

Development of an IoT-Based Prepaid KWh Meter Monitoring System with Web Monitoring and Electricity Token Balance Notifications (Case Study: PUPR Sumatera VIII Apartment Complex)

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ABSTRACT

Rusun PUPR Sumatera VIII faces three problems with its prepaid electricity system: the kWh meter alarm is inaudible from inside the units because the meters are centrally located and enclosed, there is no record of electricity consumption available to residents, and there is a risk of damage to electronic equipment due to sudden power outages. The research method was carried out by measuring the output of the prepaid kWh meter using a PZEM-004T sensor, which is then read by an ESP32 microcontroller and transmitted to a website server. The remaining token is calculated as the difference between the input token value and the energy consumed, and the system automatically sends a notification to residents via WhatsApp when the remaining token falls below 5 kWh. The test results of the PZEM-004T sensor show an average precision of 98.88 %, an accuracy of 98.12 %, and an error of 1.88 %. Based on these results, the system is feasible to be implemented in the apartment building.

Keywords: Prepaid Kwh Meter, Pzem-004t, Esp32, Website, Whatsapp Notification

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1. INTRODUCTION

Electricity is a vital basic necessity in people's lives. This includes residents of the PUPR Sumatra VIII Public Housing Complex, managed by the Ministry of Public Works and People's Housing (PUPR). Each residential unit in the complex uses a prepaid electricity system with a token-based KWH meter to measure and control each resident's electricity consumption.

The first issue underlying this study is the physical arrangement of the prepaid KWH meters at the PUPR Sumatra VIII Public Housing Complex, which are centralized in a single location and situated in an enclosed area. This arrangement prevents residents inside their respective units from hearing the warning alarm emitted by the KWH meters when their remaining electricity tokens are nearly depleted. As a result, residents are unaware that their remaining electricity tokens are critically low, so the power in their living units can suddenly cut out without them receiving any warning.

The second issue is the lack of a system for recording and monitoring daily electricity consumption for residents. Currently, residents cannot determine how much electricity they use on a daily or monthly basis. The absence of historical electricity consumption data prevents residents from evaluating their electricity usage in each unit.

The third problem is the impact of sudden power outages on electronic devices that are in use. Household electronic devices such as refrigerators, televisions, computers, and other electronic devices are highly susceptible to damage if the power supply is suddenly cut off without a normal shutdown process. This can directly shorten the lifespan of these electronic devices, resulting in financial losses for the residents of the apartment complex.

Based on the three real-world problems described above, a monitoring system solution is needed that can read electrical parameters in real time via a PZEM-004T sensor installed on the output of PLN's prepaid kWh meter as a measurement reference, display energy consumption data via a website accessible to residents in real time, and send automatic warning notifications via WhatsApp to residents when the estimated remaining token balance approaches the minimum threshold. The ESP32 was

selected as the hardware for this study because it features integrated Wi-Fi connectivity, adequate computational performance, and an economical price, making it highly suitable for implementation in an IoT system within a public housing complex. The PZEM-004T sensor is used to read AC electrical parameters, including voltage, current, active power, power factor, frequency, and energy (kWh)) (Adyan et al., n.d.)

The web-based monitoring system allows residents to track their remaining electricity tokens and view their daily kWh consumption history for the past month anytime and anywhere via a smartphone or computer (Amru et al., 2025). The automatic notification feature sends alerts to residents when their remaining electricity tokens approach the minimum threshold, allowing them to top up immediately before the power goes out and preventing their electronic devices from being damaged by sudden power outages.

2. RESEARCH METHODOLOGY

The method used in this study is the Research and Development (R&D) method, which involves designing and building a real system that can be tested and evaluated; the research stages are illustrated in fig 1

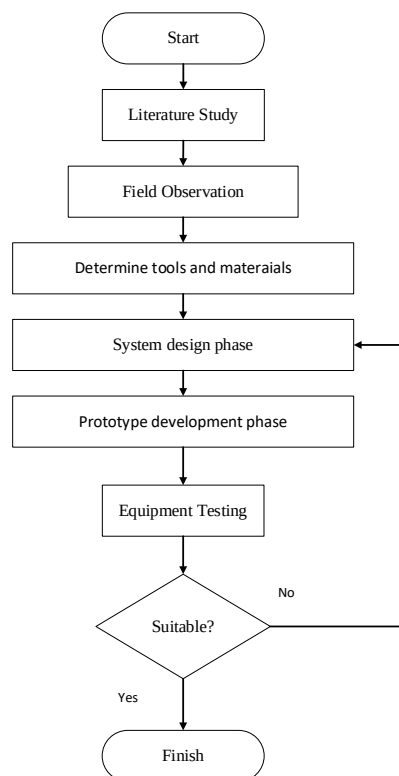


Fig 1. Research Methodology Flowchart

This study employs a method for designing and testing *a prototype of a web-based prepaid kWh meter monitoring system*. The research stages included a literature review, field observations, system design, *prototype* development, and testing. The literature review involved examining relevant books, journals, and articles to establish the theoretical foundation and system design. Field observations were conducted at the PUPR Sumatra VIII Civil Servant Housing Complex to assess the placement of kWh meters and the availability of Wi-Fi networks as a basis for system requirements.

The system was designed using an ESP32 as the microcontroller and a PZEM-004T sensor to measure voltage, current, power, energy, frequency, and power factor. The measurement data is transmitted via Wi-Fi using the MQTT protocol to a server, stored in a PostgreSQL database, and then displayed in *real-time* through *a web dashboard*. The system also includes features for managing electricity tokens and automatic notifications via WhatsApp when the remaining token balance reaches

≤5 kWh. Tests were conducted to evaluate the system's performance and reliability, including testing the website dashboard, verifying PZEM-004T sensor readings, assessing the accuracy of token calculations compared to the PLN kWh meter, and testing WhatsApp notifications. Sensor testing involved applying varying loads and comparing the readings with a standard measuring device, while token testing involved comparing changes in the system's kWh values with those of the PLN meter.

System Performance Analysis

System performance is evaluated from measurement deviation, relative uncertainty, precision, accuracy and error. For each parameter, the sensor output is compared with the reference measuring instrument.

Absolute deviation is calculated as:

$$\Delta x = | \bar{x}_{\text{sensor}} - x_{\text{reference}} | \quad (1)$$

Where Δx is the absolute deviation, $x_{\text{reference}}$ is the sensor reading, and x_{sensor} is the mean of all data. The mean deviation is calculated as:

$$\delta = \sum_{i=1}^N | \bar{x}_{\text{sensor}} - x_{\text{reference}} | / N \quad (2)$$

Where δ is the mean deviation, and N is the number of measurements.

Relative uncertainty (KR) is calculated by:

$$KR = \frac{\delta}{x} \times 100 \% \quad (3)$$

Where x is the value obtained from the standard measuring instrument.

Measurement precision is then determined by:

$$\text{Precision} = 100\% - KR \quad (4)$$

The percentage error is calculated using:

$$\text{Error \%} = \frac{\text{Reference Value} - \text{Mean Value}}{\text{Reference Value}} \times 100\% \quad (5)$$

Measurement accuracy is determined by:

$$\text{Accuracy (\%)} = 100\% - \text{error(\%)} \quad (6)$$

3. RESULTS AND DISCUSSION

Design Results

The following are the results of the design of a web-based prepaid kWh meter monitoring system with WhatsApp notifications. These design results are divided into two parts: the hardware, which reads and transmits electrical parameters, and the software (website), which displays energy consumption data to apartment residents.

1. Hardware Design Results

The design of the electrical power monitoring system for this apartment complex utilizes electronic components and several household electrical components. The overall view of this system is shown in Fig 2

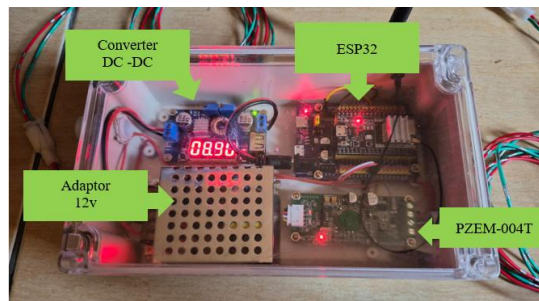


Fig 2. of the web-based prepaid kWh meter monitoring hardware

2. Website Design Results

This website features several functions, including current, voltage, frequency, power factor, and active power monitoring; a daily usage history feature; and, finally, a feature for monitoring remaining tokens and entering tokens. The website's monitoring interface is shown in Fig 3

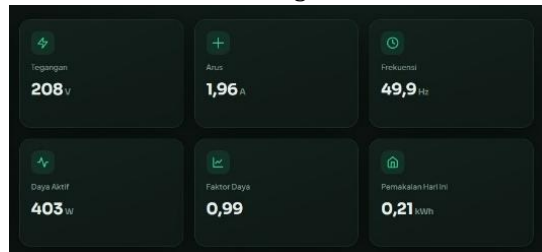


Fig 3. Overall website display for kWh meter monitoring

The power monitoring section displays real-time electrical parameters including voltage, current, active power, and power factor for each residential unit, as shown in Fig 4



Fig 4. Power monitoring section on the website

The Usage History section displays a graph of daily electricity consumption over a one-month period, allowing residents to monitor their electricity usage patterns, as shown in Fig 5

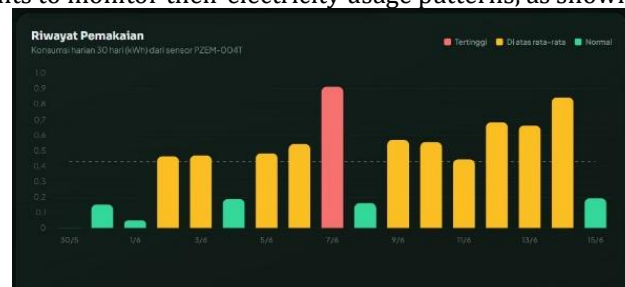


Fig 5. Usage History Monitoring Section

The Device Status section displays the device's connection status whether it is active (online) or disconnected (offline) as shown in Fig 6



Fig 6. Device Status Section on the Website

Electricity Token Section. This section displays the estimated remaining token balance and provides a manual token input feature (“set token”), where the system calculates the reduction in the remaining token balance based on energy consumption, as shown in Fig 7



Fig 7. Electricity token monitoring and token input section

Testing

At this stage, testing is conducted to determine whether the designed system functions as intended. The testing is carried out in several phases, including website reliability testing, sensor reading testing, token calculation accuracy testing, and WhatsApp notification testing.

1. Website Dashboard Reliability Testing

This test is conducted to determine whether the website dashboard functions properly and displays all its features as designed. The website can be accessed in *real-time* via a *browser* whether on a PC or a *smartphone* simply by typing the address <https://rusunmonitoring.cloud/> into the browser.

Fig 8 shows the dashboard view when accessed via a PC, while Figure 9 shows the view when accessed via a *smartphone*



Fig 8. Website dashboard display on a PC



Fig 9. Website dashboard display on a smartphone

Testing was conducted by accessing the website and then checking each section of the dashboard to ensure it could display data and function properly. The test results are shown in Table 1

Table 1. Website dashboard reliability test results

No	Section	Expected Result	Remarks
1	Power monitoring	Displays electrical parameters	Success
2	Usage History	Displaying daily consumer bar charts	Success
3	Device Status	Displaying online/offline status	Success
4	Electricity tokens and token input	Displaying remaining tokens and input functions	Success

2. Testing the PZEM-004T Sensor Readings

This test was conducted to determine the accuracy of the PZEM-004T sensor in reading electrical parameters. The test was performed by comparing the sensor's readings with those of a standard measuring instrument as a reference. Data was collected three times under different load conditions, as shown in Table 2.

Table 2. Test Load

No	Load	Rated Power
1	Fan	20 watts
2	Computer + Monitor (PC)	80 watts
3	Air Conditioner	344 watts

The measurement results from the PZEM-004T sensor readings were obtained by taking three measurement samples for each parameter, which can be used to calculate the mean and standard deviation. For example, the calculation for the Voltage (V) parameter for a computer load.

Table 3. Screenshot of the measurement layer on the website

Equipment being measured	Measurement results read by the sensor	Image
Fan	Voltage (V): 223 Volts Current (I): 0.16 A Frequency: 49.9 Hz Power (P): 23 Watts	
Computer	Voltage (V): 220 Volts Current (I): 0.44 A Frequency: 50 Hz Power (P): 80 watts	
AC	Voltage (V): 221 Volts Current (I): 1.36 A Frequency: 50 Hz Power (P): 291 Watts	

The average value is calculated using equation (1)

$$\bar{x} = \frac{(222 + 220 + 219)}{3} = \frac{661}{3} = 220,33 \text{ V}$$

The deviation value for each measurement is calculated using Equation (1):

$$\Delta_1 = |222 - 220.33| = 1.67$$

$$\Delta_2 = |220 - 220.33| = 0.33$$

$$\Delta_3 = |219 - 220.33| = 1.33$$

The average deviation is calculated using Equation (2):

$$\delta = \frac{|\Delta_1| + |\Delta_2| + |\Delta_3|}{n}$$
$$\delta = \frac{|1,67| + |0,33| + |1,33|}{3}$$

$$\delta = \frac{3,33}{3} = 1,11$$

Thus, the average result for the computer load voltage parameter is 220.33, and the average deviation is 1.11. In the same manner, calculations were performed on all measurement data in Table 4.

Table 4. Test Results for PZEM-004T Sensor Readings on Electrical Equipment and Mean Deviation

N o	Electrical Device	Parameter	Measurement No.			Average	Standard Deviation
			1	2	3		
1	Fan	Voltage (V)	223	218	219	220	2
		Current (A)	0.16	0.15	0.15	0.15	0
		Power (W)	23	22	22	22.33	0.44
2	Computer	Voltage (V)	222	220	219	220.33	1.11
		Current (A)	0.42	0.44	0.43	0.43	0.01
		Power (W)	78	80	78	78.67	0.89
3	AC	Voltage (V)	222	221	221	221.33	0.44
		Current (A)	1.37	1.37	1.36	1.37	0
		Power (W)	293	292	291	292	0.67
Average							0.42

Table 5. Voltage measurement using a voltmeter

Equipment Being Measured	Measurement results read by the meter	Image
Electric Fan	Voltage (V): 220.7 Volts	
Computer	Voltage (V): 221.1 Volts	
Air Conditioner	Voltage (V): 221.6 Volts	

Table 6. Amperage measurement using a clamp meter

Equipment Being Measured	Measurement results displayed by the meter	Image
Fan	Current (I): 0.145 A	
Computer	Current (I): 0.431 A	
Air Conditioner	Current (I): 1.363 A	

To determine the precision, accuracy, and *error* values, it is necessary to use a standard measuring instrument as a reference by comparing the measurement results of the PZEM-004T sensor with those of the standard measuring instrument. Tables 4.5 and 4.6 provide evidence of measurements taken using a standard measuring instrument.

The relative uncertainty (KR) is calculated as the average deviation from the reference measurement instrument's value. For example, the calculation for the voltage (V) parameter under a computer load.

The relative uncertainty (KR) is calculated using Equation (3):

$$KR = (\delta / \text{reference measurement value}) \times 100\% = 0.91\%$$

$$KR = (1.11 / 221.1) \times 100\% = 0.50\%$$

The precision value is calculated using Equation (4):

$$\text{Precision} = 100\% - KR$$

$$\text{Precision} = 100\% - 0.50\% = 99.50\%$$

The percentage error is calculated using Equation (5):

$$\%Error \text{ rata - rata} = \frac{|221,1 - 220,33|}{221,1} \times 100\% = 0,35\%$$

The accuracy value is calculated using Equation (6):

$$\text{Accuracy} = 100\% - \%error = 100\% - 0.348\% = 99.65\%$$

The calculation is performed in the same manner for all measurement data. The results of the precision, accuracy, and *error* calculations are shown in Table 7

Table 7. Calculations of Precision, Accuracy, and Error for the PZEM-004T Sensor

NO	ELECTRICAL EQUIPMENT	COS θ	PARAMETER	TESTING WITH MEASURING INSTRUMENTS	PRECISION	ACCURACY	ERROR
1	Fan	0.64	Voltage (V)	220.7	99.70%	99.68%	0.32%

2	Computers	0.83	Current (I)	0.145	96.93%	94.25%	5.75%
			Power (P)	20.481	97.83%	90.96%	9.04%
			Voltage (V)	221.1	99.50%	99.65%	0.35%
			Current (I)	0.431	98.45%	99.77%	0.23%
			Power (P)	79.094	98.88%	99.46%	0.54%
3	AC	0.97	Voltage (V)	221.6	99.80%	99.88%	0.12%
			Current (I)	1.363	99.67%	99.73%	0.27%
			Power (P)	292.98	99.77%	99.67%	0.33%
AVERAGE					98.88%	98.12%	1.88%

Based on Table 7, the PZEM-004T sensor has an average precision of 98.88%, an accuracy of 98.12%, and an error of 1.88%. This indicates that the sensor has a good level of accuracy and precision and is suitable for use as a measuring instrument for electrical parameters in prepaid kWh meter monitoring systems.

3. Token Calculation Accuracy Test

This test was conducted to determine the system's accuracy in estimating remaining tokens. The test involved comparing the energy reduction calculated by the system with the reduction in readings on the PLN prepaid kWh meter over the same period.

The following shows the error (%) calculation based on the comparison between PLN and the website

The error percentage was calculated using Equation (5):

$$\%Error = \frac{|\Delta PLN - \Delta Website|}{PLN} \times 100\%$$

$\Delta PLN = 17.05 - 16.70 = 0.35 \text{ kWh}$
 $\Delta Website = 17.05 - 16.68 = 0.37 \text{ kWh}$

$$\%Error = \frac{|0.35 - 0.37|}{0.35} \times 100\% = 5.71\%$$

The calculation was performed in the same manner for all measurement data. The calculation error results are shown in Table 8

Table 8. Results of the token calculation accuracy test

Experiment	Date	Load (w)	Duration	Token on PLN kWh Meter (kWh)	Token on the Website (kWh)	Difference	Error (%)
1	14/8/2026	25	6:44 a.m.-9:00 p.m. (14h 16m)	17.05 - 16.70 (0.35)	17.05 - 16.68 (0.37)	0.02	5.71
2	28/8/2026	94	6:46 a.m.-10:06 p.m. (15h20m)	17.09 - 15.59 (1.50)	17.09 - 15.60 (1.49)	0.01	0.67
AVERAGE						0.015	3.19

Based on Table 8, the difference between the PLN kWh meter token calculation and the token on the website is 0.02 kWh; using equation (5), this yields an *error* value of 5.71%. This indicates that the system can calculate the estimated remaining tokens with sufficient accuracy.

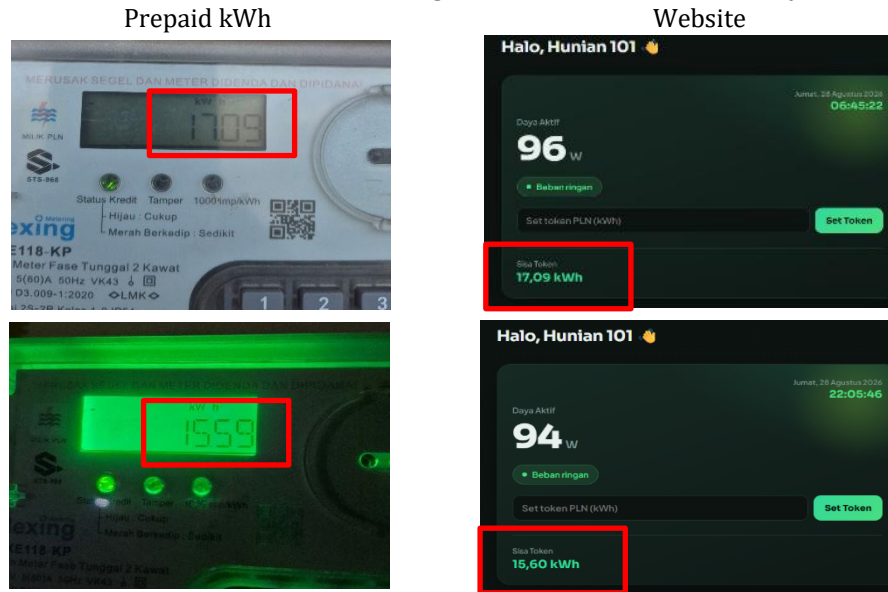


Fig 10. token for prepaid kWh and the website

4. WhatsApp Notification Testing

This test was conducted to determine the system's success in sending warning notifications to residents when the remaining token balance reaches a critical threshold below 5 kWh; the results are shown in Table 9

Table 9. Results of *WhatsApp* Notification Testing

No	Residential Unit	Remaining Tokens (kWh)	Notification Status	Notes
1	Unit 101	11.32	Not Sent	Above the limit
2	Unit 101	5	Sent	Below the minimum limit
3	Unit 101	3	Sent	Below the limit

The notification received by the resident via WhatsApp is shown in fig 11

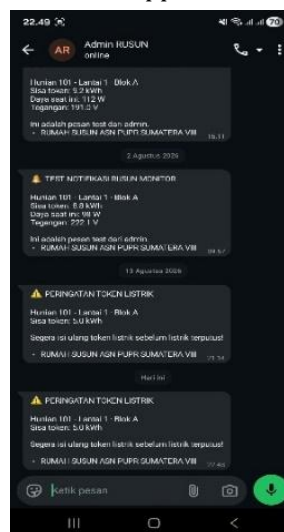


Fig 11. WhatsApp notification display

Based on the test results, the system successfully sent a WhatsApp notification automatically when the remaining token balance fell below 5 kWh, as designed.

4. CONCLUSION

Based on the research conducted on the prototype of a web-based prepaid kWh meter monitoring system with electricity token balance notifications, the following conclusions can be drawn:

1. Test results for the PZEM-004T sensor showed an average precision of 98.88%, an accuracy of 98.12%, and an error of 1.88% compared to the reference meter, making it suitable for use as an electrical parameter measurement device in this system.
2. Alerts regarding remaining electricity tokens when the minimum threshold of 5 kWh is reached were successfully sent automatically to residents' phone numbers, providing early warnings even though the kWh meters are centrally installed in a closed area.
3. The website displaying daily energy consumption data operates smoothly and can be accessed from a desktop/PC and smartphone via a web browser.

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