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Implementation of PZEM-004T and LoRa for Internet of Things–Based Monitoring of Power Supply Sources in Laboratory Building

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ABSTRACT

This research develops an Internet of Things (IoT)-based system to monitor electrical voltage parameters in two rooms of the Telecommunication Laboratory at Medan State Polytechnic. The system employs two sensor nodes (PZEM-004T, ESP32, and LoRa SX1276) and a gateway node integrated with WiFi and the Blynk cloud. The sensors measure voltage, current, power, energy consumption, frequency, and power factor, which are processed by ESP32 and transmitted via a LoRa multi-point network to the gateway for online monitoring. An automatic cut-off mechanism and email notifications are provided when abnormal voltage or current conditions occur. Experimental results show high measurement accuracy with a maximum error of 0.29% for voltage and 2.52% for current. However, data transmission experienced 20% packet loss, with an average delay of 11 seconds on Blynk and 37 seconds for email notifications. These findings indicate that the proposed system is effective in protecting laboratory equipment from abnormal power sources and provides reliable online and offline monitoring, although transmission performance requires further optimization.

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1. INTRODUCTION

The quality of the electrical power source is an important factor for both users and managers of electrical energi (Dinh et al., 2020; Ghiasi et al., 2020). Article 3.14 of the 2011 General Regulations on Electrical Installations stipulates a low voltage tolerance of ±5% of the nominal voltage of 220V, with a minimum limit of 209V and a maximum of 231V. Voltage drops due to transmission losses can cause electrical power disruptions that impact the performance of electronic equipment, especially sensitive devices such as laboratory measuring instruments. Inductive electrical loads will cause the power absorbed from the voltage source to be greater than the power used by the load, resulting in significant losses. These losses can be reduced by reactive power by installing a capacitor in parallel with the load (Arias Velásquez & Mejía Lara, 2019; Babanezhad et al., 2022; Sarkar et al., 2018). Therefore, early detection of the parameters of the electrical power source is essential to avoid equipment damage and inconsistencies in measurement results as well as losses due to inductive loads. To overcome this problem, a monitoring system for the quality of the electrical voltage source is needed that is able to provide automatic notification when a decrease in power quality occurs. PZEM-004T is an electronic device that can measure Voltage, Current, Power, Frequency, Energy and Power Factor (B & George, 2021; Sari et al., 2024; Yasa et al., 2023). The PZEM-004T module can measure power from 0 to 9999kW, measure voltage from 80VAC to 260 VAC and measure current from 0 to 100A. The PZEM-004T can also measure frequency and cos phi of an electrical voltage source. The PZEM-004T module is equipped with TTL serial communication so it is very easy to apply using a Microcontroller board such as ESP32 (Abed & Naser, 2020; Yasa et al., 2023).

Internet of Things(IoT) is a system where various things (items) are connected in such a way that they can interact intelligently with each other and can be connected with humans. In the Internet of Things, various smart objects are connected and communicate with each other, data is collected from smart objects and based on user needs, the collected data can be queried and sent back to the user. The application of the Internet of Things can identify, locate, track, monitor objects and trigger related events automatically and in real time. The Internet of Things (IoT) can collect data by integrating sensing and communication capabilities between different devices (Cui et al., 2021; Wang et al., 2022). To be able to connect devices to the internet through a network, an IoT network protocol is required, where this IoT network enables end-to-end data communication within the network. Communication and data transmission from IoT devices to the cloud can use several communication infrastructures such as WiFi, LoRa, ZigBee, Spirit, UART, and others (BHUYAN et al., 2024; Puckett, 2023).

With the Internet of Things (IoT), it is possible to monitor electrical parameters in real-time remotely (Despa et al., 2018; Onibonoje et al., 2019). However, in some cases, an internet network is not available at the monitoring location, so LoRa wireless communication is needed which has a wide range with low power consumption. With the LoRa network, data from sensor nodes can be sent to the Gateway node (Bouguera et al., 2018; Chanwattanapong et al., 2021; Zourmand et al., 2019). By using LoRa32 in the LOS area, the range can reach a distance of 800 m with a packet loss of only 20%. With the LoRa Gateway, sensor nodes are easily integrated into the cloud so that field conditions can be easily monitored in real-time via the internet (Ahmed et al., 2022; Lee & Ke, 2018). One platform that can be used for IoT-based monitoring is Blynk, which allows electrical voltage source parameters to be monitored through an application on a cellphone or computer with real-time numerical displays or graphs. Research on voltage source monitoring has been carried out, such as by Iqbal, Javed (2018), who monitored and controlled electrical energy in IoT-based dormitory rooms with a WiFi connection. However, this research has limitations in location coverage and dependence on the internet. Based on these issues, this study aims to design a power source monitoring system in the Telecommunications Laboratory building of the Medan State Polytechnic using the PZEM-004T sensor and LoRa module. This system is expected to be a cost-effective and highly effective solution for monitoring power source parameters in two rooms.

Several previous studies on IoT-based electrical monitoring systems have shown promising results, yet there are still limitations that create a research gap. For instance, Iqbal and Javed (2018) focused on WiFi-based monitoring, which is effective but limited in coverage and highly dependent on internet availability. Other studies (Bouguera et al., 2018; Zourmand et al., 2019) have applied LoRa for long-range transmission but did not integrate real-time visualization and automated protection mechanisms such as cut-off or alert notifications. Likewise, research by Despa et al. (2018) and Onibonoje et al. (2019) emphasizes real-time monitoring but does not address packet loss and delay performance as critical factors for system reliability. Based on these gaps, this study explicitly aims to design and implement an IoT-based monitoring system for electrical voltage sources in the Telecommunication Laboratory of Medan State Polytechnic by integrating PZEM-004T sensors, LoRa communication, and the Blynk cloud. The main objectives are to ensure accurate and reliable monitoring, enable online and offline accessibility, and provide automatic protection through cut-off and email notifications. Academically, this research contributes to the development of IoT-based electrical monitoring models with a focus on system reliability and efficiency. Practically, it offers a cost-effective solution to protect sensitive laboratory equipment and supports energy management in educational institutions.

2. RESEARCH METHOD

Research Flow

This research designs a monitoring system for electrical power source parameters using the PZEM-004T sensor by measuring voltage, current, power, energy, frequency, and cos phi. This system consists of two sensor nodes, a Gateway and uses the Blynk application. Each sensor node consists of an ESP-32 microcontroller, a PZEM-004T sensor, and a LoRa SX1276 module. The Gateway consists of an ESP-32 and a LoRa SX1276 which functions to receive information from two rooms (sensor nodes) and forward it to the Blynk Cloud (internet) via a WiFi connection. The dashboard in the Blynk application is designed to display the electrical parameters of the two rooms and provide notifications if an anomaly occurs in the voltage source.

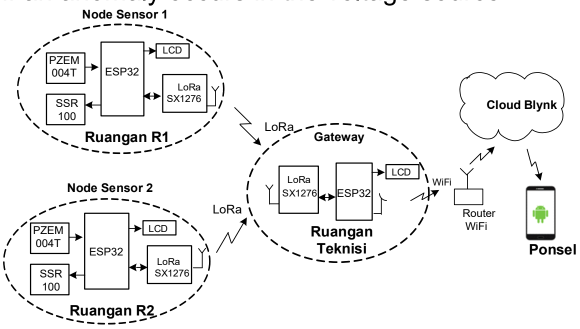


Figure 1. Block Diagram of the Electrical Voltage Source Monitoring System


PZEM-004T-100A and CT Split CoreSolid State Relay 100A


LoRa RFM95W 915MHz ESP32 Dev Kit V1

Figure 2. Main components used

The block diagram of the research to be carried out is shown in Figure 1 where the main components used are shown in Figure 2 and the laboratory layout of the monitoring location is shown in Figure 3.

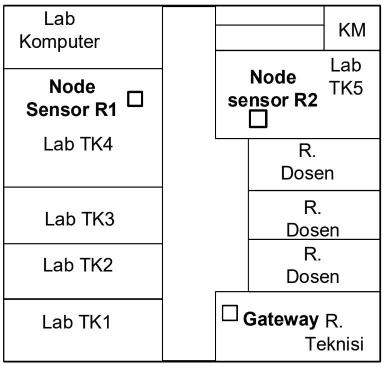


Figure 3. Laboratory Room Layout and Equipment Placement

The sensor node consists of a 5V power supply, ESP-32, LoRa SX1276 module, PZEM-004T sensor with Core Transformer Split (CT), and a 2x16 LCD as an electrical parameter display. During measurement, the Line (L) cable from the voltage source is inserted into the CT transformer to measure the electrical parameters of the voltage source. Each sensor node has a unique address that is customized in the program. The sensor node reads the electrical parameters and sends the reading results to the Gateway, which is then forwarded to the Blynk Cloud. If the voltage is below 198V or above 231V, or the current exceeds 6A for 10 seconds, the ESP-32 will activate the SSR to cut off the power to prevent damage to the equipment connected to the voltage source. The 6A current limit is determined based on the load capacity in each room. The alarm on the Blynk dashboard will sound if the current is above 5A or the voltage is above 231VAC or below 198V. The sensor node circuit is shown in Figure 4 and the program flow diagram on the sensor node is shown in Figure 5.

Gateway Network

The Gateway circuit consists of ESP-32 and LoRa SX1276 and a 4x20 LCD display as shown in Figure 6 and the program flow diagram on the Gateway is shown in Figure 7. The Gateway receives electrical parameter data from two sensor nodes via the LoRa module, processed by ESP32 and displayed on the 4x20 LCD alternately. Electrical parameter data from the two rooms are then sent to the Blynk Cloud via the ESP-32 WiFi hotspot and the internet network. If the voltage or current from one of the rooms is outside the normal limits, an alarm will sound and a notification is sent to Blynk. The Blynk dashboard displays the voltage, current, power, energy (kWh), and cos phi from both rooms. Blynk will send an email to the officer if an alarm occurs.

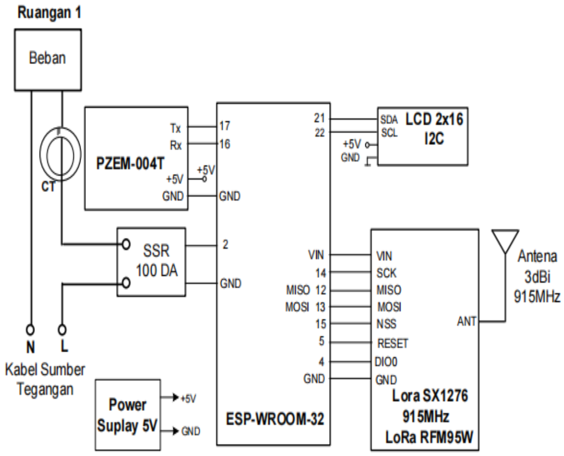


Figure 4. Sensor Node Circuit

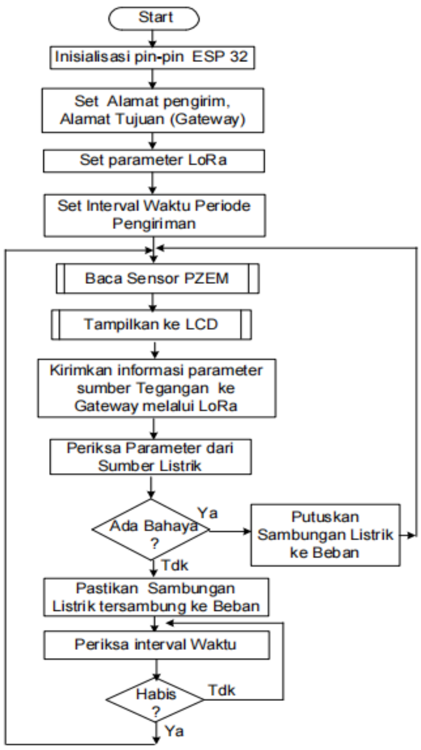


Figure 5. Sensor Node Program Flowchart

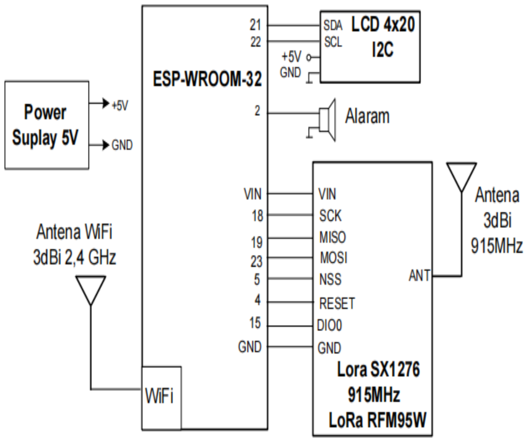


Figure 6. Gateway Circuit

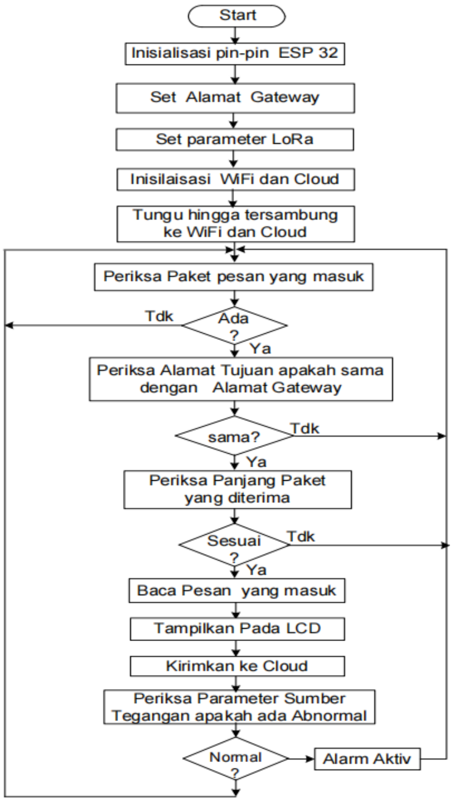


Figure 7. Gateway Circuit Program flow diagram

LoRa Network Communication Protocol Design

In this study, the LoRa network is designed with a Star topology where the destination of each end device is the Gateway node. In order to identify the source of the data, each End device (sensor node) has a unique address. The structure of the packet sent by the sensor node consists of the sender address, destination address, message length and message content. The message consists of ID, Voltage value, separator character ",", Current value, ";", Power value, "!" Energy value, "/", Frequency value, "&", Cosphi value and ends with the character "#" as shown in Figure 8. The ID for sensor node 1 is "R1", for sensor node 2 is "R2".

Alamat Pengirim	Alamat Tujuan	Panjang Pesan	ID Pengirim >	Nilai Tegangan ,	Nilai Arus ;	Nilai Daya !	Nilai Energy /	Nilai Frek &	Nilai Cos phi #

Figure 8. The structure of the packets sent by LoRa

3. RESULTS AND DISCUSSIONS

Sensor Node Testing

1. Voltage Measurement Testing

In this study, the voltage source uses a 5000VA AC voltage regulator to regulate the voltage from 0 to 250VAC. The rise and fall of the source voltage is considered normal if the maximum increase is 5% (231VAC) and the maximum decrease is 10% (198VAC), and the system will cut off the power if the voltage drops below 198V or rises above 231V. The experiment was carried out by changing the source voltage between 180V and 240V using a 220V AC Slide Regulator Transformer, with a load of two 40W fans. Voltage and current measurements were compared with a digital voltmeter and ammeter. The results of voltage and current measurements are shown in table 1 and the error graph in figure 9. The results show that the microcontroller activates the SSR to cut off the power when the voltage is below 198V or the voltage is above 231V. From figure 8, it can be seen that the difference in the measurement results of the sensor node compared to the digital voltmeter measuring instrument is a maximum of 0.6 volts or 0.29 percent.

Table 1. Measurements with changing source voltage

No	Transformer Position	PZEM(VAC) Sensor Measurement	Voltmeter (VAC) measurement	Difference		SSR Condition
				VAC	%	
1	184	184	184.8	0.8	0.44	ON
2	195	195	195.5	0.5	0.27	ON
3	198	198	198.7	0.7	0.37	OFF
4	195	195	195.3	0.3	0.15	OFF
5	200	201	200.4	0.6	0.30	OFF
6	205	205	204.3	0.7	0.34	OFF
7	210	209	208.2	0.8	0.38	OFF
8	215	216	215.6	0.4	0.19	OFF
9	220	221	220.7	0.3	0.14	OFF
10	225	226	225.6	0.4	0.18	OFF
11	230	231	230.2	0.8	0.35	OFF
12	235	236	235.1	0.9	0.38	ON
13	240	241	240.4	0.6	0.25	ON
Average error				0.6	0.29	

2. Current Measurement Testing

Current measurements are carried out with various loads and voltage sources directly from PLN. The load is changed byoperate (ON/OFF) electrical equipmentelectricity, and PCB printer heater. The current limit is set at 6A.which consists of two 40W fans,drilling machine. Current measurement results for `heaters and others are obtained exceeding 6A (number 12) which makes the SSR actively cut off the power which makes the measured load current zero.

Table 2. Measurements with Variable Load

No	Burden	PZEM Sensor		Multimeter (A)	Difference		SSR Condition
		Voltage (VAC)	Current (A)		A	%	
1	Kipas1_kec.1	217	0.18	0.19	0.01	5.6	OFF
2	Kipas1_kec.2	217	0.22	0.22	0	0.0	OFF
3	Kipas1_kec.3	217	0.23	0.24	0.01	4.3	OFF
4	Kipas1_kec.3+Kimpas2_kec.1	217	0.42	0.43	0.01	2.4	OFF
5	Fan1_kec.3+Fan2_kec.2	217	0.46	0.47	0.01	2.2	OFF
6	Fan1_kec.3+Fan2_kec.3	217	0.51	0.53	0.02	3.9	OFF
7	Kipas1_kec.3+Kimpas2_kec.3 +Infocus	217	1.35	1.33	0.02	0.8	OFF
8	Fan1_kec.3+Fan2_kec.3+Info cus+Electric Drill	217	2.61	2.59	0.02	0.8	OFF
9	Heating	216	3.89	3.94	0.04	1.3	OFF

10	Heater_+Infocus	215	4.61	4.75	0.14	3.0	OFF
11	Heater+Infocus+Electric Drill	215	5.82	5.98	0.16	2.7	OFF
12	Heater+Infocus+Electric drill+Fan1+Fan2	217	0	0	0	0	ON
					0.04	2.52	

From the error graph in Figure 10, it can be seen that the difference in sensor and ammeter measurements is a maximum of 0.04A (2.52%), with the difference tending to increase in error at higher currents.

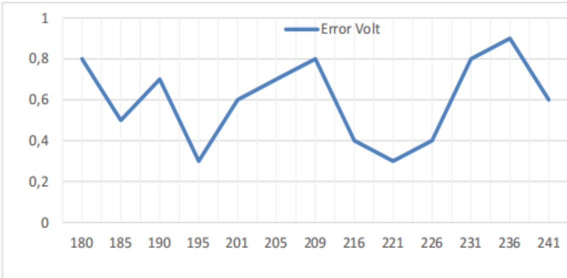


Figure 9. Graph of the difference between sensor measurements and a volt meter

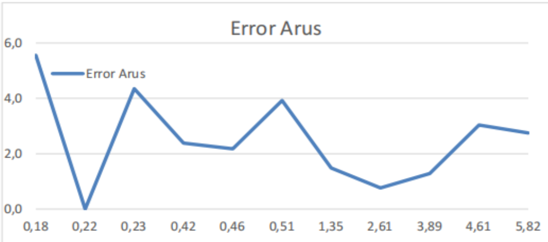


Figure 10. Graph of the Difference in PZEM Current Measurement with a multimeter

3. Power and Energy Measurement

In this measurement, the load consisted of a drill machine and a KWS AC301 brand power meter was used as a comparison. The measured source voltage during this test was 199Vac and the current was 0.72A. From Table 3, it can be seen that there is almost no difference in the measurement results with the PZEM compared to the Power meter.

Table 3. Measurement of Power and Energy Consumption of Electric Drill Machines

No	Time (minute)	Power (Watt)		Energy (kWh)		Cos Phi		Frequency (Hz)	
		PZEM Sensor	Power Meter	PZEM Sensor	Power Meter	PZEM Sensor	Power Meter	PZEM Sensor	Power Meter
1	0	138.10	139.5	0.00	0.00	0.97	0.97	50	50
2	1	138.90	139.8	0.00	0.00	0.97	0.97	50	50
3	5	137.30	138.5	0.01	0.01	0.97	0.97	50	50
4	10	137.70	138.8	0.02	0.02	0.97	0.97	50	50
5	20	136.70	134.8	0.04	0.04	0.97	0.97	50	50
6	30	139.00	136.8	0.06	0.06	0.97	0.97	50	50
7	40	138.60	136.3	0.08	0.08	0.97	0.97	50	50
8	50	137.40	136.2	0.11	0.10	0.97	0.97	50	50
9	60	137.80	136.8	0.12	0.12	0.97	0.97	50	50
10	80	138.20	138.3	0.13	0.14	0.97	0.97	50	50
11	100	138.4	138.6	0.15	0.16	0.97	0.97	50	50

4. Cos phi measurement

In this measurement, the loads measured are fans, drills, soldering irons, water heaters and measuring instruments.

A KWS AC301 brand power meter was used as a comparison. Cos phi measurements of several devices are shown in Table 4.

Table 4. Cos phi Measurement

No	Burden	Cos phi	
		PZEM	Power Meter
1	Fan	0.99	0.99
2	Infocus	0.96	0.96
3	Solder	1.00	1.00
4	Drilling machine	0.97	0.97
5	Water heater	1.00	1.00

From table 4 it can be seen that the measurement results of the PZEM Sensor and Power meter are the same, and if the load is inductive it has a Cos phi of less than 1.00.

Testing Message Delivery via LoRa

This test was conducted in the Laboratory Building where the Gateway was placed in the Technician's room and Sensor Node 1 was placed in Room R1 and Sensor Node 2 was placed in Room R2 where the distance between Room R1 and Room R2 with the Gateway was approximately 25m. Data transmission testing via LoRa was carried out by sending electrical voltage source parameter data from the R1 sensor node every 15 seconds and the R2 sensor node every 17 seconds. Next, observe the messages received on the Gateway and measure the RSSI (Received Signal Strength Indicator) and SNR (Signal-to-Noise Ratio) levels.
Package Losses are calculated using equation (1).

$$Packet\ Losses = \frac{Many\ packages\ sent\ -\ Many\ packages\ received}{Many\ packages\ sent} x100\% \quad (1)$$

The Gateway reception data from sensor R1 and sensor R2 along with RSSI and SNR values for 15 measurements are shown in Table 5.

Table 5 shows that some messages were not received by the Gateway. Of the 15 (fifteen) messages sent, 3 (three) messages did not reach the Gateway or the packet loss was 20 percent. Where Packet Loss is a condition where data is lost during transmission so that it is not received in full at the destination. This is likely due to a collision between the message signal sent by the R1 sensor node and the signal sent by the R2 sensor node, resulting in an error message. The average RSSI is -68.11 with an average SNR of 10.01.

From Table 5, it can be seen that out of 15 (fifteen) messages sent by the R2 sensor node, there were 4 (four) messages that were not received by the Gateway or the packet loss was 26.6 percent with an average RSSI of -65.7 and an average SNR of 9.63. With these test results, it can be stated that the Gateway has been able to receive messages from the R1 Sensor node and the R2 sensor node via LoRa communication.

Table 5. Messages received by the Gateway from Sensor Node R1 and Sensor Node R2.

The shipment to-	Sender			
	Sensor Node R1		R2 Sensor Node	
	RSSI	SNR	RSSI	SNR
1	-68 dBm	9.30 dB	-67 dBm	10 dB
2	-68 dBm	9.50 dB	-70 dBm	9.25 dB
3	Not accepted	Not accepted	Not accepted	Not accepted
4	-66 dBm	10.0 dB	-67 dBm	10.50 dB
5	-72 dBm	8.75 dB	-64 dBm	9.50 dB
6	-70 dBm	8.93 dB	Not accepted	Not accepted
7	-67 dBm	9.75 dB	-63 dBm	10.0 dB
9	Not accepted	Not accepted	-66 dBm	9.25 dB
10	-68 dBm	10.75 dB	Not accepted	Not accepted
11	-68 dBm	10.25 dB	-65 dBm	9.50 dB
12	-68 dBm	10.25 dB	-65 dBm	9.50 dB
13	Not accepted	Not accepted	Not accepted	Not accepted
14	-67 dBm	10.30 dB	-65 dBm	9.50 dB
15	-67 dBm	9.80 dB	-67 dBm	9.60 dB
Flat-Flat	-68.11 dBm	10.01 dB	-66 dBm	9.50 dB

Testing Delivery to Blynk Cloud

This measurement is a test of sending messages from the Gateway to the Blynk Cloud. In this test, we measured the delay time for electrical parameters in rooms R1 and R2 to be displayed on the Blynk dashboard and the length of time it takes for officers to receive alarm alert notifications via email if the electrical parameters in rooms R1 and R2 are abnormal.

Table 6. Test Results for Sending Messages from Room R1 to Cloud Blynk

No	Sent R1 sensor node		View on the blynk Dashboard			Received by Officer	
	Time Sent	Message	Time received	Teg (Vac)	Current (A)	E-mail	Receive Time
1	11:30:23.002	>R1=09:219,2.21;430.00!0.047/50&1.00#	11:30:38 Delay: 15 seconds	219	2.21	There isn't any	
2	11:32:20.012	>R1=20:219,0.22;41.85!0.054/50&1.00#	11:32:35 Delay: 15 seconds	219	0.22	There isn't any	
3	11:33:04.110	>R1=11:219,5.65;1240.20!0.052/50&0.99#	11:33:16 Delay: 12 seconds	219	5.65	There is	11:33:35 Delay: 31 seconds

This delay test was carried out by changing the load in Room R1 and Room R2 and observing the changes in the display on the Blynk dashboard. The test results are shown in Tables 6 and 7. From Table 6 it can be seen that when the current exceeds 5 Amperes on the Cloud an alarm sign is displayed as shown in Figure 11 and an email is sent to the officer as shown in Figure 12. When the load is increased by adding a load so that the current reaches more than 6A, the SSR breaker is active and cuts off the voltage source to Room R1.

Table 7. Test Results for Sending Messages from R2 Room to Blynk Cloud

No	Sent R2 sensor node		View on the blynk Dashboard			Received by Officer	
	Time Sent	Message	Time received	Voltage (Vac)	Current (A)	E-mail	Receive Time
1	11.30.47.105	>R2=41:219,0.23;45.78!0.057/50&0.99#	11:31:00 Delay: 13 seconds	219	0.23	There isn't any	---
2	11.32.42.130	>R2=44:219,5.52;1098.20!0.058/50&0.98#	11:32:49 Delay: 7 seconds	219	5.52	There is	11:33:05 Delay : 23 seconds
3	11.33.35.107	>R2=48:219,0.72;111.44!0.058/50&0.97#	11:33:53 Delay: 18 seconds	219	0.72	There isn't any	---

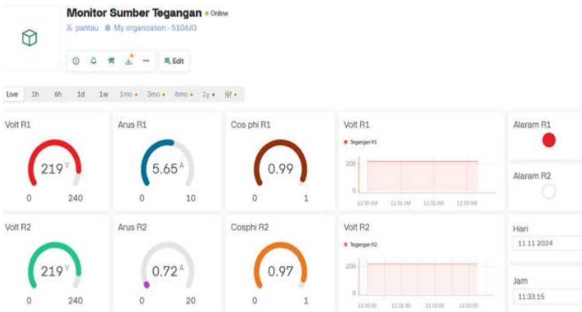


Figure 11. Dashboard display when an alarm occurs in Room R1

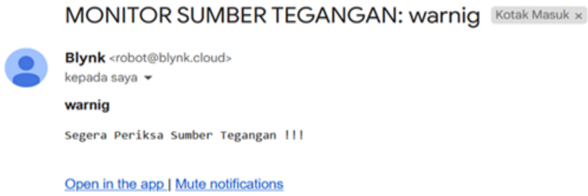


Figure 12. Email sent to Officers when an alarm occurs

Next, a comprehensive test was conducted and the dashboard display was monitored for 1 hour, varying and disconnecting the source voltage. Figure 12 shows that at several points, the source voltage was disconnected in rooms R1 and R2, and the voltage value was unstable.

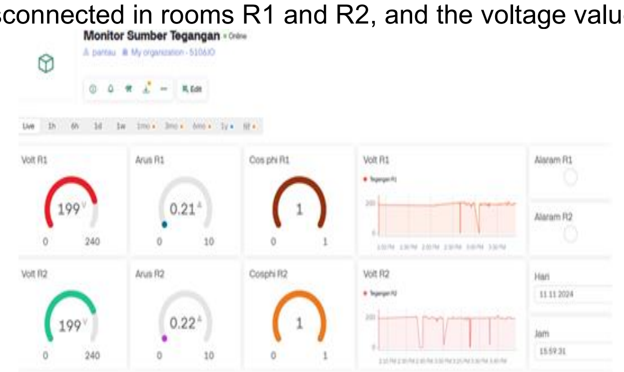
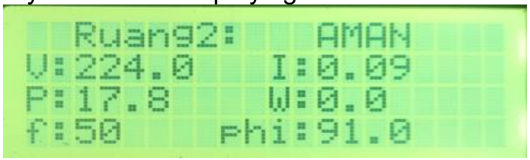


Figure 12. Dashboard display when monitoring for one hour

The image of the monitoring tool created is shown in Figure 13 and the LCD display on the R1 sensor node and R2 sensor node is shown in Figure 14.

Figure 13. Photo of voltage source monitoring tool

Gateway view when displaying the condition of room R1



Gateway view when displaying the condition of room R2

Display on LCD Node Sensor R1

Display on the LCD of the R2 Sensor Node

Figure 14 LCD display on sensor node R1 and sensor node R2

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4. CONCLUSION

This study successfully developed an IoT-based monitoring system for electrical voltage sources using PZEM-004T sensors, ESP32, and LoRa communication integrated with the Blynk cloud. The system demonstrated high measurement accuracy with a maximum error of 0.29% for voltage and 2.52% for current. The SSR-based protection mechanism effectively cut off the power source under abnormal voltage or current conditions, while the LoRa module enabled data transmission with an average RSSI of –65.7, SNR of 9.63, and 25% packet loss at a distance of 25 m indoors. The system also provided online monitoring through Blynk with an average delay of 11 seconds and email notifications within 37 seconds, which is sufficient for real-time monitoring. Compared to previous studies that relied solely on WiFi or LoRa without integrated protection or cloud-based visualization, this research contributes a more comprehensive model by combining long-range communication, automatic cut-off, and multi-platform monitoring. Practically, the system enhances the protection of sensitive laboratory equipment and offers a cost-effective solution for educational institutions. Future research may focus on optimizing LoRa communication to minimize packet loss, integrating adaptive data transmission protocols, and extending the system to support multi-phase monitoring, thereby increasing its applicability in broader industrial and institutional contexts.

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