Implementation of Token-Based Electricity Monitoring and Payment System Using Mobile Application in Boarding House Rooms

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***Abstract* — A boarding house, where multiple rooms are occupied by different individuals, faces challenges in managing electricity costs and payments due to varying consumption and different lengths of stay. To address this, a device was developed to monitor each tenant's electricity usage and integrate with the Internet of Things (IoT) via an Android application. This system utilizes key components, including the ESP-01 microcontroller and the PZEM-004T module, allowing tenants to track their electricity consumption, check remaining token balances, and make payments using Midtrans. The landlord can also monitor the electricity usage of each room, which simplifies the overall management of electricity consumption. Testing data revealed that the device's sensor accuracy is generally reliable, though there are slight discrepancies compared to standard measurement tools. In room 1, the sensor's current measurement has an average error rate of 0.247%, while in room 2, the error rate is just 0.007%. For voltage measurements, room 1's sensor shows an average error rate of 0.062%, and room 2's sensor shows 0.045%. Power measurement accuracy also varies, with room 1 showing a 0.561% error rate and room 2 showing a 0.675% error rate. Overall, the sensor demonstrates satisfactory accuracy, with room 2 performing slightly better.**

***Keywords*— Android, Application, ESP-01, Midtrans, PZEM-004T**

I. INTRODUCTION

Electricity is an essential need for humans. Electricity usage can be monitored through the electricity meter provided by Perusahaan Listrik Negara (PLN), the electricity distributor in Indonesia. PLN installs these meters in every building that requires electricity upon request. Installing more than one meter is possible, but it incurs additional costs and requires significant modifications to the existing installation if a meter was already installed. A boarding house is a residential building with many rooms that can be used by multiple people. The electricity needs of each occupant in a boarding house vary. This is particularly true for the boarding house at Jl. Bunga Srigading Gg SD No.27B, Lowokwaru, Kota Malang. This boarding house still uses a postpaid electricity system, resulting in varying electricity usage among rooms. The landlord faces challenges from tenants regarding the equitable distribution of electricity bills. Additionally, managing payments is difficult due to the varying times that tenants spend in the boarding house.

To address these issues, an innovation was made based on previous research titled "Design and Development of an Online Electricity Monitoring Device for Dormitories Using ESP32" [1]. This previous research used the Blynk application, which could not display the latest data when the device's internet connection was lost. Furthermore, this research lacked a payment mechanism for electricity bills. In response to these evaluations, the new device is designed using the ESP-01, has a smaller size compared to the ESP32 and fewer pins but is still adequate for monitoring and controlling systems. The interface uses an application developed with Android Studio, where recorded data is stored in a Firebase database. The application has two access levels: admin and user, facilitating better management of electricity usage. The admin application features monitoring capabilities to track each tenant's electricity usage, including current, voltage, and power used in each room. Additionally, the admin can view the remaining electricity tokens available in the tenant's room and could turn devices on or off if tenants exceed the established limits.

The user application includes a monitoring feature for tracking electricity usage in their room and checking the remaining electricity tokens. It also offers a billing feature, allowing users to purchase electricity tokens at predefined prices and quantities (kWh). This feature is equipped with a payment method through Midtrans. Consequently, this application offers convenience for boarding house tenants in using electricity efficiently and economically. Additionally, this research provides advantages over previous studies in terms of the system's capabilities. The device used in this research is based on the Internet of Things, incorporating various technologies broadly combined into a single unit, including sensors for data reading, internet connection with various network topologies, radio frequency identification (RFID), wireless sensor networks, and evolving technologies according to needs [2].

The components used in the device include the ESP-01 microcontroller, PZEM-004T sensor module, power supply,

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MP1584 module, and relay. The interface used is the Android Studio application, and the database is managed using Firebase. Android Studio offers numerous features that enhance productivity when building Android applications, such as a flexible Gradle-based build system, a fast and feature-rich emulator, code templates and GitHub integration to help create common application features and import sample code, a comprehensive testing framework and tools, and support for C++ and NDK. Android Studio has rapidly evolved as an innovative platform. This is largely due to the main development behind it, namely Google. Google acquired Android Studio and then developed it into a platform [20]. In this research, the Firebase feature used will be the real-time database for monitoring and controlling electricity usage in boarding house rooms. The real-time database will be used in applications to monitor current, voltage, power, and kWh to support the application in real time. Its operational process is identical to manually created server applications, where applications connected to the Firebase database will automatically perform tasks as integrated with the devices [21].

II. METHOD

The following are the methods used in the research conducted.

A. Research Stages

The research stages for making the device consist of several stages as in the following flowchart.

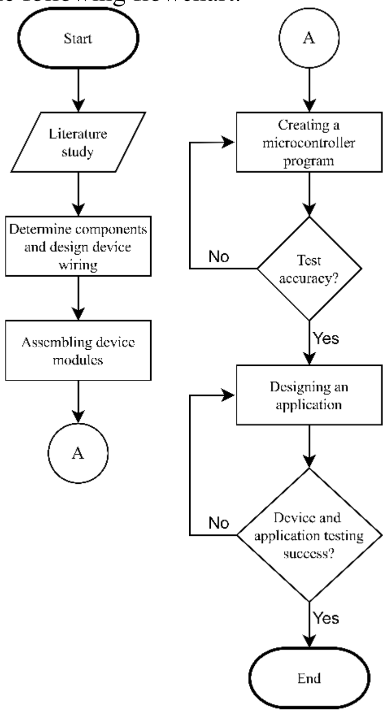


Figure 1. Research Stages Flowchart

In Figure 1, the initial process carried out is conducting literature research by studying supporting theories that can aid in the design and identification of the components used. The literature research is conducted by searching for references through theses and journals related to monitoring or recording electrical energy using the ESP-01 microcontroller and the PZEM-004T sensor module from various institutions.

The microcontroller programming includes reading the PZEM-004T sensor module, processing and storing the total kWh of electricity usage and sending the total kWh to the application based on the room ID. The application design or programming points include login page to enter the username and password, main page that includes monitoring, controlling, and payment features, monitoring page to view electricity usage, controlling page to turn the device on or off and payment page to make payments via Midtrans.

B. System Flowchart

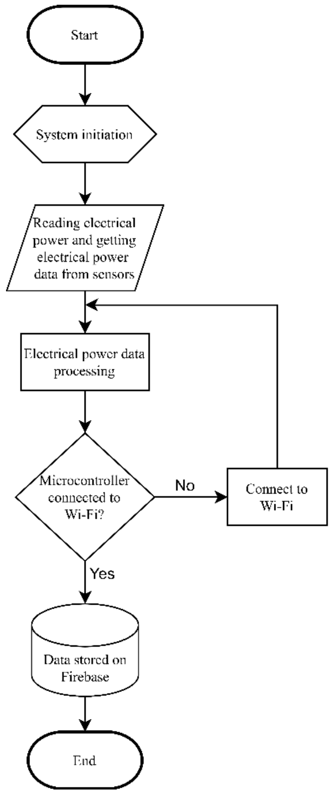


Figure 3. System Flowchart

In the flowchart shown in Figure 3, the diagram outlines the process of integrating the microcontroller with the Firebase database. This process begins with the system initialization stage, which includes various preparatory steps involving the hardware and sensors to be used. During this initialization stage, the devices and sensors are prepared to start functioning, ensuring everything works correctly before proceeding to the next stage.

Once the initialization process is complete, the prepared sensors begin to operate by measuring electrical parameters such as current, voltage, and power being used. The data collected from these sensors is then sent to the ESP01 microcontroller. The microcontroller plays a crucial role in receiving data from the sensors and processing it into more useful and comprehensible information, such as the amount of current flowing, the existing voltage, and the power consumed in the system.

C. System Block Diagram

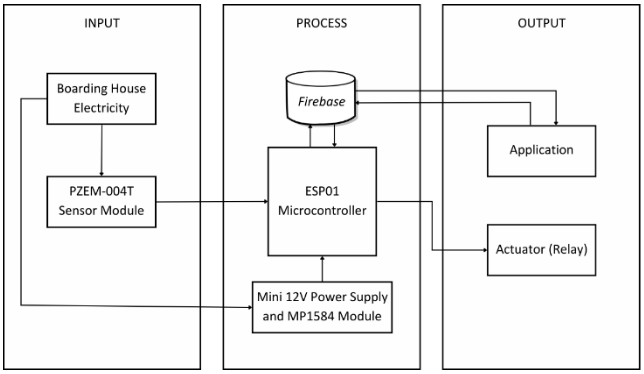


Figure 2. System Block Diagram

From Figure 2, the working principle of this device is to read the amount of electricity usage in a boarding room in kWh using the PZEM-004T module. The readings are then processed and stored in the microcontroller, which is the ESP01. The data is subsequently sent to a database, namely Firebase. After that, the data is sent to an application that is then directed to the boarding house users. The device operates when there is a Wi-Fi connection, integrating with the application that has been developed and accessed through devices such as smartphones. This device is equipped with a relay that can control the electricity usage by the user, such as turning the device on or off if the user consumes electricity beyond the specified limits.

III. RESULTS AND DISCUSSION

A. *Implementation Hardware*

The design has been successfully implemented, and the system operates according to the procedures. The results can be seen in Figure 3 below:

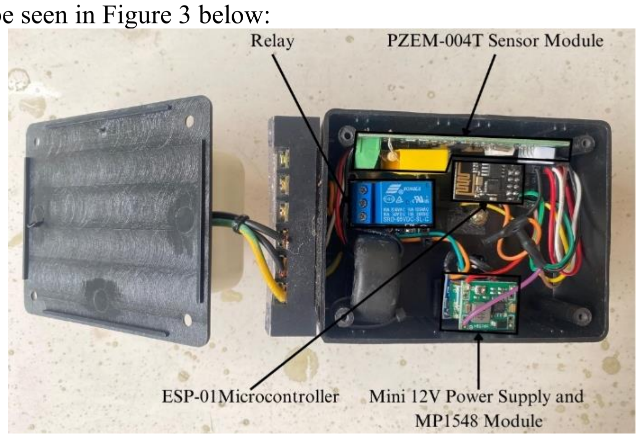


Figure 4. Result of Device

Figure 4 shows the result of the device construction with several components within it. This device includes an ESP-01 microcontroller, which is used to manage the device's processing automatically, such as data processing. It also features a PZEM-004T sensor module used to measure current, voltage, and electrical power consumption. The device is equipped with a 12V mini power supply connected to an MP1548 module, which serves as the power source for the device. The power source for this device comes from PLN's electrical grid, providing 12V to the mini power supply, which is then stepped down by the MP1548 module to 5V to be supplied to the ESP-01 microcontroller and the PZEM-004T sensor module. The output pins from the PZEM-004T sensor module are connected to the RX and TX pins of the ESP-01 microcontroller for data communication, which is then processed and sent to the Firebase database and application. A Wi-Fi connection is required for data transmission to the Firebase database and application. Additionally, this device is equipped with a relay that can be used to turn the device on or off.

The next step is to ensure that the microcontroller is connected to a Wi-Fi network. Wi-Fi connectivity is essential as it allows the microcontroller to transmit the processed data to Firebase over the internet. If the microcontroller is not connected to Wi-Fi, the system will automatically attempt to establish a connection. Once the connection is successfully established, the microcontroller can start sending the processed data to Firebase, where it will be stored in real-time.

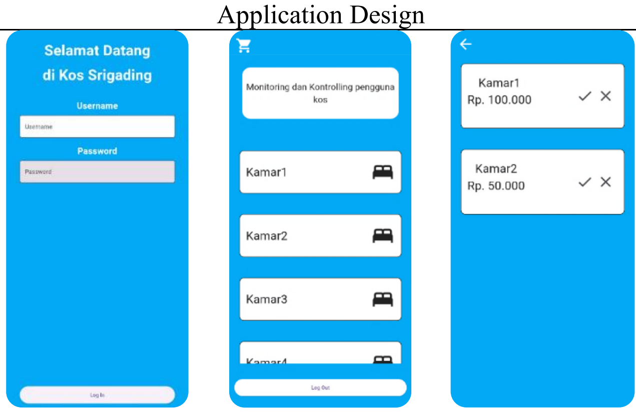
Firebase is a real-time database platform that allows the stored data to be accessed directly by various connected applications. Applications designed to access data in Firebase have differentiated access rights for users and admins. In the user application, there is a menu designed to display information about the current usage of current, voltage, and power. Additionally, users can make electricity token payments through the application to ensure that the devices remain operational.

On the other hand, the admin application has additional features that enable the admin to monitor electricity usage by users. The admin can view the amount of current, voltage, and power used by each user, as well as the remaining electricity tokens. Furthermore, the admin can turn devices on or off if users are found to be using electricity beyond the established limits.

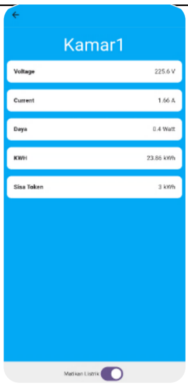
B. *Implementation Application*

Application implementation is a crucial part of the process, as it relates to the interaction between the admin and users with the application. The implementation of the application will be explained in more detail as follows:

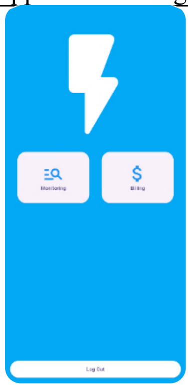
TABLE I
APPLICATION DESIGN

Application Design		
		
(a)	(b)	(c)

Application Design



(d)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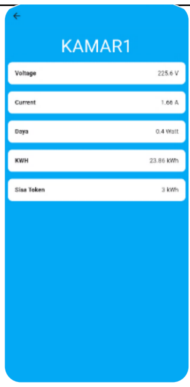
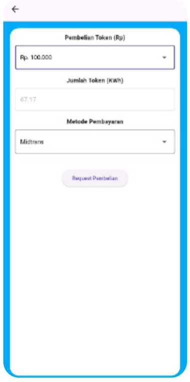


(f)


(g)


(h)

Table 1(a) shows the login page of the application, which includes fields for the username and password, allowing users to securely access their accounts. Table 1(b) shows the main page of the application for the admin, displaying several rooms of the boarding house users, and providing an overview of the current status of each room. Table 1(c) shows the transaction page for the admin, which is used to approve or reject the purchase of electricity tokens by users, ensuring proper authorization and management of transactions. Table 1(d) shows the monitoring and controlling page for the admin, displaying electricity usage data such as current, voltage, power, and kWh, along with buttons to turn the user's device on or off, providing control over electrical devices. Table 1(e) shows the main page of the application for the boarding house users, which includes features for monitoring and payments, offering a user-friendly interface. Table 1(f) shows the monitoring page for the users, displaying electricity usage data such as current, voltage, power, and kWh for the user's room, helping them track their consumption. Table 1(g) shows the payment page for the users, displaying the purchase of electricity tokens and the total of tokens (kWh) obtained. Table 1(h) shows the payment page via Midtrans, which offers multiple payment methods, including e-wallets.

C. System Test Results

The system testing aims to ensure that the sensors on the PZEM-004T Module work with a high level of accuracy and ensure that the data obtained from the sensor testing matches the data from the measuring instrument, as shown in table 2 to table 9.

TABLE II
ROOM 1 CURRENT SENSOR TEST RESULTS

No	Electrical Load	Sensor Reading (Ampere)	Measuring Instrument Reading (Ampere)	Measurement Difference (Ampere)	Error (%)
1	LED lights (7W)	0,05	0,059	0,009	0,153
2	Iron	1,71	1,548	0,162	0,105
3	Rice Cooker (cook)	1,45	1,329	0,121	0,091
4	Rice Cooker (warm)	0,04	0,054	0,014	0,259
5	Fan	0,04	0,093	0,053	0,570
6	Charging Laptop	0,25	0,218	0,032	0,147
7	Charging Mobile Phone	0,1	0,073	0,027	0,370
8	Printer	0,09	0,088	0,002	0,023
	Total	3,73	3,46	0,42	0,247
		Average			0,215

Table 2 shows the measurement data of the accuracy of the current sensor on the PZEM-004T module in reading the current of the device used in room 1. The sensor reading data is compared with the power meter to obtain the difference and error. Overall, although there are variations in measurement errors for various electrical loads, the measurement results from the sensor as a whole still show a good level of accuracy.

TABLE III
ROOM 2 CURRENT SENSOR TEST RESULTS

No	Electrical Load	Sensor Reading (Ampere)	Measuring Instrument Reading (Ampere)	Measurement Difference (Ampere)	Error (%)
1	LED lights (3W)	0,05	0,055	0,005	0,091
2	Iron	1,66	1,5	0,16	0,107
3	Rice Cooker (cook)	1,66	1,63	0,03	0,018
4	Rice Cooker (warm)	0,15	0,13	0,02	0,154
5	Fan	0,04	0,093	0,053	0,570
6	Charging Laptop	0,3	0,261	0,039	0,149
7	Charging Mobile Phone	0,16	0,133	0,027	0,203
8	Printer	0,09	0,088	0,002	0,023

No	Electrical Load	Sensor Reading (Ampere)	Measuring Instrument Reading (Ampere)	Measurement Difference (Ampere)	Error (%)
	Total	4,11	3,89	0,34	0,007
		Average			0,164

Table 3 shows the measurement data of the accuracy of the current sensor on the PZEM-004T module in reading the current of the device used in room 2. The sensor reading data is compared with the power meter to obtain the difference and error. Overall, although there are variations in measurement errors for various electrical loads, the measurement results from the sensor as a whole still show a good level of accuracy.

TABLE IV
ROOM 1 VOLTAGE SENSOR TEST RESULTS

No	Electrical Load	Sensor Reading (Volt)	Measuring Instrument Reading (Volt)	Measurement Difference (Volt)	Error (%)
1	LED lights (7W)	228,4	229,9	1,5	0,007
2	Iron	239,3	237,0	2,3	0,010
3	Rice Cooker (cook)	233,8	239,4	5,6	0,023
4	Rice Cooker (warm)	234,3	243,2	8,9	0,037
5	Fan	237,2	238,4	1,2	0,005
6	Charging Laptop	240,5	236,0	4,5	0,019
7	Charging Mobile Phone	235,8	238,2	2,4	0,010
8	Printer	237,6	239,7	2,1	0,009
	Total	1886,90	1901,80	28,50	0,062
		Average			0,015

Table 4 shows the measurement data of the voltage sensor accuracy on the PZEM-004T module in reading the current of the device used in room 1. The sensor reading data is compared with the power meter to obtain the difference and error. Overall, although there are variations in measurement errors for various electrical loads, the measurement results from the sensor as a whole still show a good level of accuracy.

TABLE V
ROOM 2 VOLTAGE SENSOR TEST RESULTS

No	Electrical Load	Sensor Reading (Volt)	Measuring Instrument Reading (Volt)	Measurement Difference (Volt)	Error (%)
1	LED lights (3W)	239,1	239,9	0,8	0,003
2	Iron	235,4	236,8	1,4	0,006
3	Rice Cooker (cook)	220,5	223	2,5	0,011
4	Rice Cooker (warm)	223,7	226	2,3	0,010
5	Fan	238,0	238,4	0,4	0,002
6	Charging Laptop	229,3	230,1	0,8	0,003
7	Charging Mobile Phone	237,0	238,8	1,8	0,008
8	Printer	239,2	239,7	0,5	0,002
	Total	1862,20	1872,70	10,50	0,045
		Average			0,006

Table 5 shows the measurement data of the voltage sensor accuracy on the PZEM-004T module in reading the current of the device used in room 2. The sensor reading data is compared with the power meter to obtain the difference and error. Overall, although there are variations in measurement errors for various electrical loads, the measurement results from the sensor as a whole still show a good level of accuracy.

TABLE VI
ROOM 1 POWER SENSOR TEST RESULTS

No	Electrical Load	Sensor Reading (Watt)	Measuring Instrument Reading (Watt)	Measurement Difference (Watt)	Error (%)
1	LED lights (7W)	8,7	7,9	0,8	0,101
2	Iron	402,1	410,1	8	0,020
3	Rice Cooker (cook)	338,9	354,7	15,8	0,045
4	Rice Cooker (warm)	9,37	13,1	3,73	0,285
5	Fan	9,3	8,5	0,8	0,094
6	Charging Laptop	26,5	26,4	0,1	0,004
7	Charging Mobile Phone	11,9	6,7	5,2	0,776
8	Printer	7,1	7,6	0,5	0,066
	Total	813,87	835,00	34,93	0,561
		Average			0,174

Table 6 shows the measurement data of the power sensor accuracy on the PZEM-004T module in reading the current of the device used in room 1. The sensor reading data is compared with the power meter to obtain the difference and error. Overall, although there are variations in measurement errors for various electrical loads, the measurement results from the sensor as a whole still show a good level of accuracy.

TABLE VII
ROOM 2 POWER SENSOR TEST RESULTS

No	Electrical Load	Sensor Reading (Watt)	Measuring Instrument Reading (Watt)	Measurement Difference (Watt)	Error (%)
1	LED lights (3W)	3,8	3	0,8	0,267
2	Iron	390,4	396,1	5,7	0,014
3	Rice Cooker (cook)	366,03	363,49	2,54	0,007
4	Rice Cooker (warm)	33,5	29,38	4,12	0,140
5	Fan	9,4	8,5	0,9	0,106
6	Charging Laptop	35,2	34,8	0,4	0,011
7	Charging Mobile Phone	17,8	15,2	2,6	0,171
8	Printer	7,5	7,6	0,1	0,013
	Total	863,63	858,07	17,16	0,675
	Average				0,091

Table 7 shows the measurement data of the power sensor accuracy on the PZEM-004T module in reading the current of the device used in room 2. The sensor reading data is compared with the power meter to obtain the difference and error. Overall, although there are variations in measurement errors for various electrical loads, the measurement results from the sensor as a whole still show a good level of accuracy.

TABLE VIII
ROOM 1 KWH TEST RESULTS

No	Electrical Load	Sensor Reading (kWh)	Measuring Instrument Reading (kWh)	Measurement Difference (kWh)	Error (%)
1	LED lights (7W)	0,01	0,013	0,003	0,231
2	Iron	0,04	0,044	0,004	0,091
3	Rice Cooker (cook & warm)	0,01	0,095	0,085	0,895
4	Fan	0,01	0,016	0,006	0,375
5	Charging Laptop	0,05	0,055	0,005	0,091
6	Charging Mobile Phone	0,01	0,096	0,086	0,896
7	Printer	0,01	0,015	0,005	0,333
	Total	0,14	0,33	0,19	2,911
	Average				0,416

Table 8 shows the data of kWh electricity measurements from the PZEM-004T sensor module in reading the electricity consumption in Room 1. The sensor readings are compared with a power meter to determine the difference and error. Overall, despite variations in measurement errors for different electrical loads, the sensor's measurement results still demonstrate a good level of accuracy.

TABLE IX
ROOM 2 KWH TEST RESULTS

No	Electrical Load	Sensor Reading (kWh)	Measuring Instrument Reading (kWh)	Measurement Difference (kWh)	Error (%)
1	LED lights (3W)	0,01	0,011	0,001	0,091
2	Iron	0,04	0,047	0,007	0,149
3	Rice Cooker (cook & warm)	0,01	0,098	0,088	0,898
4	Fan	0,01	0,011	0,001	0,091
5	Charging Laptop	0,05	0,051	0,001	0,020
6	Charging Mobile Phone	0,01	0,099	0,089	0,899
7	Printer	0,01	0,097	0,087	0,897
	Total	0,14	0,41	0,27	3,044
	Average				0,435

Table 9 shows the data of kWh electricity measurements from the PZEM-004T sensor module in reading the electricity consumption in Room 2. The sensor readings are compared with a power meter to obtain the difference and error. Overall, despite variations in measurement errors for different electrical loads, the sensor's measurement results still demonstrate a good level of accuracy.

D. Discussion of System Test Results Data

The test data from Table 2 to Table 9 shows a comparison between sensor readings and measurements from a power meter for various parameters such as current, voltage, power, and kWh in Room 1 and Room 2. Overall, there are variations in the error rate, with some sensor readings being higher or lower than those from the power meter. For current measurement, the average error for Room 1 is 0.215% with a difference of 0.42 A, and for Room 2, it is 0.164% with a difference of 0.34 A. Voltage measurements show an average error of 0.015% in Room 1 with a difference of 28.50 V, and 0.006% in Room 2 with a difference of 10.50 V. Power measurements indicate an average error of 0.174% in Room 1 with a difference of 34.93 W, and 0.091% in Room 2 with a difference of 17.16 W. kWh measurements show an average error of 0.416% in Room 1 with a difference of 0.19 kWh, and 0.435% in Room 2 with a difference of 0.27 kWh. Despite some significant errors in certain readings, such as with the rice cooker and phone charging, overall, the sensor accuracy is still considered acceptable and within reasonable limits.

IV. CONCLUSION

The "Token-Based Electricity Monitoring and Payment System" device is designed using the PZEM-004T sensor module connected to the ESP-01 microcontroller, which has Wi-Fi connectivity to transmit data to the application. This device is installed on the boarding house electricity supply to measure current, voltage, power, and energy consumption in kWh. The electricity usage data is sent to a Firebase database for storage and further processing, and the data is then displayed on an Android application. This application can be used by both boarding house tenants and owners, facilitating accurate management of electricity usage. Additionally, the payment system on the application is designed to simplify electricity token payments for users. Payments can be made through the Midtrans method. Users and owners can view the remaining electricity tokens on the application. Furthermore, users receive notifications on the application when their electricity tokens are running low. And based on the testing data, the "Token-Based Electricity Monitoring and Payment System" device demonstrates a commendable level of accuracy in measuring current, voltage, and power. In Room 1, the current readings have an average error of 0.215%, voltage readings have an average error of 0.015%, and power readings have an average error of 0.174%. In Room 2, the current readings have an average error of 0.164%, voltage readings have an average error of 0.006%, and power readings have an average error of 0.091%. Additionally, the kWh readings show an average error of 0.416% in Room 1 and 0.435% in Room 2, which are still within acceptable limits. Overall, the measurements show a high degree of accuracy with relatively small average errors.

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