Jurnal Teknologi Elekterika, 2025, Volume 22 (2): 107-114 e- ISSN 2656-0143

Smart Monitoring System for Voltage, Current, and Security Measurement Based on Raspberry Pi in Distribution Substations

Muh. Imran Bachtiar [1), A. Inggrid P.M [1), Fitriyani [1), Satriani Said Akhmad [1), M.P Lukman [1)

[1] Department of Electrical Engineering, State Polytechnic of Ujung Pandang, Makassar, 90234, Indonesia.

email: muh.imranb@poliupg.ac.id; inggridpmantari02@gmail.com; ftryahmad06@gmail.com; satrianisaid86@gmail.com; musfirahputrilukman@gmail.com

Abstract*—Monitoring voltage, current, and security in distribution substations is crucial to maintain power system reliability and to prevent losses caused by disturbances or theft. This study presents the design and implementation of a smart monitoring system for voltage, current, and security based on a Raspberry Pi platform. The system integrates a PZEM-004T voltage and current sensor, a PIR motion sensor, a USB camera, and a DS3231 RTC module. It enables real-time measurement of electrical parameters and automatically detects unauthorized access to substation panels. The monitoring data is transmitted to a Firebase Realtime Database and visualized through an Android application developed using MIT App Inventor. When motion is detected, the system automatically captures images and video footage, which are then uploaded to Google Drive as visual evidence. Additionally, the system provides real-time notifications to the user through the application, thereby enhancing the efficiency and effectiveness of substation monitoring and security. Experimental results demonstrate that the system operates accurately and responsively in both electrical parameter measurement and security threat detection.

***Keywords*—Raspberry Pi, Distribution Substation, Voltage and Current Monitoring, Smart Security, Internet of Things (IoT), PZEM-004T Sensor, PIR Sensor, Firebase, MIT App Inventor**

I. Introduction

The electric power system consists of various components such as generators, transformers, loads, and protective equipment, which are integrated through the processes of generation, transmission, and distribution [1]. Distribution substations play a crucial role in delivering electrical power to consumers; however, voltage and current monitoring is still largely performed manually, making it inefficient and non–real-time [2].

In addition, distribution substations are vulnerable to cable and component theft. Conventional security systems such as CCTV or alarms are often ineffective because they only record or notify when the incident is already occurring, resulting in delayed response and continued losses.

The development of the Internet of Things (IoT) enables the integration of sensors with internet connectivity to achieve more efficient monitoring [3]. With the implementation of IoT, a Raspberry Pi–based monitoring system can measure voltage and current while also detecting security threats in real time. The data is transmitted via Wi-Fi to an Android application, allowing users to remotely monitor substation conditions and automatically receive reports related to load status and security events.

This study aims to design a Raspberry Pi–based smart monitoring system for voltage, current, and security in distribution substations, capable of providing early detection of potential disturbances while improving monitoring efficiency and security.

II. Research Methodology

The method used in the development of this system is the Prototype model, which consists of seven main phases. This method was selected for designing the "Raspberry Pi-Based Smart Monitoring System for Voltage, Current, and Security in Distribution Substations" because it enables iterative refinement of the system based on user feedback.

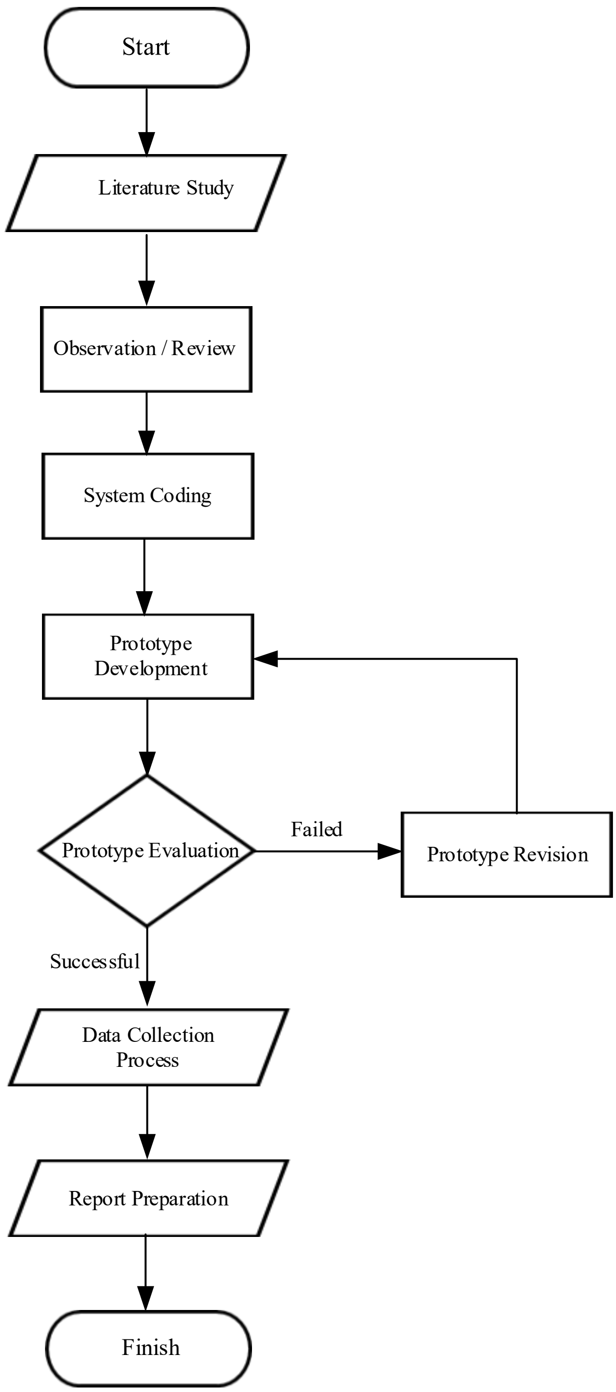

Figure 1. Research Flowchart

1) Literature Study: Collecting references to understand fundamental concepts, relevant technologies, and similar systems.
2) Observation / Review: Conducting field observations to obtain real-world insights about the existing system.
3) System Coding: Writing program code to read sensor data, transmit data to the cloud, and display information.
4) Prototype Development: Developing both hardware and software components of the prototype.
5) User Evaluation: Conducting initial user testing to ensure system functionality.
6) Prototype Refinement: Iteratively improving the prototype until optimal performance is achieved.
7) Product Implementation and Maintenance: Finalizing the system, performing full-scale testing, and maintaining the system to ensure stability.

2.1 Hardware Design

The hardware design process consists of two main stages: block diagram design and circuit layout design. The following are the stages involved in the hardware design process.

2.1.1 Block Diagram

The block diagram is designed as a reference for hardware development to simplify the assembly process.

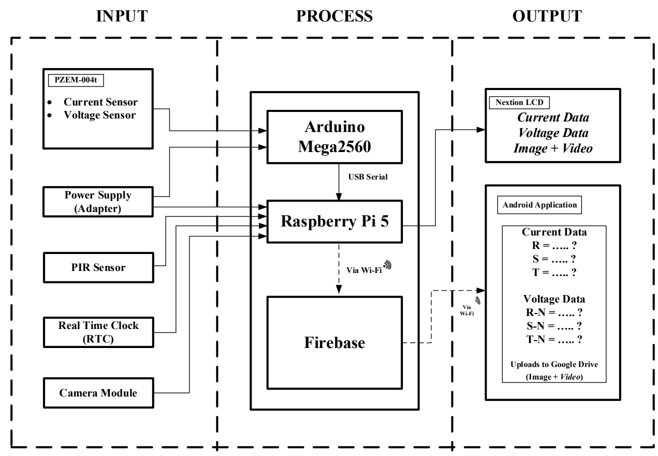

Figure 1. Block Diagram

In the input section, the system utilizes a power adapter, a GPS module for location tracking, a camera for visual documentation, an RTC module for timestamping, a PIR sensor for motion detection, and a PZEM-004T sensor to measure voltage and current.

In the processing section, the Raspberry Pi 5 functions as the central controller, receiving and processing data from all sensors and transmitting it to

Firebase via Wi-Fi, with the ESP32 serving as an additional communication module.

In the output section, the data is displayed through a Nextion LCD and a Firebase-based Android application, enabling users to monitor electrical load conditions and substation security in real time.

2.1.2 Hardware Design

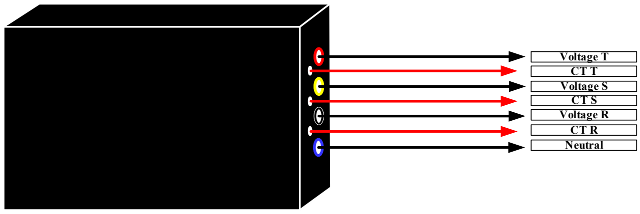

Figure 2. Hardware for Voltage and Current Monitoring

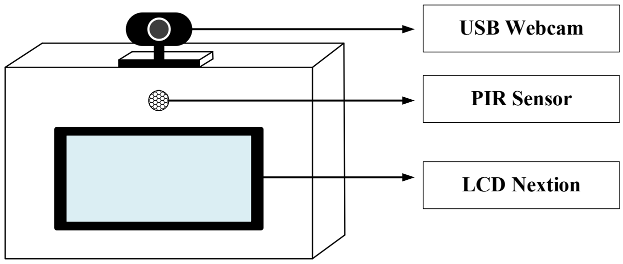

Figure 3. Security Hardware Monitoring

2.1.3 Circuit Design

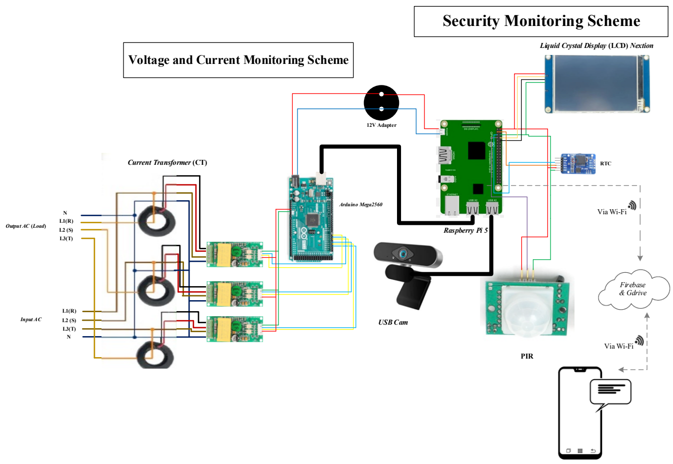

Figure 4. Circuit Design

2.2 Sofware Design

The software design consists of three stages: monitoring, application, and integration. Raspberry Pi and Arduino process voltage, current, and PIR sensor data in real time. When motion is detected, the camera automatically records and uploads the footage to Google Drive. The Android application, developed using MIT App Inventor, displays sensor data and provides access to recorded media, while the integration stage ensures that sensor data is transmitted to Firebase and can be monitored in real time.

2.2.1 Software Design for Monitoring

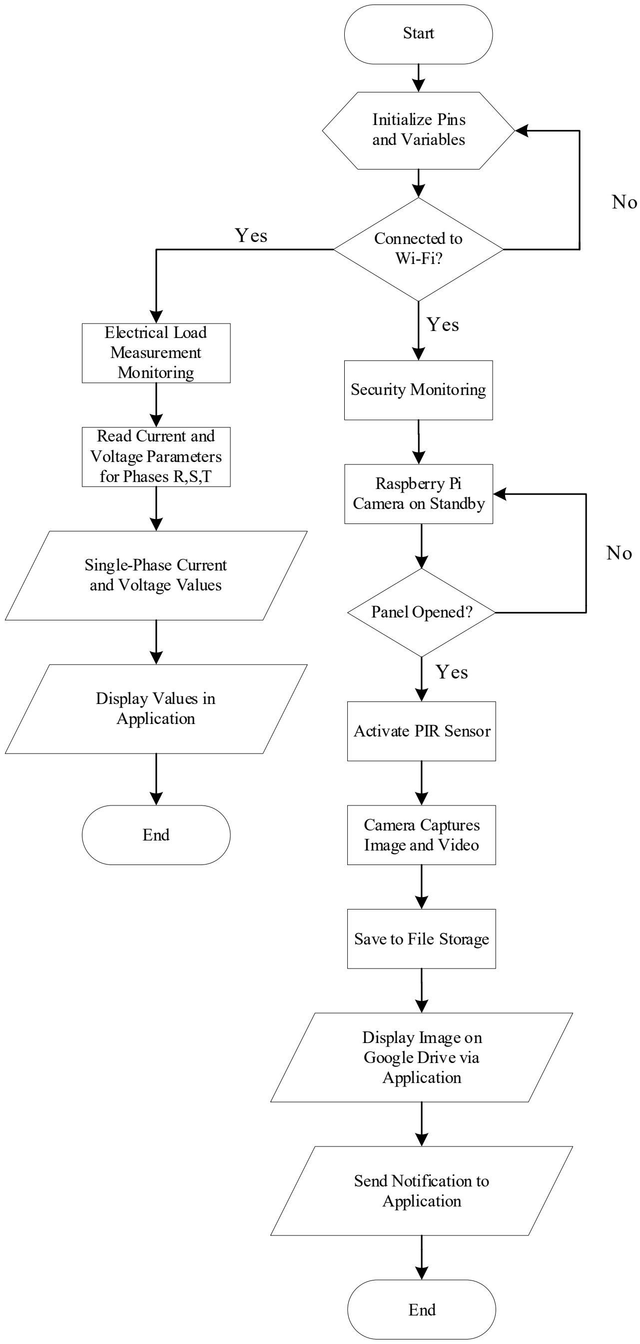

Figure 5. Flowchart of the Device Operation

2.2.2 Device Testing

Testing was conducted to ensure that all components operate optimally according to the design specifications. The PZEM-004T sensor, PIR sensor, DS3231 RTC module, and camera were tested by comparing their readings with standard measurement instruments, while data communication was evaluated through Firebase and Google Drive access via the Android application. The success criteria were defined as measurement errors of less than 5%, stable IoT connectivity, and a fully functional application interface. The test results indicate that the system is capable of operating optimally under real distribution substation conditions.

III. Results and Discussion

The Raspberry Pi–based monitoring system that was developed has been tested on a distribution substation to verify the performance of all components.

3.1 Component Testing Results

3.1.1 PZEM-004T Sensor

a) AC Voltage Measurement

Table 1. AC Voltage Measurement Test Results Using the PZEM-004T Sensor and a Standard Measuring Instrument

Sensor No.	Measurement Result (Sensor)	Measurement Result (Measuring Instrument)	Accuracy
Phase R (1)	232.2 V	231.6 V	99.74%
Phase S (2)	229.4 V	229.1 V	99.87%
Phase T (3)	230.3 V	227.5 V	98.77%

The test results show that the PZEM-004T sensor is capable of measuring AC voltage with an average accuracy of 99.61% and an error of less than 5%. This indicates that the sensor operates consistently, reliably, and is suitable for use as a primary component in the electrical voltage monitoring system.

b) AC Current Measurement

Table 2. AC Current Measurement Test Results Using the PZEM-004T Sensor and a Standard Measuring Instrument.

Sensor No.	Measurement Result (Sensor)	Measurement Result (Measuring Instrument)	Accuracy
Phase R (1)	2.1 A	2.1 A	100%
Phase S (2)	0.22 A	0.21 A	95.24%
Phase T (3)	0.31 A	0.30 A	96.67%

The PZEM sensor was able to measure AC current with an average accuracy of 97.1% and an error of < 5%. These results indicate that the sensor is sufficiently precise, stable, and suitable for use in the electrical current monitoring system.

3.1.2 PIR Sensor

Table 3. PIR Sensor Test Results

No	Distance from Panel (m)	Angle to Panel (°)	Panel Opened?	Movement Detected?	Remarks
1	1	0 (directly in front)	Yes	Yes	Normal detection
2	2	0	Yes	Yes	Optimal detection
3	3	0	Yes	Yes	Effective distance limit test
4	2	45	Yes	Yes	Tilted angle test
5	2	90	Yes	No	Side angle test
6	2	135 (behind sensor)	Yes	No	Out of angle range
7	1	0	No	No	False detection test
8	2	0	No	No	Normal without movement

The test results indicate that the PIR sensor effectively detects motion within an angle range of 0°–45° at distances up to 3 meters, while detection performance decreases at angles ≥90°. The sensor also does not respond when the panel is closed, thereby preventing false detections. Therefore, the PIR sensor is considered suitable for use in monitoring the security of distribution substation panels.

3.1.3 RTC DS3231 Sensor

Table 4. RTC DS3231 Sensor Test Results

No	RTC Time	Netbook Time	Difference (seconds)	Remarks
1	2025-07-27 16:37:53	2025-07-27 16:37:53	0.91	Accurate
2	2025-07-27 16:37:59	2025-07-27 16:37:59	0.98	Accurate
3	2025-07-27 16:38:05	2025-07-27 16:38:05	0.98	Accurate
4	2025-07-27 16:38:11	2025-07-27 16:38:11	0.98	Accurate
5	2025-07-27 16:38:17	2025-07-27 16:38:17	0.98	Accurate

Based on the test results above, it can be concluded that the RTC module used (DS3231) demonstrates good accuracy, as the time deviation only occurs at the second-level difference.

3.1.4 USB Camera

Table 5. USB Camera Test Results

No	File Name	File Type	Lighting Condition	Image Quality	Remarks
1	Gardu1_20250722_133314.jpg	Image	Daytime	Adequate	Object appears clear
2	Gardu1_20250722_192812.jpg	Image	Nighttime	Adequate	Low lighting, lower area is dark
3	Gardu1_20250722_132825.mp4	Video	Daytime	Good	Object activity clearly recorded
4	Gardu1_20250722_200244.mp4	Video	Nighttime	Good	Object activity recorded well, slight noise
5	Gardu1_20250722_083109.jpg	Image	Morning	Clear	Object appears clear

The USB camera test results indicate that the image and video quality is sufficiently clear during daytime operation, although reduced illumination and noise were observed at night. However, activity remains detectable, indicating that the USB camera is effective for substation monitoring, provided that lighting adjustments are applied to optimize performance during nighttime conditions.

3.1.4 Microcontroller

Table 6. Microcontroller Testing Results

No	Tested Component	Testing Activity	Expected Result	Status	Remarks
1	Arduino Mega2560	Reading voltage and current from PZEM-004T sensor (3-phase)	Voltage and current data appear on serial monitor	✓	Functioning normally
2	USB Serial Communication	Sending data from Arduino Mega to Raspberry Pi via USB	Data can be read by Raspberry Pi via USB serial port	✓	Stable connection
3	Raspberry Pi	Retrieving data from serial port and sending to Firebase DB	Data appears in Firebase (voltage, three-phase current)	✓	Synchronization successful
4	PIR Sensor	Testing motion detection when panel is opened	Status “1” appears in Firebase and sends image/video with attribute “panel open”	✓	PIR is sensitive and accurate
5	USB Camera (Webcam)	Capturing image and video when PIR is active	Images/videos stored, filenames match RTC time	✓	Image is clear enough
6	Google Drive API	Automatically uploading images/videos after capture	Files appear in the specified Google Drive folder	✓	URL accessible
7	RTC DS3231	Reading time when PIR is active and displaying in event log	Time synchronized with system and appears in Firebase	✓	Good time accuracy
8	MIT App Inventor Application	Firebase App (panel status, voltage, current, images, video + notification)	All data displayed in app, notification works	✓	App runs smoothly

The test results show that the Arduino Mega 2560 is capable of accurately reading three-phase voltage and current data and transmitting them to the Raspberry Pi for real-time upload to Firebase. The PIR sensor effectively detects panel opening and triggers the USB camera to record, with timestamps provided by the RTC DS3231. Media files are successfully uploaded to Google Drive and accessed via the Android application. Overall, the system operates reliably and effectively for real-time remote monitoring.

3.2 Data Acquisition

3.2.1 Voltage Monitoring Results at the Distribution Substation

Table 7. Voltage Monitoring Results for Phases R, S, and T at the Distribution Substation.

No	Date/Time	Voltage R (Volt)	Voltage S (Volt)	Voltage T (Volt)	Remarks
1	2025-07-21 19:41:44.009931	234.1	232.9	235.4	Night
2	2025-07-21 19:47:52.011488	233.2	232.1	234.9	Night
3	2025-07-21 20:02:58.442775	234.1	233.1	235.6	Night
26	2025-07-22 01:47:09.345029	238.2	230.7	239.6	Late Night
27	2025-07-22 01:10:09.789402	238.6	236.2	239.4	Late Night
28	2025-07-22 01:27:09.168329	237.9	236.8	239.1	Late Night
47	2025-07-22 07:54:18.558893	239.0	237.2	239.8	Morning

No	Date/Time	Voltage R (Volt)	Voltage S (Volt)	Voltage T (Volt)	Remarks
48	2025-07-22 07:50:52.886423	236.9	235.9	238.7	Morning
49	2025-07-22 07:32:51.975299	239.5	237.1	238.7	Morning
66	2025-07-22 11:50:53.392529	236.1	234.4	235.5	Afternoon
67	2025-07-22 12:02:45.905437	236.2	236.4	237.4	Afternoon
68	2025-07-22 12:15:47.896321	236.8	234.2	237.4	Afternoon
82	2025-07-22 15:17:52.636281	236.5	233.2	235.4	Late Afternoon
83	2025-07-22 16:02:54.748593	235.1	233.2	236.5	Late Afternoon
84	2025-07-22 16:17:55.403146	235.5	233.7	236.3	Late Afternoon

At the beginning of the test, the voltage of all three phases was within the range of 234–235V, then gradually increased to a peak of 239.9V on phase T at 05:47, before decreasing again to approximately 231–234V in the late afternoon. These values are still within the acceptable tolerance limits of the standard (±10% of 220V or up to 242V). The voltage fluctuation is influenced by load variations, where light load conditions at night increase voltage levels, while higher daytime loads cause voltage reduction.

3.2.2 Current Monitoring Results for Phases R, S, and T at the Distribution Substation.

Table 8. Current Monitoring Results for Phases R, S, and T at the Distribution Substation

No	Date/Time	Current R (Ampere)	Current S (Ampere)	Current T (Ampere)	Remarks
1	2025-07-21 19:41:44.009931	4.32	3.93	18.18	Night
2	2025-07-21 19:47:52.011488	4.31	3.9	15.03	Night
3	2025-07-21 20:02:58.442775	4.31	3.58	15.58	Night
26	2025-07-22 01:47:09.345029	4.29	3.6	13.42	Late Night
27	2025-07-22 01:10:09.789402	4.23	3.49	13.86	Late Night
28	2025-07-22 01:27:09.168329	4.24	3.62	13.67	Late Night
47	2025-07-22 07:54:18.558893	1.3	0.62	9.68	Morning
48	2025-07-22 07:50:52.886423	1.28	0.6	9.51	Morning
49	2025-07-22 07:32:51.975299	0.97	0.72	9.1	Morning
66	2025-07-22 11:47:53.392529	1.01	0.62	12.11	Afternoon
67	2025-07-22 12:02:45.905437	1.02	0.62	12.22	Afternoon
68	2025-07-22 12:15:47.896321	1.03	0.6	12.27	Afternoon
82	2025-07-22 15:17:52.636281	1.03	0.6	12.92	Late Afternoon
83	2025-07-22 16:02:54.748593	1.06	0.6	12.55	Late Afternoon
84	2025-07-22 16:17:55.403146	1.04	3.05	12.82	Late Afternoon

The highest current was recorded on phase T during nighttime (18.18 A), while a significant decrease occurred during the daytime due to minimal activity. Toward the evening, the current increased again, reaching 17.72 A. Overall, the load is higher at night, with an unbalanced distribution due to the dominance of phase T.

3.2.3 Security Monitoring Results at the Distribution Substation

The security system test results show that the PIR sensor functions effectively, as it only detects movement when the substation panel is opened, while the system displays the status "Panel Closed" on the Android application when the panel remains closed.

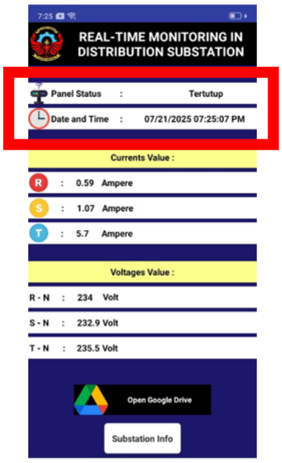

Figure 6. Android Application Display When the Panel Is Closed

When the panel is opened, the PIR sensor detects movement and triggers the Raspberry Pi to activate the USB camera. Images and videos are stored locally with filenames based on the substation name and timestamp to facilitate event identification.

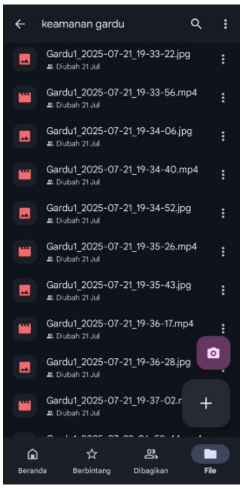

Figure 7. Proof of Images and Videos Successfully Uploaded to Google Drive

Following local storage, the system automatically uploads images and videos to Google Drive and transmits real-time notifications to the Android application. This allows users to be immediately informed when the panel is opened and to access the captured data through the application.

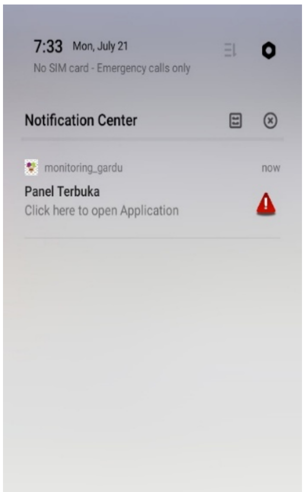

Figure 8. Real-Time Notifications Displayed on the Android Application When the Panel Is Opened and the PIR Is Activated

The Android application displays the panel status in real-time, changing from 'Closed' to 'Opened,' and provides a Google Drive link to access the documentation of images and videos of the incident.

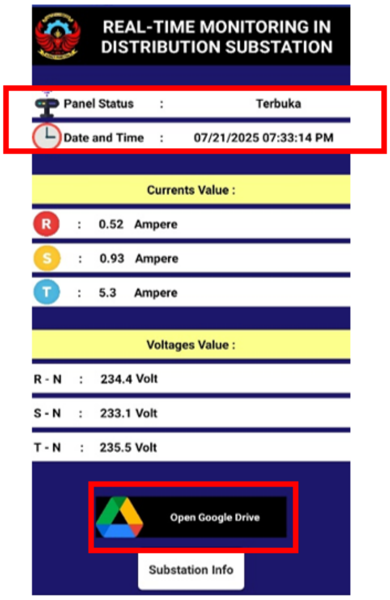

Figure 9. Android Application Interface Showing the Panel Status Changing to 'Opened' and the Link to Access Google Drive

The system is capable of detecting movement inside the panel, storing visual evidence, sending notifications, and providing cloud-based documentation, thereby effectively and efficiently maintaining the security of the distribution substation.

IV. Conclusion

1. The voltage and current monitoring system was successfully implemented using Arduino Mega 2560, Raspberry Pi 5, and the PZEM-004T sensor. Data can be automatically sent to Firebase for remote real-time monitoring.
2. The security system can detect panel openings through the PIR sensor, trigger a USB camera to capture images and videos, store them on Google Drive, and send real-time notifications to the Android application.
3. The Android application displays voltage, current, and substation security status in real-time, provides access to visual documentation on Google Drive, and issues notifications for suspicious activities, making it effective for monitoring and prevention.

ACKNOWLEDGMENTS

The author expresses sincere gratitude to Politeknik Negeri Ujung Pandang for the support of facilities, and to the supervising lecturers for their guidance and advice throughout the completion of this research.

References

[1] Ahmad, J., Dwi, W., & Ananto Pamungkas, P. D. (2016). Web-Based Monitoring and Maintenance System for IT Devices at the IT Department of PT Denso Indonesia Bekasi. *Jurnal Mahasiswa Bina Insani*, 1(1).

[2] Andipa, R. A., & Asyrafi, R. (2018). Remote Monitoring System for Body Temperature and IV Fluid Based on Raspberry Pi. Politeknik Negeri Ujung Pandang.

[3] Badawi, A., & Harahap, R. R. (2023). IoT-Based Monitoring of Distribution Substation Voltage and Temperature. *Journal of Science and Social Research*, 6(3), 778–783.

[4] Desyantoro, E., Rochim, A. F., & Martono, K. T. (2015). Automatic Control System of Home Electronic Devices Using PIR, LM35, and LDR Sensors. *Jurnal Teknologi dan Sistem Komputer*, 3(3), 405–411.

[5] Hamma, N. I. (2021). Distribution Substation Planning at PT. Maccon Indonesia. *Seminar Nasional Teknik Elektro dan Informatika (SNTEI)*.

[6] Hariyadi, S., Hartono, H., I.S, R., Setiyo, S., & Julaihah, S. (2023). IoT-Based Control and Monitoring System of Low Voltage Power Flow in Distribution Networks Using Microcontrollers. *Jurnal Penelitian*, 8, 151–164. https://doi.org/10.46491/jp.v8i2.1501

[7] Ibrahim, R. R., & Yulianti, B. (2022). Design and Development of IoT-Based Electricity Consumption Monitoring System for PLN. *Jurnal Teknologi Industri*, 11(2).

[8] Janis, J. W., Mamahit, D. J., Sugiarso, B. A., & Rumagit, A. M. (2020). Design and Development of an Online Construction Worker Service Ordering Application Based on Location. *Jurnal Teknik Informatika*, 15(1), 1–12.

[9] Kartika, E. A. Y. (2024). IoT-Based 150 kV Substation Monitoring System Using Raspberry Pi 3 Model B. Universitas Mercu Buana Jakarta.

[10] Nurahman, M. A., Sukowati, A. I., & Situmeang, A. (2021). Design and Development of Arduino MEGA 2560-Based Heart Rate and Blood Oxygen Saturation Detection Device. *Jurnal Ilmiah Komputasi*, 20(1), Jakarta Selatan, Indonesia.

[11] Parmana, I., Partha, C., & Utama, N. (2017). Design and Development of Load Current Monitoring System in Distribution Substations Using Short Message Service. *Majalah Ilmiah Teknologi Elektro*, 17. https://doi.org/10.24843/MITE.2018.v17i01

[12] Rayan, R. (2021). Development of a Lecture Attendance Data Application at Universitas Komputer Indonesia. Universitas Komputer Indonesia.

[13] Rifandi, R., & Sutarti, S. (2021). Design and Development of Surveillance Camera Using Raspberry Pi with Telegram Application Based on IoT. *PROSISKO: Jurnal Pengembangan Riset dan Observasi Sistem Komputer*, 8(1), 18–32.

[14] Roviqoh, V., Damayanti, A., & Wardhani, I. (2023). Human-Computer Interaction (HCI) System for Smart Home Security Based on IoT. *Jurnal Ilmu Komputer dan Informatika*, 3, 65–72. https://doi.org/10.54082/jiki.29

[15] Salamah, K. S., Kadarina, T. M., & Iklima, Z. (2020). Introduction to MIT Inventor for Students in Kembangan Utara. *Jurnal Abdi Masyarakat (JAM)*, 5(2), 5.

[16] Samsinar, R., Fadliondi, F., Alamanda, D., & Ansori, R. (2021). Prototype for Monitoring and Controlling Three-Phase Transformer Current and Load Using IoT. *Prosiding Semnastek*.

[17] Septiawan, R. (2022). IoT-Based Lighting Control System Using Raspberry Pi and Mobile Application. *Jurnal Portal Data*, 2(10).

[18] Suparmono, S., Harahap, K., Cholish, C., Sembiring, M., & Abdullah, A. (2021). Maintenance Study of Main Components in Portal-Type Distribution Substations at PT. PLN (Persero) Medan Baru. *RELE (Rekayasa Elektrikal dan Energi): Jurnal Teknik Elektro*, 4(1), 42–47.

[19] Suryanto, M. J. D., & Rijanto, T. (2019). Design and Development of an Electricity Usage Cost Recording Device in Boarding Houses Using GSM 800L Module Based on Arduino Uno. *Jurnal Teknik Elektro*, 8(1).

[20] Tobing, Y. R. L. (2021). Distribution of Medium Voltage (20 kV) Network to Residential Areas at PT. Mustika Asahan Jaya. Universitas Medan Area.