voltage and Electric Current: Node-Red can connect with various sensors and devices that measure electrical parameters such as electric current and voltage [22-24]. These sensors may be linked to a microcontroller or directly to the Raspberry Pi, which acts as the central hub.

The equation for Power Measurement in Node-Red: to measure power (P) in Node-Red, you typically need to gather voltage (V) and current (I) readings from the sensors. The basic formula for electrical power is:

$$P = V.I \tag{1}$$

P is the power in watts (W), V is the voltage in volts (V), and I is the current in amperes (A). [2] Data Transmission: The processed data can be transmitted to remote servers, cloud storage, or dashboards in real time. For instance, Node-Red can send data to an IoT platform where it can be stored, visualized, and further analyzed. This functionality is crucial for monitoring the performance of electrical systems and identifying any anomalies.

2.2 Circuit Breaker

A circuit breaker is an essential electrical safety device designed to protect an electrical circuit from damage caused by overloads or short circuits. Its main function is to interrupt the current flow when a fault is detected [25]. Unlike a fuse, which must be replaced after it operates once, a circuit breaker can be reset, either manually or automatically, to restore normal functionality. This resettable feature makes circuit breakers a more convenient and durable solution for circuit protection.

2.3 Disconnecting Switch

A vital electrical device is designed to completely de-energize a circuit for maintenance or service [26]. It ensures a visible and reliable disconnection from the power source, thereby enhancing the safety of personnel working on the electrical system. Typically operated manually, this switch creates a clear visual gap between contacts, confirming that the circuit is open. Disconnecting switches is essential for safety, providing a dependable method of isolating electrical equipment. They are commonly utilized in electrical substations, industrial facilities, and commercial buildings to safely isolate specific sections of the electrical system as needed.

3. Method

In this chapter, the author will outline the design of the tool to be developed, providing a straightforward and clear explanation of each component and its functionality.

3.1 Block Diagram

Figure 1 provides a detailed Block Diagram that encompasses the input, processing, and output stages of the system.

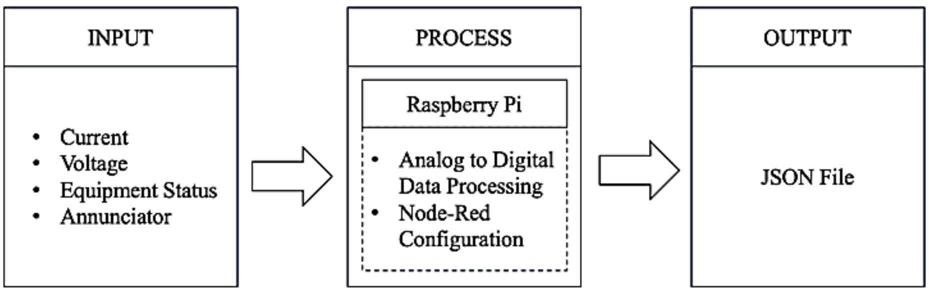

Figure 1. Block Diagram

Inputs: The system receives inputs in the form of current values, voltage, equipment status, and annunciators. The current and voltage are measured using a PQM meter. Equipment status includes the open/close status of circuit breakers and disconnect switches. Annunciators cover high-voltage trips, low-voltage trips, and anomalies.
Process: In this stage, the current and voltage values measured by the PQM meter are converted into digital signals and transmitted via RS-485 communication to the Raspberry

Pi. The equipment status and annunciator inputs are processed through the GPIO pins on the Raspberry Pi. All input data is then processed using the Node-Red application installed on the Raspberry Pi.

Output: The output from the Node-Red application is a JSON (JavaScript Object Notation) file, which is subsequently synchronized to the HTTP server.

3.2 Flowchart System

The flowchart explanation will be presented in Figure 2, which outlines the entire system from start to end.

1) *Data Inputs:*
   - Current, Voltage, Frequency, Power:
     These electrical parameters are measured using the Schneider PM5300 device.
   - Indication, Annunciator, Equipment Status:
     These status indicators are monitored through the GPIO (General Purpose Input/Output) pins.
2) *Devices:*
   - Schneider PM5300:
     This device is used to measure electrical parameters such as current, voltage, frequency, and power.
   - GPIO:
     The GPIO pins on the Raspberry Pi are used to monitor the indication, annunciator, and equipment status signals.
3) *Communication Protocol:*
   - RS485:
     The Schneider PM5300 communicates with the Raspberry Pi using the RS485 communication protocol, which is suitable for long-distance and noisy environments.
4) *Processing Unit:*
   - Raspberry Pi 3 Model B:
     The Raspberry Pi acts as the central processing unit, collecting data from the Schneider PM5300 and GPIO pins.
5) *Data Processing and Analysis:*
   - The Raspberry Pi processes the incoming data to analyze the electrical parameters and the status of the equipment.
6) *Node-Red Configuration:*
   - Node-Red:
     This is used for configuring the data processing flows, handling the analysis, and managing the data transmission processes.
7) *Fault Detection:*
   - The system checks for any faults or abnormalities in the data.
     Yes (Fault Detected):
     If a fault is detected, the binary status of the equipment is set to 0, and the annunciator is set to 1.
     No (No Fault):
     If no fault is detected, the binary status of the equipment is set to 1, and the annunciator is set to 0.
8) *Output Data Handling:*
   - The resulting data, including the status and any detected faults, is formatted into a JSON file for further use.
9) *Data Transmission:*
   - Cloud HTTP Input:
     The JSON file is sent to a cloud platform using HTTP for storage, visualization, and further analysis.

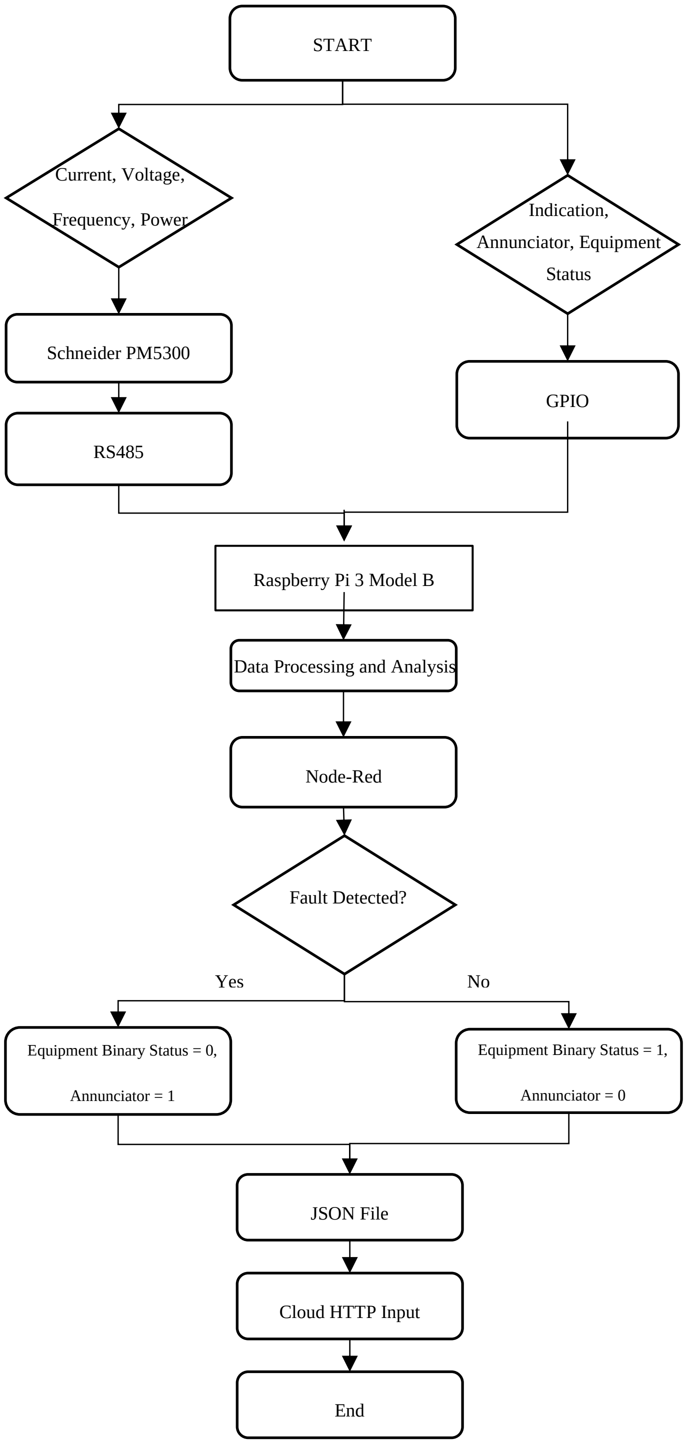

Figure 2. Flowchart System

3.3 Design Hardware

Configuration and programming are performed on a computer that shares the same local network as the Raspberry Pi, utilizing VNC viewer software. The Raspberry Pi employed in this research features the following specifications:

- Raspberry Pi 3 Model B
- 5V 3A Power Adapter
- Wireless LAN
- Schneider PM 5300
- RS485 communication module.

For a detailed view of the tool design results, please refer to Figure 3.

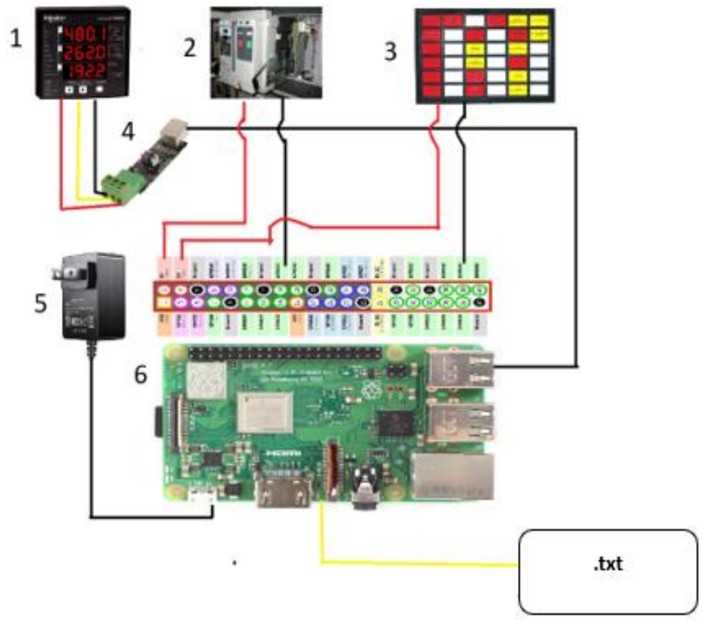

Figure 3. Design of Hardware Circuit

Figure 4. Completed Hardware Configuration

3.4 Fuzzy Mamdani Method

The Fuzzy Mamdani method, also referred to as Mamdani fuzzy inference, is a widely used technique in fuzzy logic for decision-making and control systems [27-29]. It excels at managing uncertainties and imprecise data. In the realm of power, wattage, and frequency data, the Fuzzy Mamdani method can be employed to develop a rule-based system that effectively processes and transmits data. Consider a straightforward example where the inputs are Power (P), Wattage (W), and Frequency (F), and the output is Data Transmission (D). Fuzzification can be seen in equations 2, 3, and 4, while Defuzzification can be seen in equation 5.

$$\mu_{Low}(P) = Max(0, \min\left(\frac{30-P}{10}, 1\right)) \tag{2}$$

$$\mu_{Medium}(W) = Max(0, \min\left(\frac{W-10}{10}, \frac{30-W}{10}\right)) \tag{3}$$

$$\mu_{High}(F) = Max(0, \min\left(\frac{W-50}{10}, 1\right)) \tag{4}$$

$$D = \frac{\sum(\mu_{Rule\ i} \cdot d_{centroid})}{\sum \mu_{Rule\ i}} \tag{5}$$

4. Result and Discussion

In this experiment, the author provides a detailed analysis by comparing various methods of testing and data collection, including the use of an AVO (Ampere Voltage Ohm) meter, a Power Quality Meter (PQM), and data collection through Modbus Read on Node-Red. The calculations will employ both the Fuzzy Mamdani Method and manual numerical computations, with the findings presented in comprehensive figures and tables. Initially, the author will focus on voltage detection, utilizing multiple comparisons between the Fuzzy Mamdani Method and manual calculations to ensure accuracy and reliability.

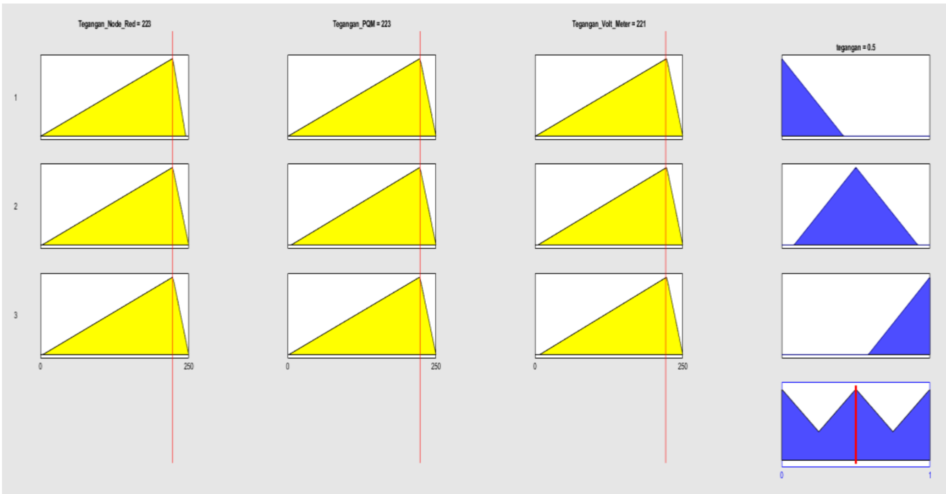

Figure 5. Fuzzy Logic Mamdani Voltage

Figure 5 illustrates the outcomes of the Fuzzy Mamdani calculations, effectively comparing the results of the three different methods. Table 1. provides the precise figures obtained from the three tools, revealing an average error of 0.14%.

Table 1. Voltage Detection

No	Node-Red	PQM	Volt Meter	Presentation
1	223	222.79	223	0.09%
2	222.96	223.03	223	0.06%
3	223.22	223.09	223	0.09%
4	223.33	223.14	223	0.09%
5	223.50	223.23	223	0.12%
6	223.44	223.04	223	0.18%
7	223.46	223.27	223	0.09%
8	223.46	223.28	223	0.08%
9	223.76	223.16	223	0.27%
10	223.98	223.16	223	0.37%
Presentation Error Average				0.14%

In this section, the author elaborates on the measurement of electric current, providing a comparative analysis of the results obtained using a Power Quality Meter (PQM) and Node-Red.

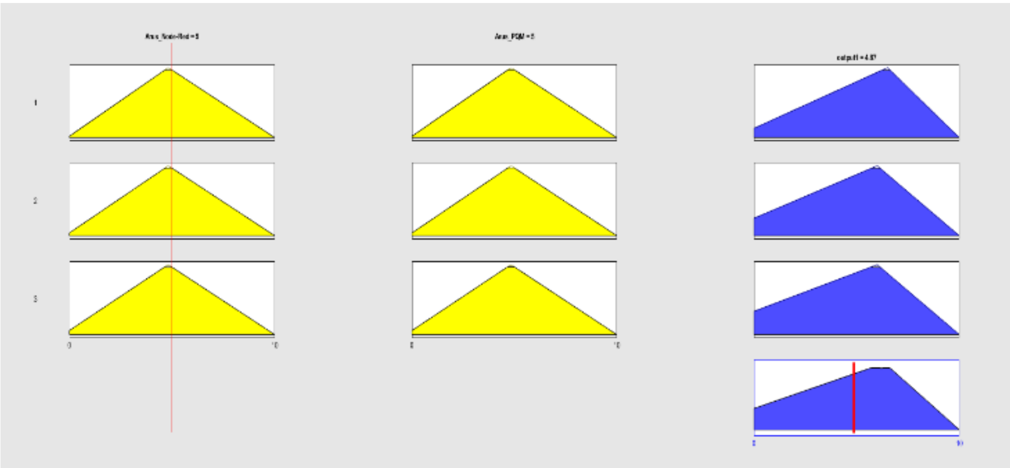

Figure 6. Fuzzy Logic Mamdani Electric Current

Figure 6 presents the outcomes of the Fuzzy Mamdani Method calculations for measuring electric current. Table 2. provides precise results to verify their accuracy. These findings compare the data obtained from Node-Red and the Power Quality Meter (PQM), revealing an average error of 0.31%.

Table 2. Electric Current Detection

No	Node-Red	PQM	Presentation
1	4.83	4.85	0.41%
2	4.80	4.85	0.83%
3	4.80	4.85	0.62%
4	4.80	4.85	0.21%
5	4.82	4.85	0.23%
6	4.80	4.85	0.16%
7	4.80	4.85	0.06%
8	4.80	4.85	0.05%
9	4.80	4.85	0.35%
10	4.79	4.85	0.15%
Presentation Error Average			0.31%

The author will discuss the frequency of data transmission by comparing the frequencies obtained from the Power Quality Meter (PQM) and Node-Red. This comparison will be illustrated using the Fuzzy Mamdani Method and will include a table detailing the precise calculation results of both methods.

The results illustrated in Figure 7 and detailed in Table 3. indicate that the frequency of data transmission has an exceptionally low error percentage, averaging just 0.02%. This confirms that both Node-Red and PQM frequencies are extremely accurate and efficient. Therefore, this monitoring system is well-suited for practical use and operational deployment. With an error rate below 1%, the system ensures highly accurate results and demonstrates outstanding operational effectiveness, validating the author's proposed methodology.

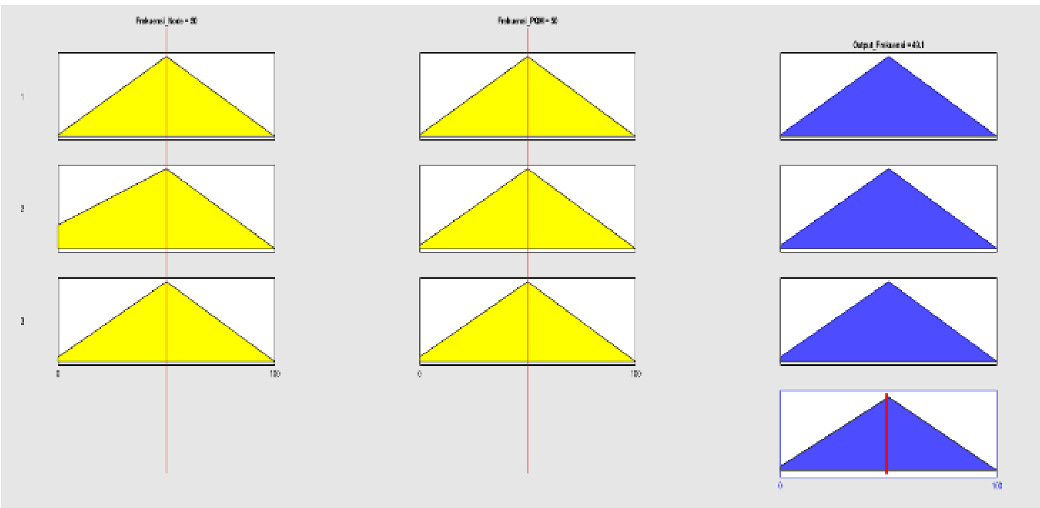

Figure 7. Fuzzy Logic Mamdani Frequency of Data Transmission

Table 3. Frequency of Data Transmission

No	Node-Red	PQM	Presentation
1	50.05	50.04	0.02%
2	50.05	50.04	0.02%
3	50.04	50.04	0.00%
4	50.05	50.04	0.04%
5	50.06	50.04	0.02%
6	50.05	50.04	0.02%
7	50.05	50.04	0.02%
8	50.05	50.04	0.02%
9	50.05	50.04	0.02%
10	50.05	50.04	0.02%
	Presentation Error Average		0.02%

5. Conclusion

This research has successfully developed and implemented a device utilizing the Raspberry Pi 3 Model B to enhance the reliability of substations through advanced hardware and software integration. The system effectively measures and analyzes critical parameters such as power, current, voltage, and frequency, enabling early detection of potential anomalies. The approach is cost-effective, with integrated sensors and detection algorithms ensuring high accuracy and seamless integration with existing infrastructure. Additionally, the solution optimizes energy consumption, allowing continuous operation without adding extra load to the substation. Overall, this innovation significantly enhances substation monitoring and maintenance, contributing to more efficient and reliable electricity management.

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Author contributions: All authors are responsible for building Conceptualization, Methodology, analysis, investigation, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision of project administration, funding acquisition, and have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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