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Improved Real-Time Thermal Monitoring for Substation Equipment

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Abstract

The efficient operation and safety of electrical substations are crucial for ensuring reliable energy distribution. At the Kemena Substation 275kV in Bintulu, Sarawak, the traditional method of manual thermal inspection for monitoring the temperature of primary equipment presents significant challenges, such as time consumption, potential oversight of issues between inspections, and worker exposure to high-voltage areas. This project aims to address these limitations by implementing an improved real-time thermal monitoring system that uses thermal imaging cameras and Google Spreadsheet analysis for data collection and visualization. The system employs NodeMCU ESP8266 microcontrollers and AMG8833 thermal sensors to monitor temperature continuously, with data transmitted wirelessly to Google Spreadsheets for real-time analysis. The findings show that the system enhances the reliability of thermal monitoring by providing continuous temperature data, enabling early detection of anomalies, and minimizing worker exposure to hazardous conditions. This improvement supports Sarawak Energy Berhad's goal of maintaining safe and efficient electricity services. The success of the system at Kemena Substation demonstrates its potential for wider application across other substations, with further research suggested to explore the integration of predictive maintenance features.

Keywords: Thermal monitoring, Real-time monitoring, NodeMcu ESP8266, AMG8833 sensors, Google Spreadsheet.

Introduction

Electrical substations play a crucial role in the generation, transmission, and distribution of electrical power, serving as the backbone of energy infrastructure. As energy demand continues to rise, ensuring the reliable operation of substation equipment is critical for preventing disruptions and ensuring a continuous power supply. One of the most significant challenges in the maintenance of substations is monitoring the temperature of primary equipment, such as transformers and circuit breakers, to detect potential overheating, which can lead to failures and safety hazards. Traditionally, thermal inspections have been conducted manually, which is not only time-consuming but also poses risks to personnel working in close proximity to live, high-voltage equipment.

At the Kemena Substation 275kV in Bintulu, Sarawak, manual thermal inspections are the standard approach for monitoring the temperature of primary equipment. However, this approach has inherent limitations, including the inability to provide continuous data, the risk of overlooking issues between inspections, and the potential for exposing workers to dangerous high-voltage environments. To address these challenges, the need for an improved thermal monitoring system that can provide real-time, continuous data while minimizing worker exposure to hazardous conditions is essential.

This project aims to develop and implement an improved version of a real-time thermal monitoring system at the Kemena Substation. The proposed system uses thermal imaging sensors and Google Spreadsheet analysis to collect and analyze temperature data continuously. The system utilizes NodeMcu ESP8266 microcontrollers and AMG8833 thermal sensors, which transmit real-time data wirelessly to a cloud-based platform, enabling remote monitoring and immediate anomaly detection. The primary objectives of this project are to enhance the reliability of thermal monitoring, detect abnormal temperature readings promptly, and reduce human exposure to high-voltage areas. By integrating these advancements, this project aims to contribute to the overall safety, efficiency, and reliability of substation operations, supporting SDG 7 (Affordable and Clean Energy) by improving energy infrastructure and SDG 8 (Decent Work and Economic Growth) by enhancing worker safety and operational efficiency.

Literature Review

The monitoring of electrical substations is integral to ensuring the safety and reliability of power distribution networks. Substations serve as the central nodes for the transmission of electrical energy, transforming voltages and facilitating the distribution of electricity across regions. The performance of critical equipment, such as transformers and circuit breakers, is often assessed by monitoring their temperature, as overheating is a primary indicator of impending failures (Li et al., 2017). This section discusses the evolution of thermal monitoring practices, focusing on current methods, advancements in thermal monitoring technologies, and the integration of real-time data collection and analysis for improved substation operations.

2.2. Traditional Thermal Monitoring Methods

Historically, thermal monitoring in substations has relied on manual inspections using infrared (IR) thermography cameras, which are widely recognized for their ability to detect hotspots and assess the condition of equipment (Zhao et al., 2018).

Thermography, as a non-destructive testing technique, is advantageous because it allows for the detection of abnormalities without interrupting the operation of equipment (Li et al., 2017). However, manual inspections are inherently limited by their periodic nature, as they only capture data at specific points in time, potentially allowing faults to develop unnoticed between inspections. Furthermore, manual inspections require technicians to work in close proximity to live equipment, exposing them to safety risks associated with high-voltage areas (Wang et al., 2019).

2.3. Limitations of Manual Inspections

Despite their effectiveness in detecting thermal anomalies, manual inspections using thermography are not without significant drawbacks. The frequency of inspections is often insufficient to ensure continuous monitoring of equipment, especially in large substations with numerous critical components. As a result, minor faults may persist unnoticed, leading to increased maintenance costs and the risk of equipment failure (Yang et al., 2020). Additionally, the need for technicians to access potentially hazardous zones further elevates the safety risks involved in manual thermal inspections. Therefore, while manual thermography provides valuable insights, it is not an optimal solution for ensuring real-time monitoring and long-term reliability (Zhao et al., 2018)

2.4. Advancements in Thermal Monitoring Technologies

To overcome the limitations of manual inspections, researchers have explored various advanced thermal monitoring technologies. One of the most promising innovations is the use of real-time temperature monitoring systems, which utilize thermal imaging sensors combined with automated data collection and analysis tools. For instance, Distributed Fibre Optic Sensing (DFOS) has been proposed as an advanced method for continuously monitoring the temperature of power transformers. DFOS enables real-time temperature tracking by embedding optical fibers into transformer windings, providing comprehensive data on thermal behavior and hotspot location (Xie et al., 2020). This system allows for continuous monitoring and provides more accurate insights into the health of the equipment.

Moreover, the integration of multi-parameter composite sensing systems, which combine temperature measurements with other critical parameters such as pressure and moisture, offers a more holistic approach to transformer monitoring (Yang et al., 2020). These systems provide a broader understanding of the operational environment and allow for more informed decision-making regarding maintenance and repairs.

2.5. Wireless Data Transmission and Cloud-Based Analysis

Recent advancements have also focused on integrating wireless communication technologies for data transmission. For example, the NodeMcu ESP8266 microcontroller, a low-cost Wi-Fi-enabled microcontroller, has been widely used in various Internet of Things (IoT) applications. In the context of substation monitoring, NodeMcu allows for the wireless transmission of temperature data from thermal sensors to cloud-based platforms for real-time monitoring and analysis (Wang et al., 2019). This approach significantly improves the speed and accuracy of data collection, providing operators with continuous, remote access to temperature information without the need for on-site presence.

Google Spreadsheet has emerged as an accessible and effective platform for storing and analyzing data in real-time. By integrating Google Spreadsheet with cloud-based platforms such as ThingSpeak, real-time temperature data can be logged, visualized, and analyzed with minimal effort, enabling proactive maintenance and immediate detection of abnormal temperature readings (Fang et al., 2021). This system offers numerous advantages, including the ability to monitor large numbers of substations remotely, reducing the need for frequent site visits and increasing operational efficiency.

2.6. Integration of Predictive Maintenance

The incorporation of real-time data monitoring also enables predictive maintenance, a strategy that aims to predict equipment failures before they occur. By continuously monitoring temperature trends and analyzing historical data, predictive maintenance algorithms can identify patterns that precede equipment failures, allowing for timely intervention and minimizing downtime (Cheng et al., 2018). The combination of real-time data and predictive maintenance can significantly enhance the reliability of substations, reduce repair costs, and extend the lifespan of equipment.

Methodology

This section outlines the systematic approach adopted for the implementation of the real-time thermal monitoring system for substation primary equipment at Kemena Substation 275kV in Bintulu, Sarawak. The methodology is structured to address the objectives of the project, which include detecting abnormal temperature readings, establishing continuous monitoring, and reducing human exposure to high-voltage areas. The process is divided into multiple phases: system design, hardware and software implementation, data collection, and real-time monitoring and analysis

3.1 System Design and Planning

The first phase of the project involved the design and planning of the real-time thermal monitoring system. The objective of the system is to monitor the temperature of primary equipment, such as transformers and circuit breakers, at the Kemena Substation. The design considered the following factors:

a) Selection of critical equipment: The low voltage bushing of Power Transformer No. 1 was identified as a key component for temperature monitoring.
b) System components: The system design incorporated the AMG8833 thermal imager array temperature sensor, NodeMcu ESP8266 microcontroller, and Google Spreadsheet for data storage and analysis. The system was designed to provide continuous data transmission and real-time analysis.
c) Safety considerations: The design aimed to minimize the need for workers to be in close proximity to energized equipment by allowing remote monitoring.

3.2 Hardware Components

The hardware components were selected based on their reliability, cost-effectiveness, and compatibility with the system's objectives. The primary hardware components are as follows:

a) NodeMcu ESP8266: This microcontroller was chosen due to its Wi-Fi capability, allowing it to transmit temperature data wirelessly to a cloud-based platform. It serves as the central control unit for data transmission.
b) AMG8833 Thermal Imager Array Temperature Sensor: This sensor features an 8x8 grid of infrared sensors, which are used to detect temperature variations at various points within the substation equipment. It provides detailed thermal readings that can be analyzed for abnormal temperature patterns.
c) Breadboard and Jumper Wires: These were used for prototyping and connecting the components without the need for soldering, facilitating easy modifications and troubleshooting.
d) Laser Pointer: This device helped pinpoint the exact area being monitored by the thermal sensor, ensuring accurate readings.
e) Power Supply: A portable power bank was used to ensure that the system had a reliable and uninterrupted power source for continuous operation.
f) Monopod: The monopod served as a stable, adjustable platform for positioning the thermal sensor and microcontroller at the correct angles for optimal monitoring.

3.3 Software Components

The software implementation comprised several tools and platforms that facilitated data collection, transmission, and analysis:

a) Arduino IDE: The NodeMcu ESP8266 was programmed using Arduino IDE, which provides a simple interface for writing and uploading scripts to the microcontroller. The code was developed to collect temperature data from the AMG8833 sensor and transmit it via Wi-Fi.
b) ThingSpeak and Blynk: These cloud-based platforms were used for real-time data visualization and analysis. ThingSpeak provided a robust data storage and analytics platform, while Blynk allowed for mobile-friendly real-time monitoring.
c) Google Spreadsheet: Google Spreadsheet was integrated as the primary platform for receiving and analyzing the temperature data. It was configured to automatically update with the incoming data and provided visualization tools to display temperature trends.

3.4 Data Collection Process

The data collection process involved capturing temperature readings from the thermal sensor at regular intervals. The following steps outline the data collection process:

a) Sensor Calibration: The AMG8833 thermal sensor was calibrated by comparing its readings against a known temperature reference to ensure accuracy.
b) Positioning the Sensor: The sensor was mounted on a monopod and positioned at the low voltage bushing of Power Transformer No. 1 to monitor the temperature in real time.
c) Data Logging: The NodeMcu ESP8266 microcontroller was programmed to collect temperature data from the sensor at five-minute intervals and transmit it to a cloud-based platform for storage and analysis.

3.5 Data Transmission

Data transmission from the thermal sensor to the cloud-based platform was facilitated through the NodeMCU ESP8266. The following steps describe the transmission process:

a) Data Processing: The temperature data captured by the AMG8833 sensor was processed by the NodeMcU microcontroller. The data was then formatted and prepared for transmission.
b) Wireless Transmission: The NodeMcu microcontroller sent the processed data wirelessly to Google Spreadsheet via the Wi-Fi network. The transmission was handled using HTTP POST requests, ensuring efficient and secure data transfer.
c) Cloud-Based Storage: The data was stored in Google Spreadsheet, providing an easily accessible platform for analysis. Real-time updates allowed the monitoring team to track temperature variations continuously.

3.6 Real-Time Monitoring and Analysis

The real-time monitoring and analysis phase focused on continuous tracking of the temperature data and immediate identification of any abnormal readings. The steps involved in real-time monitoring are as follows:

a) Data Visualization: The data received in Google Spreadsheet was visualized through charts and graphs. Conditional formatting was applied to highlight temperature anomalies, such as readings exceeding 40°C.
b) Anomaly Detection: Real-time monitoring algorithms were implemented within the spreadsheet to detect temperature anomalies. If a temperature exceeded the pre-set threshold, the system flagged the reading and alerted the monitoring team for immediate action.
c) Remote Access: The use of Google Spreadsheet allowed for remote monitoring, meaning that technicians and engineers could access the data from any location, minimizing the need for on-site presence and reducing the risks associated with working in hazardous areas

3.7 System Testing and Validation

The final stage of the methodology involved testing and validating the thermal monitoring system under real-world conditions. The testing process included the following steps:

a) System Deployment: The system was deployed at the Kemena Substation to collect data from the primary equipment over a five-day period.
b) Performance Comparison: The system's performance was compared with traditional manual inspection methods. The accuracy and effectiveness of the real-time monitoring system were assessed based on its ability to detect temperature anomalies promptly.
c) Validation: The system was validated by comparing the temperature readings with known benchmarks and historical data. The results were used to ensure that the system met the project's objectives of providing continuous monitoring, detecting abnormalities, and enhancing worker safety

Results and Discussion

This section presents the results of the implementation of the real-time thermal monitoring system at Kemena Substation 275KV in Bintulu, Sarawak. The primary aim of this project was to develop a system that provides continuous temperature monitoring of the substation's primary equipment, enables early detection of abnormal temperature readings, and minimizes worker exposure to high-voltage areas. The data collected over a five-day monitoring period demonstrates the system's effectiveness in achieving these objectives

4.1 Overall System Performance

The thermal monitoring system successfully captured temperature data from the low-voltage bushing of Power Transformer No. 1 at Kemena Substation. The system utilized the AMG8833 thermal imager array sensor and NodeMcu ESP8266 microcontroller for real-time data transmission to Google Spreadsheet. The system was able to monitor and report temperature changes every five minutes, providing continuous data that was analyzed and visualized in real-time.

As shown in Table 4.1, the temperature fluctuated throughout the day. The highest recorded temperature was 45.03°C, which exceeded the set threshold of 40°C, indicating an abnormal condition.

The following Figure 4.1 provides a visual representation of the temperature trends over the five-day monitoring period. This chart highlights both normal and abnormal temperature behaviors, helping to identify patterns and trends in equipment temperature.

Table 4.1. Temperature data for 15 August 2024

Power Transformer No.1 Low Voltage Bushing Red Phase		
Date	**Time**	**Temperature (℃)**
15/8/2024	15:15:56	30.52
15/8/2024	15:20:56	35.64
15/8/2024	15:25:56	33.41
15/8/2024	15:30:56	38.94
15/8/2024	15:35:56	42.4
15/8/2024	15:40:56	40.59
15/8/2024	15:45:56	37.71
15/8/2024	15:50:57	38.87
15/8/2024	15:55:56	44.55
15/8/2024	16:00:56	42.4
15/8/2024	16:05:56	42.25
15/8/2024	16:10:56	42.92
15/8/2024	16:15:56	40.93
15/8/2024	16:20:56	41.48
15/8/2024	16:26:02	42.09
15/8/2024	16:30:56	41.29
15/8/2024	16:35:56	40.63
15/8/2024	16:40:56	41.68
15/8/2024	16:45:56	42.79
15/8/2024	16:50:56	44
15/8/2024	16:55:56	44.93
15/8/2024	17:00:56	45.03

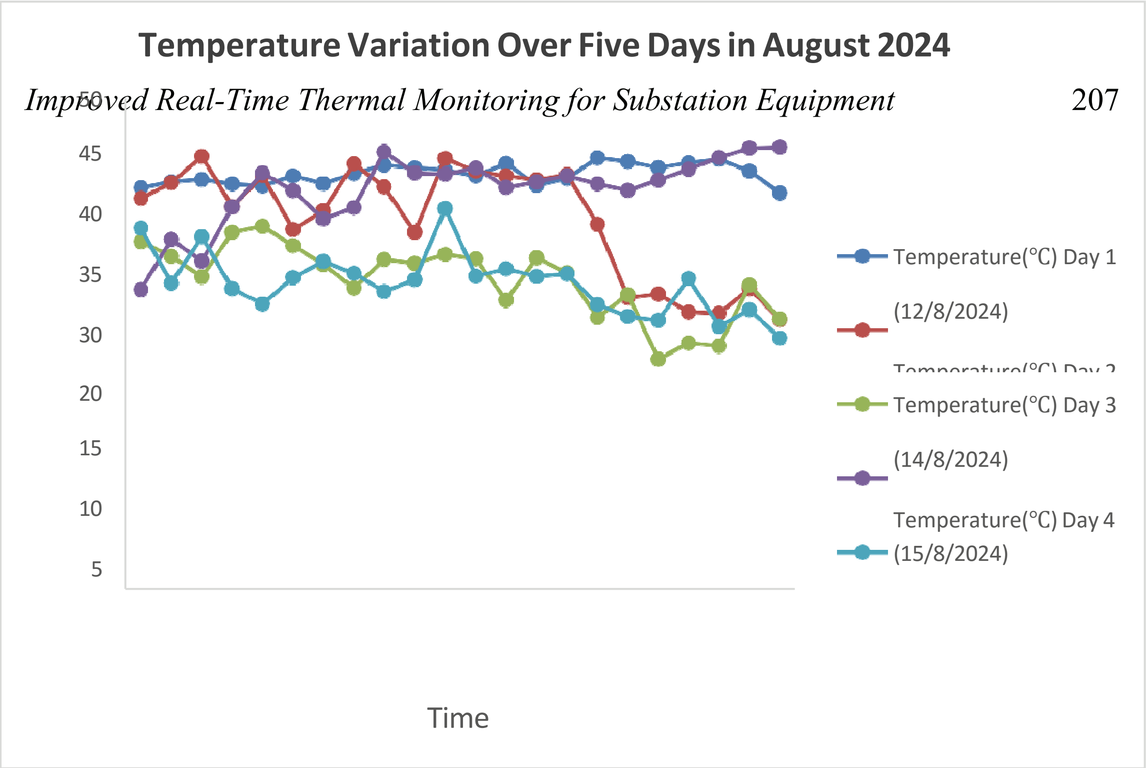

Figure 4.1 Temperature trends over five days from 15:15 to 17:00

The chart clearly shows significant temperature fluctuations, with the highest spike recorded on Day 4. This corresponds with an abnormal reading of 45.03°C at 17:00, which is marked in the system as an anomaly.

4.2 Abnormal Temperature Detection and Reporting

One of the primary objectives of the system was to detect and report abnormal temperature readings in real-time. The system was programmed to trigger an alert when the temperature exceeded 40°C. The results demonstrate the system's ability to identify these abnormal readings promptly.

For instance, on Day 4, the system detected and flagged a temperature reading of 45.03°C at 17:00, which was above the 40°C threshold. This detection triggered an immediate alert, notifying the monitoring team to take action. The real-time reporting provided timely visibility of the anomaly, facilitating quick intervention and reducing the risk of potential equipment failure

Table 4.2 Temperature for Day 4

Day 4 (Thursday)		
Date	**Time**	**Temperature (℃)**
15/8/2024	15:15:56	30.52
15/8/2024	15:20:56	35.64
15/8/2024	15:25:56	33.41

15/8/2024	15:30:56	38.94
15/8/2024	15:35:56	42.4
15/8/2024	15:40:56	40.59
15/8/2024	15:45:56	37.71
15/8/2024	15:50:57	38.87
15/8/2024	15:55:56	44.55
15/8/2024	16:00:56	42.4
15/8/2024	16:05:56	42.25
15/8/2024	16:10:56	42.92
15/8/2024	16:15:56	40.93
15/8/2024	16:20:56	41.48
15/8/2024	16:26:02	42.09
15/8/2024	16:30:56	41.29
15/8/2024	16:35:56	40.63
15/8/2024	16:40:56	41.68
15/8/2024	16:45:56	42.79
15/8/2024	16:50:56	44
15/8/2024	16:55:56	44.93
15/8/2024	17:00:56	45.03

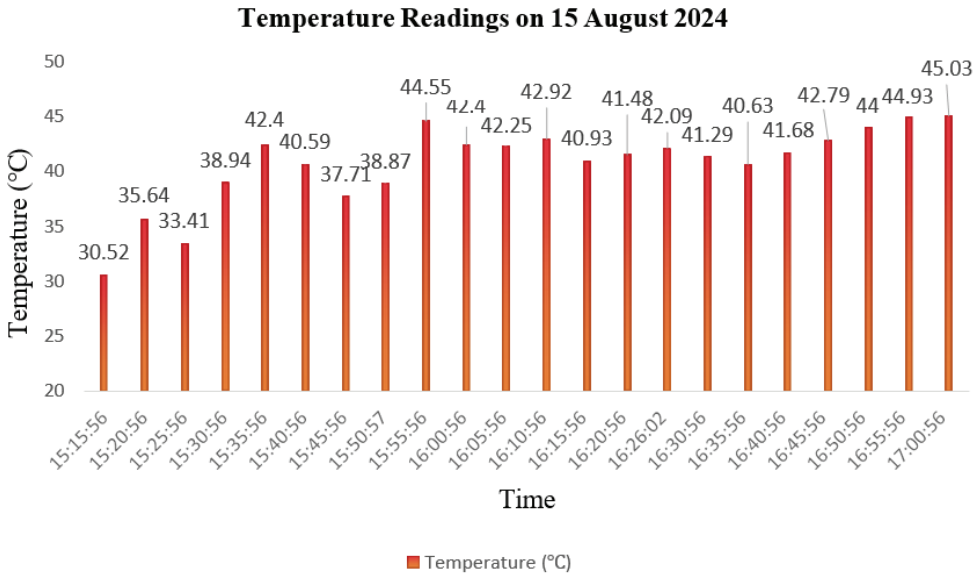

Figure 4.2: Abnormal Temperature Alert System Flow

This diagram illustrates the process flow for detecting and reporting abnormal temperature readings. When a reading exceeds the threshold of 40°C, the system triggers an alert, which is recorded in the Google Spreadsheet for further analysis

4.3 Continuous Monitoring and Data Visualization

The system was designed to provide continuous, real-time monitoring of the transformer's temperature. The data collected over five days was logged in Google Spreadsheet, where it was visualized using charts and graphs. The continuous data collection ensured that no anomalies went unnoticed between inspections

Table 4.3 Temperature Monitoring Over Five Days Hourly Data from 12th to 16th August 2024

Power Transformer No.1 Low Voltage Bushing Red Phase					
Time	**Temperature(℃)**				
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
	(12/8/2024)	**(13/8/2024)**	**(14/8/2024)**	**(15/8/2024)**	**(16/8/2024)**
15:15:56	40.9	39.8	35.4	30.52	36.77
15:20:56	41.51	41.41	33.9	35.64	31.18
15:25:56	41.75	44.08	31.82	33.41	35.89
15:30:57	41.28	38.95	36.37	38.94	30.61
15:35:57	41.09	42.14	36.98	42.4	29.04

15:40:56	42.11	36.66	35	40.59	31.75
15:45:56	41.3	38.53	33.08	37.71	33.39
15:50:56	42.33	43.32	30.67	38.87	32.17
15:55:56	43.22	40.98	33.59	44.55	30.31
16:00:58	42.91	36.35	33.2	42.4	31.54
16:05:56	42.68	43.89	34.11	42.25	38.77
16:10:56	42.1	42.56	33.64	42.92	31.88
16:15:56	43.38	42.08	29.44	40.93	32.64
16:20:56	41.15	41.69	33.73	41.48	31.84
16:25:56	41.85	42.24	32.25	42.09	32.11
16:30:56	43.95	37.17	27.69	41.29	28.99
16:35:56	43.58	29.7	30	40.63	27.79
16:40:56	42.94	30.06	23.45	41.68	27.39
16:45:56	43.42	28.23	25.06	42.79	31.65
16:50:56	43.79	28.11	24.77	44	26.75
16:55:56	42.57	30.61	30.98	44.93	28.46
17:00:56	40.37	27.44	27.52	45.03	25.58

Table 4.3 displays hourly temperature monitoring for each day, providing detailed temperature readings across the five-day period. These readings help demonstrate the consistency of data collection and highlight the anomalies detected on Day 4

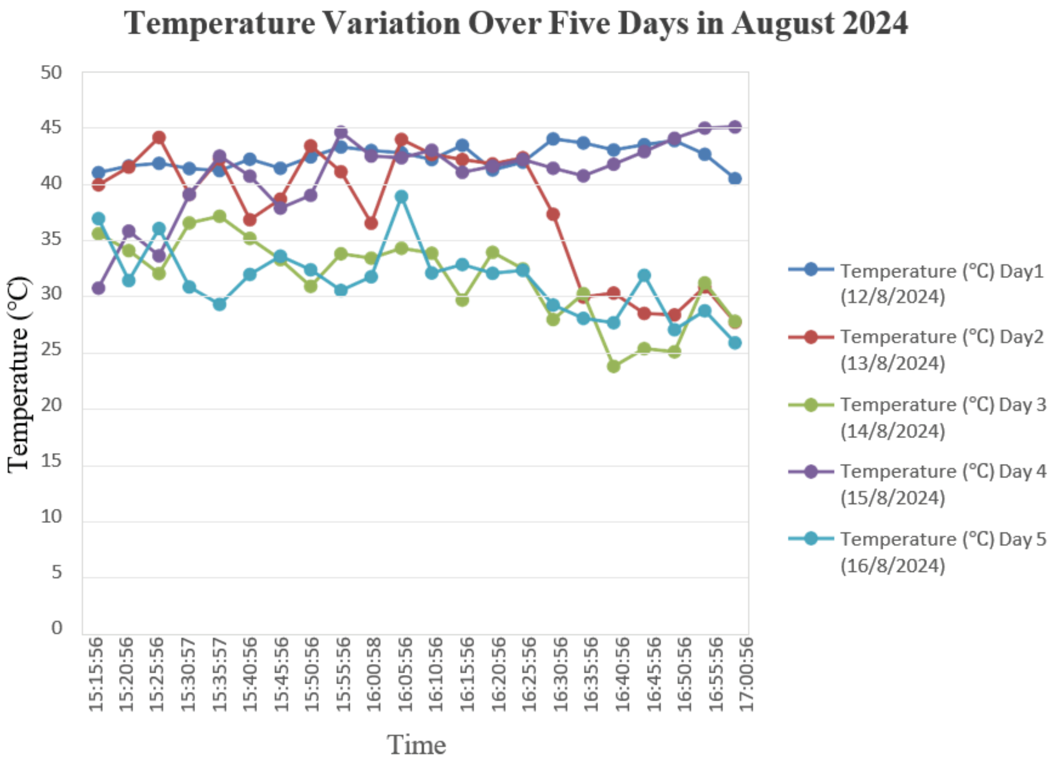

Figure 4.3: Line Graph Showing Temperature Trends Over Five Days

4.4 System Effectiveness and Reliability

The system effectively achieved its objectives of continuous temperature monitoring, anomaly detection, and real-time reporting. It provided a reliable and efficient method for monitoring the health of the transformer, with immediate alerts issued when the temperature exceeded the threshold. The ability to remotely monitor the temperature from any location significantly reduced the need for manual inspections and minimized the risks associated with worker exposure to live equipment.

The findings from the five-day monitoring period confirm that the system can detect abnormal temperature readings promptly, enabling timely intervention. The real-time updates provided by the Google Spreadsheet ensured that operators were able to respond to potential issues without delay, which is essential for preventing equipment failure and ensuring uninterrupted power supply

Conclusion

This project successfully developed and implemented a real-time thermal monitoring system for the primary equipment at Kemena Substation 275KV in Bintulu, Sarawak. The system utilized thermal imaging sensors, NodeMcu ESP8266 microcontrollers, and Google Spreadsheet for continuous data collection, analysis, and visualization. The project met its primary objectives of detecting abnormal temperature readings, establishing continuous real-time monitoring, and minimizing worker exposure to high-voltage areas.

The results confirmed that the system effectively captured temperature fluctuations, detected abnormal readings in real-time, and provided immediate alerts to operators for timely intervention. This system proved to be more reliable than traditional manual inspections, offering continuous monitoring without the limitations of infrequent inspections and human error. By integrating wireless data transmission and cloud-based analysis, the system enabled remote monitoring, reducing the need for technicians to be in close proximity to live equipment and enhancing overall safety.

Additionally, the real-time temperature data allowed for proactive maintenance and early detection of potential equipment failures, supporting the long-term health of the substation's infrastructure. The successful implementation of this system aligns with Sarawak Energy Berhad's goals of ensuring reliable and safe electricity services.

In conclusion, the project demonstrated the potential of using modern thermal monitoring technologies to enhance the efficiency, reliability, and safety of substation operations. The system developed in this project can be applied to other substations, and future research could explore the integration of predictive maintenance capabilities to further optimize performance and minimize downtime. The findings from this study indicate that the system holds great promise for improving the overall maintenance strategy within the electrical power industry

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