Research Article

Design and Implementation of a Real-Time Monitoring System for a 150 kV Substation with Multi-Platform Notification and Visualization

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Abstract: This paper presents the development and implementation of an innovative real-time monitoring and notification system for a 150 kV electrical substation, leveraging Raspberry Pi 3, Node-RED, MySQL, and Firebase. The system measures key electrical parameters such as voltage, current, power, and frequency using sensors connected to a Programmable Logic Controller (PLC). The data is processed and displayed through a single-line diagram on both a web-based dashboard and an Android application. Color-coded indicators, controlled by JavaScript, reflect real-time equipment status, with normal conditions marked in red and fault conditions indicated in black. The novelty of this system lies in its integration of real-time data processing, dynamic visualization, and multi-channel notification mechanisms, combining web, mobile app, and messaging services like WhatsApp and email for operator alerts. This multi-layered approach improves operator response time and enhances monitoring accuracy, especially in remote or field environments. Experimental tests, including high-voltage and low-voltage fault simulations, demonstrated the system's ability to accurately detect faults and communicate them through the notifications in real-time, with an average measurement error of just 1.56%. The system not only provides enhanced situational awareness but also offers an efficient, cost-effective solution for remote substation monitoring, ensuring continuous supervision and immediate response to power system anomalies.

Keywords: IoT irrigation systems, precision agriculture, water conservation, wireless sensor networks, smallholder farming, cost-benefit analysis

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1. Introduction

The development of science and technology has become a crucial factor in enhancing both technological progress and the welfare of society and industry. In the electrical power sector, electricity is a vital resource that supports daily activities and industrial operations. The demand for electrical energy extends beyond urban areas to rural and coastal regions, with various power generation sources such as Diesel Power Plants (PLTD) [1], [2], Hydroelectric Power Plants (PLTA) [3], [4], [5], Gas Power Plants (PLTG), and Combined Cycle Gas Turbine Plants (PLTGU) being developed to meet this need.

One of the key technologies driving innovation in this field is the Internet of Things (IoT) [6], [7], [8], which has been integrated into the electricity industry. This study builds on previous research, where Arduino was used for substation monitoring by sending real-time data to the cloud via GSM [9], [10], [11], [12], [13]. However, unlike that approach, this research proposes a monitoring system for a 150 kV substation using Raspberry Pi 3, where data will be stored in a MySQL database such as the study in [14], [15], [16], [17] and sent to Firebase for real-time monitoring via an Android application and website. The data will also be validated by comparing it to measurements from a multimeter.

The system consists of several components: a sensor reads power data, which is processed by a Programmable Logic Controller (PLC) [18], [19], [20] before being sent to the Raspberry Pi [21], [22], for further processing. Node-RED [23] is used on the Raspberry Pi to send the processed data to the MySQL database and Firebase. The data is then transmitted to various outputs, including notification systems such as WhatsApp Gateway, Email Gateway, Android Apps, and Website, to alert operators in case of system anomalies or disturbances. These outputs ensure that operators can monitor and respond to power system conditions, even when they are not on-site.

Once the system processes the data, JavaScript is used to control the color changes in the single-line diagram based on the equipment's status. A value of 0 represents normal operating conditions (red), while a value of 1 represents a fault or anomaly (black). This visual feedback, triggered by real-time data from the database, enables operators to easily identify and address issues in the power system.

2. Methodology

2.1 Architecture System Design

The architecture of the system, as illustrated in Figure 1, is designed to effectively monitor and send notifications regarding the power system's condition. The system begins with a sensor that reads power data at 150kV, which is then passed to a Programmable Logic Controller (PLC) for processing. The PLC prepares the data and sends it to the next stage for further handling. After processing by the PLC, the power information is forwarded to a Raspberry Pi through a HUB for more in-depth analysis and management. In the Raspberry Pi, Node-RED is employed as a flow-based development tool to send the processed data to a MySQL database installed locally. Node-RED automates the flow of information, allowing efficient data management and storage. Additionally, the Raspberry Pi sends the data to Firebase using the HTTP protocol, enabling cloud storage and further processing.

The system outputs data to several notification and monitoring channels, including WhatsApp Gateway, Email Gateway, Client, Android Apps, and Website. These outputs serve the purpose of notifying users in real time if any disturbances or anomalies occur within the power system. The processed information is sent through notifications or messages to alert the operator or user about conditions that need immediate attention. The Client in this system refers to devices like laptops, PCs, or smartphones that users can utilize to access the monitoring dashboard or interface. The Android App also provides a direct monitoring interface on mobile devices, making it convenient for operators to track the system remotely. Both the Whatsapp Gateway and Email Gateway function as communication tools to notify the operator of any issues or anomalies, even when they are not physically present at the substation or monitoring site.

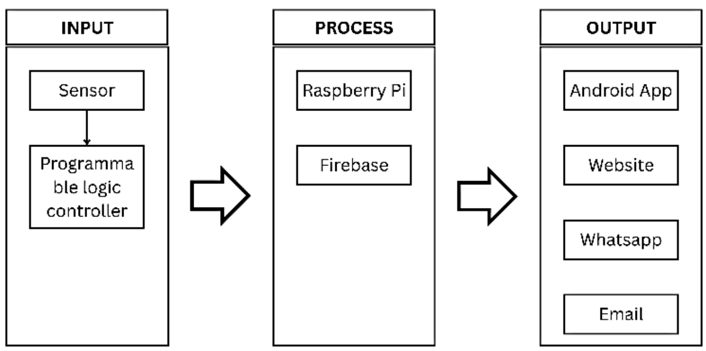

Figure 1. Overall of System Architecture

Overall, this system is designed to ensure comprehensive monitoring and supervision of the power system's condition by integrating modern technologies such as Raspberry Pi, Node-RED, Firebase, and various notification and monitoring media like Android apps and WhatsApp. This enables operators to stay informed about critical power conditions, ensuring quick responses to any issues or disturbances that may arise, even if they are not on-site.

2.2 Design of Trigger Warnings

The system utilizes JavaScript to manage the logic for changing colors in a single-line diagram. This color coding is used to indicate the status of the system's electrical equipment. In this system, a value of 0 represents a normal condition, while a value of 1 indicates a fault condition or a situation where the equipment has lost voltage. JavaScript is employed to interpret these values and adjust the colors of the corresponding equipment in the diagram to reflect the real-time status of the power system.

When a fault or anomaly occurs in the power system, the database sends logic data (either 1 or 0) based on the equipment's status. This data triggers the JavaScript script, which then updates the single-line diagram with the appropriate value. The script interprets the data, and based on the value received (1 or 0), the corresponding equipment's color will change accordingly, providing a clear visual cue to the operator regarding the system's status.

In the system, 1 represents an anomalous condition (marked in black), indicating that the equipment is in a faulty state, while 0 signifies the normal condition (marked in red) as shown in Figure 2. This color distinction allows operators to quickly and easily identify which components of the power system are functioning properly and which are experiencing issues. The use of JavaScript to automate this logic enhances the efficiency of the monitoring process, making it more intuitive and user-friendly for system operators.

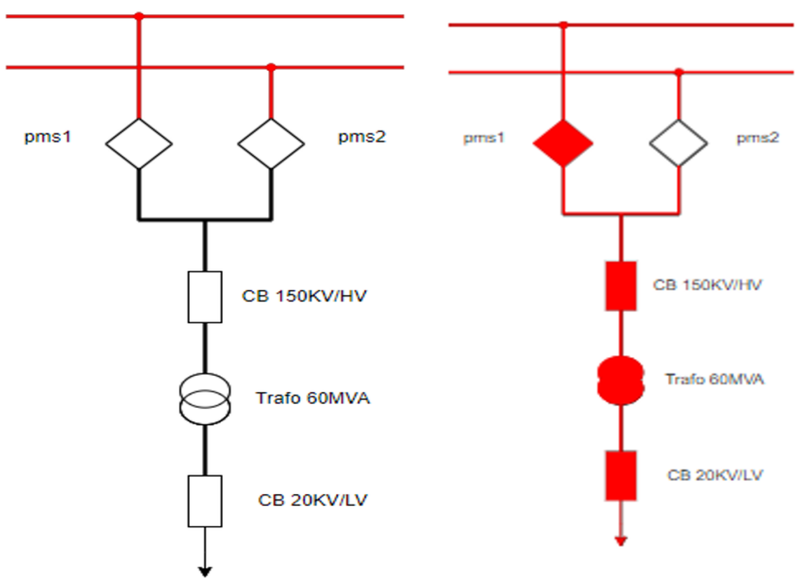

Figure 2. Unvoltage condition and normal condition

3. Result and Discussion

3.1 System Implementation and Interface Results

The developed substation monitoring system integrates multiple interfaces and notification channels to provide real-time visibility and alerting for electrical equipment conditions. The system is designed to operate on a Raspberry Pi 3B using Node-RED for processing and MySQL for data storage. Monitoring data is visualized via a website and Android app, and is also transmitted through WhatsApp and email notifications to ensure remote awareness, even when operators are not physically present at the substation.

The website interface as shown in Figure 3 presents a real-time dashboard that includes a history graph of power measurements, a single-line diagram, and a table of electrical parameters such as voltage, current, power, reactive power, and frequency. The single-line diagram visually displays the status of equipment using color indicators, where red indicates an active fault or anomaly.

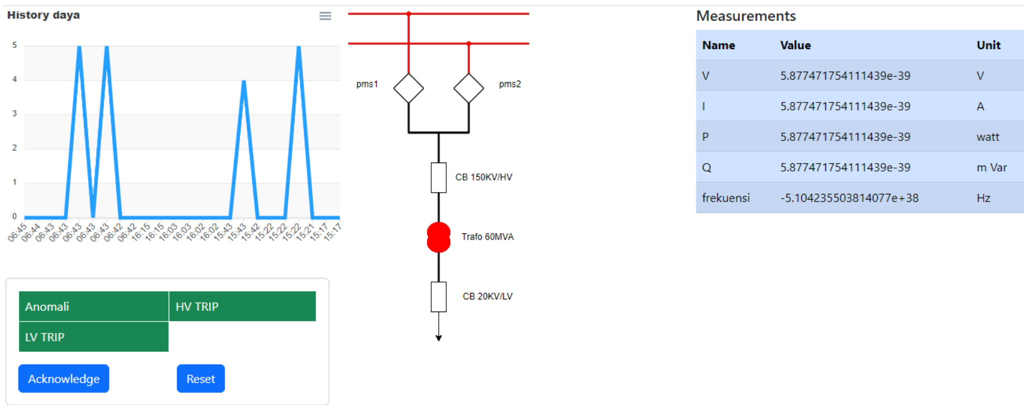

Figure 3. Website Appearance

The Android application in Figure 4 mirrors many of the website's core functions but focuses primarily on delivering system status and a notification list. At the top, it shows the current states such as High Voltage Trip, Low Voltage Trip, and Anomaly, with each condition displayed in a clear and color-coded format. Below that, a scrolling list of notifications shows time-stamped system alerts, such as "*Terjadi gangguan sisi HV Trafo: periksa bagian HV pada trafo*" and "*Terjadi anomaly: periksa peralatan sistem tenaga*". These alerts help operators quickly identify and locate the issue. However, due to the frequent repetition of similar messages, it's recommended to implement event grouping or deduplication to improve readability and user experience.

The WhatsApp notification system in Figure 5 acts as an extension of the alert mechanism, ensuring operators are informed via direct messaging. The messages replicate the alerts shown on the app and website, delivered instantly with a timestamp. This enhances operational flexibility, especially in field environments where internet access may be limited, but mobile connectivity is available. Similar to the Android app, a suggestion for future improvement is to add equipment identifiers or location tags to the messages to help operators act more efficiently.

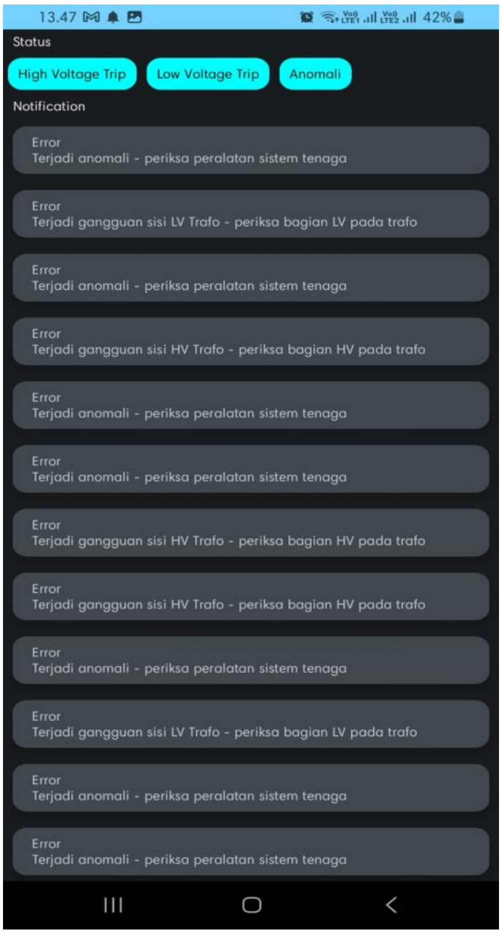

Figure 4. Android App View

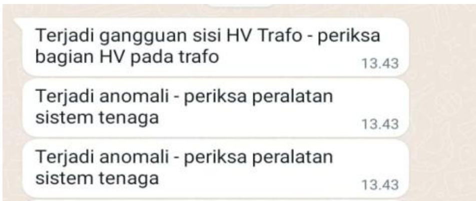

Figure 5. Whatsapp Notification View

The email notification feature provides another reliable communication path as shown in Figure 6. Alerts are sent from a configured sender email to the operator, containing concise messages that describe the nature of the issue, such as transformer faults or general anomalies. The inclusion of timestamps ensures accurate tracking of when issues occur. Email alerts are especially valuable for documentation and serve as a formal log of system status over time. To enhance the utility of this channel, it would be beneficial to include structured subject headers, severity classifications, or even real-time snapshots/logs as attachments.

Figure 6. Email Notification View

In summary, the system effectively combines multiple platforms—web, Android app, WhatsApp, and email—to offer comprehensive, real-time monitoring and notification for power substations. Each channel plays a complementary role in increasing system reliability and ensuring that operators are kept informed under various operational conditions. Future improvements should focus on data formatting, alert management, and user feedback mechanisms to enhance the overall responsiveness and usability of the system.

3.2 *Sensor Data Accuracy Analysis*

Accuracy testing of the sensor and website display was conducted after all components were assembled and operational. The purpose of this test was to evaluate the consistency between actual instrument readings and the data displayed on the website. This experiment focused on verifying the accuracy of voltage, current, and frequency measurements obtained from various tools including an AVO Meter, Power Quality Meter (PQM), and the website interface.

As shown in Table 1, the results reveal slight differences in the measurement values between the AVO meter, PQM meter, and the web interface. For example, the voltage readings were 223 V from the AVO Meter, 222.79 V from the PQM Meter, and 217.88 V on the website, resulting in a percentage error of 4.50%. Current readings varied slightly, with 4.9 A, 4.84 A, and 4.74 A respectively, producing an error of 0.13%. Frequency values recorded were 50.04 Hz and 49.98 Hz, leading to a minimal error of 0.06%. These results indicate that although the readings are not perfectly identical, they remain within acceptable tolerance limits and do not differ significantly in terms of electrical parameters.

Table 1. Comparison of Measurement Accuracy between Instruments and WEB Display

Data Name	AVO Meter	PQM Meter	Website	Unit	% Error
Voltage	223	222.79	217.88	Volt	4.50%
Current	4.9	4.84	4.74	Ampere	0.13%
Frequency		50.04	49.98	Hertz (Hz)	0.06%
Average Error					1.56%

Based on these tests, the average error rate is 1.56%, which is generally acceptable for practical monitoring systems, especially in non-critical applications. However, this does suggest that improvements can be made to enhance measurement accuracy. Factors such as sensor calibration, data transmission delays, and conversion processes from hardware to the website display could contribute to these discrepancies. Therefore, regular calibration of sensors and verification of web interface data integrity is recommended to ensure the high reliability and accuracy of the monitoring system.

To improve precision, it is recommended to perform periodic calibration of the measurement instruments, strengthen communication between components, and refine data processing on both the Raspberry Pi and the web interface. Additionally, implementing real-time error-checking or auto-calibration algorithms in the software can help minimize deviation. Moreover, to ensure the system performs reliably over time, it is suggested to measure Quality of Service (QoS) parameters such as latency, packet loss, data update interval, and system availability. Monitoring these metrics will provide a deeper understanding of the system’s responsiveness, reliability, and overall performance, which is especially important for real-time monitoring applications in power systems.

3.3 Single-Line Diagram Consistency and Notification Analysis

The monitoring system was tested to evaluate its accuracy in displaying real-time data and providing notifications during fault conditions. This section discusses the results of two experiments: the high-voltage fault simulation and the low-voltage fault simulation, both of which were tested using the system’s single-line diagram (SLD), measurement parameters, and notification system.

Figure 7 illustrates the results of the high-voltage fault simulation. When a fault occurred on the HV side of the transformer, the single-line diagram updated correctly to show the Circuit Breaker (CB) as "open" (indicated by the red status) and activated the HV Trip condition. The system also accurately displayed the measurement data, showing abnormal values in voltage, current, power, and frequency due to the fault. At the same time, the WhatsApp notification successfully alerted the operator with the message “*Terjadi gangguan sisi HV Trafo - periksa bagian HV pada trafo*” (A disturbance occurred on the HV side of the transformer – check the HV section), confirming the system’s ability to provide real-time notifications.

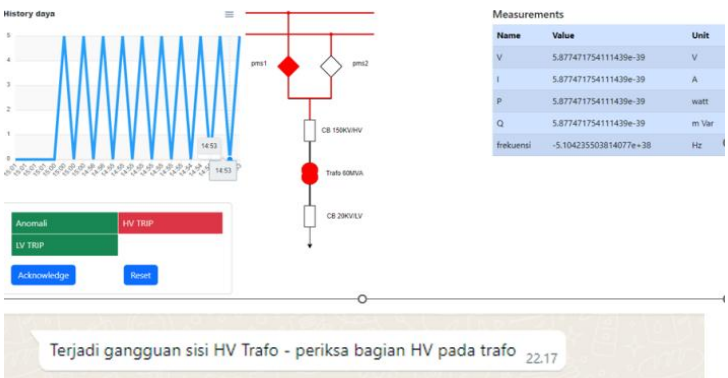

Figure 7. High-voltage fault simulation

Similarly, Figure 8 shows the results of the low-voltage fault simulation. When a fault occurred on the low-voltage side of the transformer, the system accurately updated the single-line diagram to reflect the open Circuit Breaker (CB) status and triggered the LV Trip condition. As with the high-voltage fault, the system displayed abnormal values for electrical parameters, indicating the system’s capability to track and visualize low-voltage faults in real time. The notification system, which included WhatsApp, email, and the

Android app, also performed as expected, delivering timely alerts to the operator about the fault and providing relevant information to facilitate prompt action.

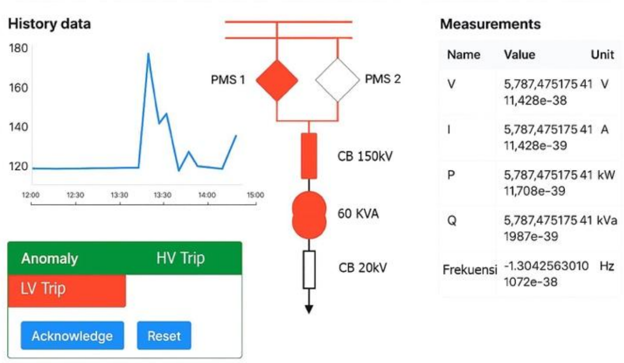

Figure 8. Low-voltage fault simulation

The experiments demonstrated that the monitoring system is effective in visualizing fault conditions, updating the single-line diagram correctly, and providing accurate measurement data for voltage, current, power, and frequency. Additionally, the multi-channel notification system ensured that operators were promptly informed through multiple communication channels, including WhatsApp, email, and the Android app. This integration of real-time monitoring, visual updates, and alerts validates the effectiveness of the system in enhancing the operational response to faults in the power system.

To further improve the system's performance, future work could focus on data validation, event grouping in notifications, and incorporating timestamp logging for better tracking of fault events. These improvements would help reduce redundancy and enhance the user experience during monitoring and fault management.

4. Conclusion

The proposed monitoring system successfully integrates real-time data acquisition, visualization, and multi-platform notifications to provide an effective and responsive solution for substation monitoring. Through the use of Raspberry Pi, Node-RED, and cloud services such as Firebase, the system enables seamless communication between field devices and operators. The use of JavaScript for color-coded visualization in the single-line diagram improves operator interpretation of system status, while the notification system ensures timely alerts through email, WhatsApp, and mobile applications. Testing confirmed that the system performs reliably under fault conditions, with correct status updates and synchronized notifications across all interfaces. The measurement accuracy, with an average error of 1.56%, falls within acceptable limits for operational monitoring. To further enhance system performance, future developments should include automatic data validation, grouped alert messaging, and Quality of Service (QoS) monitoring such as latency and uptime metrics. Overall, the system demonstrates strong potential for scalable, low-cost deployment in modern substation environments, supporting safer and more efficient electrical grid management.

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