

Design and Development of a NodeMCU-Based Lamp Power Control and Monitoring Device Using the PZEM-004T Module

Sultan Aziz Syaifullah^{a,1}, Huzain Azis^{b,2},

^a Program Studi Teknik Informatika, Universitas Muslim Indonesia, Jalan Urip Sumoharjo, Makassar 90231, Indonesia

^b Universiti Kuala Lumpur, 50250 Kuala Lumpur, Malaysia

¹ 13020200073@umi.ac.id; ² huzain.azis@s.unik.edu.my

ARTICLE INFORMATION	ABSTRACT
Received : 10 – 06 – 2024 Revised : 05 – 03 – 2025 Published : 25 – 04 – 2025	This research aims to design and develop a power control and monitoring device based on NodeMCU and the PZEM-004T module as the central controller and monitoring unit, enabling users to remotely control and monitor household lamp power consumption. The method used in this study is an experimental approach to evaluate the performance of the developed lamp power control and monitoring device. The NodeMCU ESP8266 microcontroller is employed to execute program instructions and enable remote control, while the PZEM-004T module functions as the power consumption meter. Through serial communication, it provides real-time data on power (Watt), energy consumption (kWh), and cost (IDR) to a smartphone via the Thingier.io web platform. Users can manage the ON-OFF status of home lighting and monitor power usage in real-time. The testing results indicate that the developed prototype successfully supports real-time control and monitoring with an average power measurement error of only 0.10%.
Keywords: NodeMCU ESP8266 Internet of Things PZEM-004T Thingier.io	

I. Introduction

Electricity is one of the essential needs in modern human life. In industrial settings, electricity is used continuously for 24 hours. Even a brief power outage lasting only a few seconds can cause losses amounting to millions or even billions of rupiah. According to the Indonesian Retailers Association (APRINDO), the potential losses incurred by their members due to power outages can reach IDR 90–100 billion for every six hours of blackout [1]. In contrast to the industrial sector, household electricity usage does not require a continuous 24-hour supply, as electricity—particularly lighting—is typically turned on only when needed and turned off when not in use. However, homeowners often forget to switch off lights in certain situations, which can lead to negative consequences such as unnecessary energy consumption and an increased risk of electrical short circuits. The electricity usage in a household depends on how many appliances are in use. The more devices in operation, the higher the power consumption, which may result in electrical overload.

The rapid development of technology in recent years has significantly influenced societal behavior and lifestyle. Electronic technologies, particularly those related to control systems, have also advanced rapidly. People continuously seek more efficient and user-friendly control mechanisms. Remote control systems are no longer a novelty and have been widely implemented in various applications.

Home automation, known as the concept of Smart Homes, has been around for many years. It refers to the automatic control of household devices and appliances, including remote control functionality [2]. Various remote control systems have been developed, each focusing on different applications and scenarios. For instance, an Android-based remote control system was developed by Immanuel [3], while Affan Bachri and Nurhadiyan [4][5] explored remote light switch control via Short Message Service (SMS). In addition, Berlianti and Amir implemented an Internet of Things (IoT)-based system using Arduino, a Wi-Fi module, and the Blynk application to control electric switches remotely [6][7].

Previous studies have primarily focused on the control aspects of lighting systems without incorporating features for power consumption measurement. Therefore, this study proposes the development of a device titled “Design and Development of a NodeMCU-Based Lamp Power Control and Monitoring Device Using the PZEM-004T Module”, which integrates a web-based platform (Thingier.io) to enable both remote control and real-time monitoring of electrical power usage.

II. Method

This study discusses the design and development of a device for controlling and monitoring the electrical power consumption of a lamp. The design process involves both hardware and software development. In this context, the researcher employs an experimental method.

A. Device Design

The design presented in this study is a simple control system for operating the ON/OFF function and measuring the power consumption of a lamp. The complete device circuit integrates several components, including the NodeMCU ESP8266, the PZEM-004T sensor, a relay, a lamp, and other supporting elements. All these components are assembled into a single package referred to as the device circuit design. The overall schematic diagram of the device is shown in **Figure 1**.

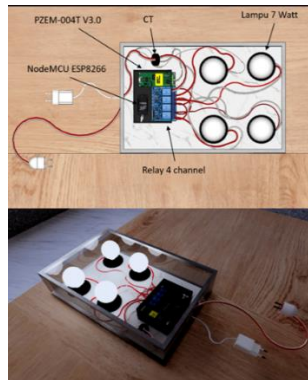


Figure 1. Device Design Diagram

1) Internet of Things (IoT)

The Internet of Things (IoT) has become an independent field of research due to the rapid development of internet technology and communication media. As technological demands continue to evolve, an increasing number of studies have emerged. IoT is one such innovation, developed by researchers to optimize the accessibility and control of room-based devices in smart home environments [8].

2) Thingier.io Web Server

Thingier.io is an emerging platform that has captured the interest of the scientific and technological communities. It provides a ready-to-use cloud service for connecting devices to the Internet, enabling remote sensing and actuation through online interfaces. Thingier.io offers a free-tier service for connecting a limited number of devices and also allows the installation of its software outside the cloud, providing full access to manage data and devices privately without any limitations [9][10].

3) NodeMCU ESP8266

The ESP8266, part of the ESP series developed by Expressive Systems, supports firmware based on the Lua scripting language. The term "NodeMCU" originally refers to the firmware rather than the development board itself. However, NodeMCU is also commonly associated with the Arduino-style development board that uses the ESP8266 chip. In addition to Lua, NodeMCU is compatible with the Arduino IDE, allowing users to program the board by adding the appropriate board URL to the Board Manager [11][12][13].

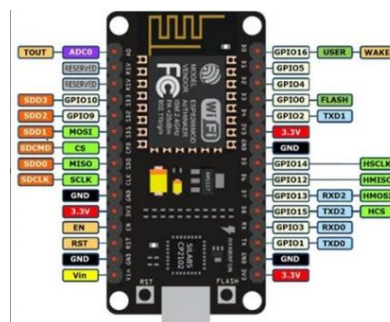


Figure 2. Mapping Pin NodeMCU ESP 8266[14]

4) Arduino IDE

IDE stands for Integrated Development Environment, which refers to a unified platform used for software development. It is called an "environment" because it integrates various tools to enable the Arduino to perform embedded tasks through programming syntax. Arduino uses a programming language that is similar to C. The Arduino programming language (known as Sketch) has been simplified from its original form to facilitate ease of use, especially for beginners. Before being marketed, Arduino microcontroller ICs are pre-loaded with a program called the Bootloader, which functions as a mediator between the Arduino compiler and the microcontroller [15].

5) Relay Modul

A relay is a type of electrically operated switch that is controlled by current. It consists of a low-voltage coil wound around a core. When current flows through the coil, an iron armature is attracted toward the core. This armature is connected to a spring-loaded lever. When the armature is pulled toward the core, the common contact switches from the normally-closed (NC) contact to the normally-open (NO) contact. Relays can be used to control AC motors using a DC control circuit or to operate loads with different voltage levels between the control circuit and the load voltage [16].



Figure 3. Relay Modul [17]

6) PZEM-004T Module

The PZEM-004T module is a multifunctional sensor module designed to measure power, voltage, current, and energy within an electrical circuit. This module is equipped with an integrated voltage sensor and a current transformer (CT) sensor. It is intended for indoor use only, and the connected load must not exceed the module's specified power rating [18].



Figure 4. PZEM-004T V3.0[19]

III. Results and Discussion

A. Research Results

1) System Blok Diagram

This system is designed to control a lamp using a relay as an ON/OFF switch and to measure the lamp's electrical power consumption using the PZEM-004T module. The measured values are processed by the NodeMCU ESP8266, which then transmits the data to be displayed on the Thingier.io web platform. The fundamental concept of the system is illustrated as follows.

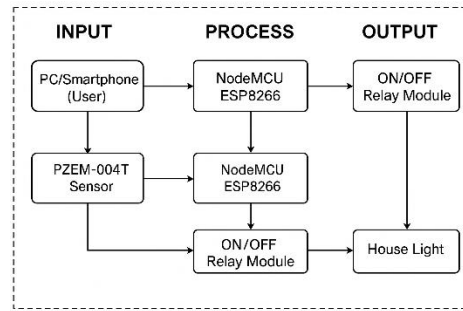


Figure 5. System Block Diagram

2) Flowchart of the Lamp Power Control and Monitoring System

The flowchart illustrates the system's operational workflow, beginning with input, followed by processing, and culminating in the desired output. To clarify the system design and workflow analysis, a general overview of the system's flowchart is presented as follows.

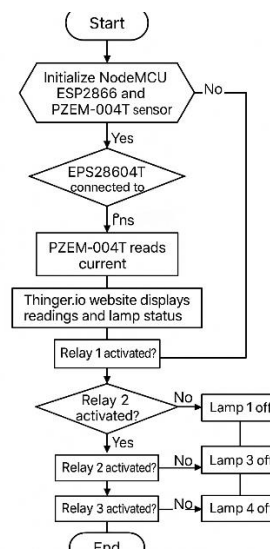


Figure 6. Flowchart of the Lamp Power Control and Monitoring System

3) Design Results of the NodeMCU and PZEM-004T-Based Lamp Power Control and Monitoring Device

This research resulted in a device design developed through several stages, starting from component assembly to comprehensive testing. The overall testing of the system was conducted to evaluate its performance and the success rate of the proposed design. Based on the results obtained, the operational behavior of each interconnected component can be analyzed, forming a control and power monitoring system for lamps based on the NodeMCU ESP8266 and the PZEM-004T module. The design consists of a 5VDC power supply (USB), a NodeMCU ESP8266, a 4-channel relay module, a PZEM-004T module, and a lamp as the controlled object.

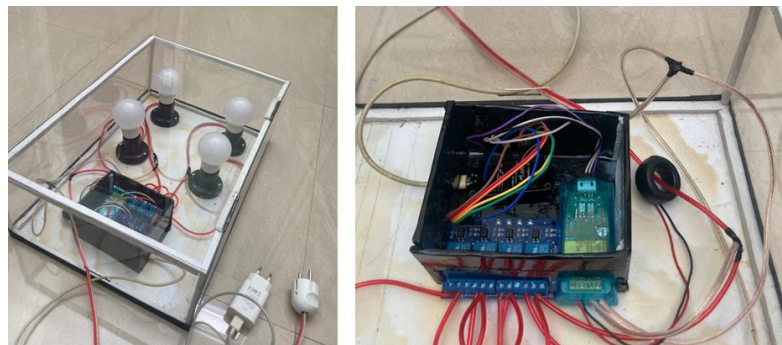


Figure 7. External and Internal Views of the Device

4) Hardware Circuit of the NodeMCU and PZEM-004T-Based Lamp Power Control and Monitoring Device

The detailed hardware circuit of the lamp power control and monitoring device based on NodeMCU and the PZEM-004T module is presented in Figure 8 below.

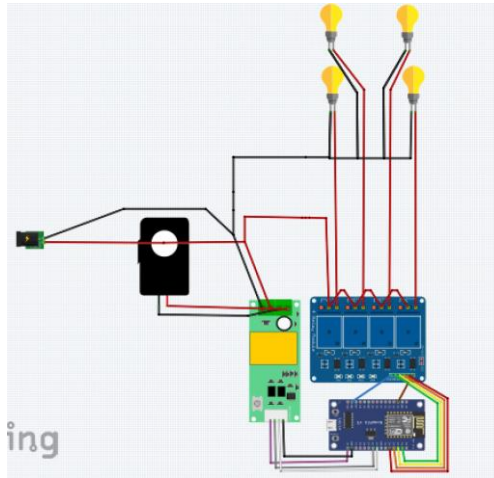


Figure 8. Rangkaian Perangkat Keras Alat Pengontrol dan Penghitung Daya Listrik Berbasis NodeMCU dan Modul PZEM-004T

B. Discussion

1) Device Testing

Using the average formula, the system’s response time for turning the lamp on and off was measured. The average delay values obtained can be seen in **Table 1**.

$$\text{Average Delay} = \frac{\text{Total delay}}{\text{Number of delay measurements received}} \tag{1}$$

Table 1. Test Results of Lamp Control Functionality

No	Lamp	Delay (s)	Lamp Condition
1.	Lamp 1	3,00	On
2.	Lamp 2	1,28	On
3.	Lamp 3	0,98	On
4.	Lamp 4	1,03	On
5.	Lamp 1	1,15	Off
6.	Lamp 2	2,56	Off
7.	Lamp 3	2,63	Off
8.	Lamp 4	1,11	Off
Average delay		1,71	

Based on **Table 1**, the results reflect the performance of the lamp control functionality. The highest delay recorded was 3.00 seconds for Lamp 1 in the ON condition, while the lowest delay was 0.98 seconds for Lamp 3, also in the ON condition. The average delay measured across all lamps—both in ON and OFF states—was 1.71 seconds.

Table 2. Test Results of the PZEM-004T Module (Lamp 1 ON)

Time (2 minutes)	Cost (Rp)	Power (Watt)	Actual Power (Watt)	Energy (kWh)
2:49:27 AM	24.97	6.80	7	0.0166
2:51:16 AM	72.98	6.80		0.0486
2:53:05 AM	120.08	6.69		0.0800
2:54:54 AM	169.18	6.69		0.1127
2:56:43 AM	217.77	6.69		0.1451

Time (2 minutes)	Cost (Rp)	Power (Watt)	Actual Power (Watt)	Energy (kWh)
2:58:33 AM	266.87	6.69		0.1779
Average power measurement results		6,72	-	-

Based on **Table 2**, the results show the performance of the PZEM-004T module when Lamp 1 is turned ON. The average power consumption recorded over a 10-minute period was 6.72 Watts.

Table 3. PZEM-004T Test Results (Lamp 1 and 2 ON)

Time (2 minutes)	Cost (Rp)	Power (Watt)	Actual Power (Watt)	Energy (kWh)
3:00:22 AM	315.59	13.30		0.2103
3:02:12 AM	364.84	13.19		0.2432
3:04:00 AM	413.08	13.10	14	0.2753
3:05:49 AM	461.46	13		0.3076
3:07:38 AM	509.84	13		0.3398
3:09:27 AM	557.81	13.10		0.3718
Average power measurement results		13,11	-	-

According to **Table 3**, the PZEM-004T test was conducted with Lamp 1 and Lamp 2 turned ON. The average power consumption recorded during the 10-minute measurement was 13.11 Watts.

Table 4. PZEM-004T Test Results (Lamp 1, 2, and 3 ON)

Time (2 minutes)	Cost (Rp)	Power (Watt)	Actual Power (Watt)	Energy (kWh)
3:11:16 AM	606.84	19.60		0.4045
3:13:06 AM	655.46	19.5		0.4369
3:14:55 AM	704.64	19.39	21	0.4697
3:16:44 AM	753.94	19.39		0.5026
3:18:34 AM	803.29	19.29		0.5355
3:20:22 AM	852.25	19.29		0.5681
Average power measurement results		19.41	-	-

As shown in **Table 4**, the power measurement test of the PZEM-004T was carried out when Lamp 1, Lamp 2, and Lamp 3 were turned ON. The average power consumption recorded was 19.41 Watts over a 10-minute duration.

Table 5. PZEM-004T Test Results (Lamp 1, 2, 3, and 4 ON)

Time (2 minutes)	Cost (Rp)	Power (Watt)	Actual Power (Watt)	Energy (kWh)
3:22:12 AM	901.80	25.70		0.6012
3:24:01 AM	950.95	25.60		0.6339
3:25:50 AM	1000.20	25.60	28	0.6668
3:27:40 AM	1050.61	25.60		0.7004
3:29:29 AM	1100.11	25.60		0.7334
3:31:18 AM	1150.24	25.60		0.7668
Average power measurement results		25.61	-	-

Table 5 presents the test results for the PZEM-004T when all four lamps (Lamp 1, 2, 3, and 4) were turned ON. The average power measured over 10 minutes was 25.61 Watts.

Table 6. Overall Test Results of the PZEM-004T Module

No	Time (2 minutes)	Cost (Rp)	Power (Watt)	Actual Power (Watt)	Energy (kWh)
1.	6:24:20 PM	11.72	25	28	0.0078
2.	6:26:20 PM	12.29	25		0.0081

No	Time (2 minutes)	Cost (Rp)	Power (Watt)	Actual Power (Watt)	Energy (kWh)
3.	6:28:19 PM	12.85	25		0.0085
4.	6:32:20 PM	13.99	24.89		0.0093
5.	6:30:20 PM	13.42	25		0.0089
6.	6:34:21 PM	14.56	24.89		0.0097
7.	6:38:23 PM	15.70	24.89		0.0104
8.	6:36:21 PM	15.13	24.89		0.0100
9.	6:40:23 PM	16.27	24.89		0.0108
10.	6:42:24 PM	16.85	24.89		0.0112

From **Table 6**, it can be seen that the measured power values of the device and the actual power consumption of the load are slightly different. Therefore, the percentage of overall measurement error can be calculated as follows [20]:

$$\text{Power Error \% (1)} = \frac{25-28}{28} \times 100\% = 0,10\%$$

$$\text{Power Error \% (2)} = \frac{25-28}{28} \times 100\% = 0,10\%$$

$$\text{Power Error \% (3)} = \frac{25-28}{28} \times 100\% = 0,10\%$$

$$\text{Power Error \% (4)} = \frac{24,89-28}{28} \times 100\% = 0,11\%$$

$$\text{Power Error \% (5)} = \frac{25-28}{28} \times 100\% = 0,10\%$$

$$\text{Power Error \% (6)} = \frac{24,89-28}{28} \times 100\% = 0,11\%$$

$$\text{Power Error \% (7)} = \frac{24,89-28}{28} \times 100\% = 0,11\%$$

$$\text{Power Error \% (8)} = \frac{24,89-28}{28} \times 100\% = 0,11\%$$

$$\text{Power Error \% (9)} = \frac{24,89-28}{28} \times 100\% = 0,11\%$$

$$\text{Power Error \% (10)} = \frac{24,89-28}{28} \times 100\% = 0,11\%$$

Based on the power measurement error calculations presented above, the average percentage of measurement error can be calculated as follows:

$$= \frac{0,10+0,10+0,10+0,11+0,10+0,11+0,11+0,11+0,11+0,11}{10}$$

$$= \frac{1,06}{10}$$

$$= 0,10\%$$

2) Testing on the Thinger.io Website

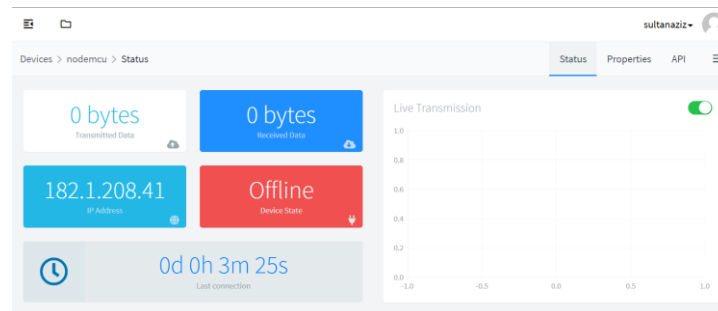


Figure 9. Offline Website Display

Figure 9 shows the initial display of the website when the system is in an offline state. The white box indicates that transmitted data is 0 bytes, the dark blue box shows received data as 0 bytes, the light blue box displays the IP address as 182.1.208.4, and the red box indicates that the device state is offline.

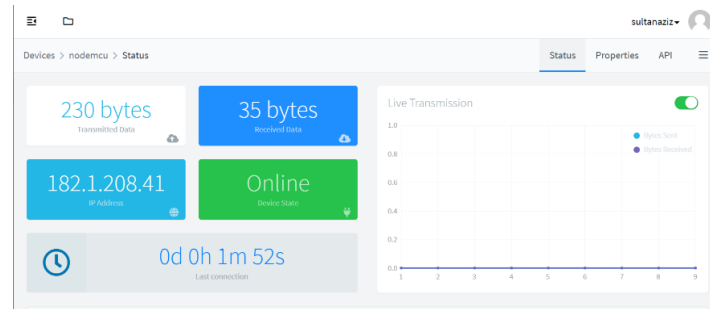


Figure 10. Online Website Display

Figure 10 presents the website display when the system is in an online state. The white box indicates that transmitted data is 230 bytes, the dark blue box shows received data as 35 bytes, the light blue box displays the IP address as 182.1.208.41, and the red box indicates that the device state is online.



Figure 11. Measurement Display When Lamp 1 is ON

Figure 11 shows the measurement display when Lamp 1 is turned ON. The results obtained include a power consumption of 6.70 Watts, a kilowatt-hour (kWh) value of 0.1933 measured by the PZEM-004T module, and an electricity cost per kWh of IDR 304.04.

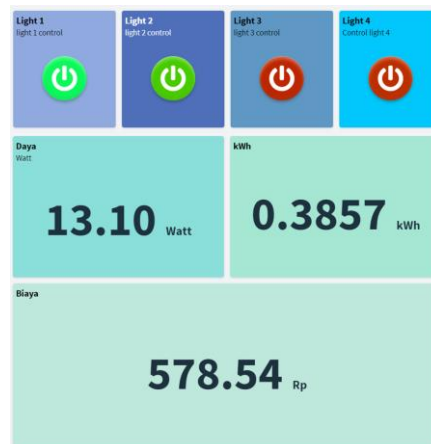


Figure 12. Measurement Display When Lamp 1 and 2 are ON

Figure 12 displays the measurement results when Lamp 1 and Lamp 2 are turned ON. The recorded power consumption is 13.10 Watts, with a kilowatt-hour (kWh) reading of 0.3857 as measured by the PZEM-004T module, and an electricity cost per kWh of IDR 578.54.

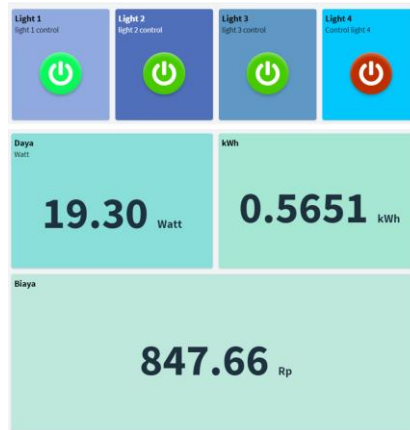


Figure 13. Measurement Display When Lamp 1, 2, and 3 are ON

Figure 13 illustrates the measurement results when Lamps 1, 2, and 3 are turned ON. The power consumption recorded is 19.30 Watts, with a kilowatt-hour (kWh) reading of 0.5651 measured by the PZEM-004T module, and an electricity cost per kWh of IDR 847.66.

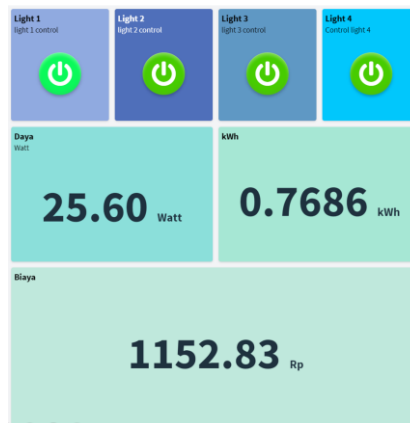


Figure 14. Measurement Display When Lamp 1, 2, 3, and 4 are ON

Figure 14 shows the measurement results when Lamps 1, 2, 3, and 4 are turned ON. The power consumption recorded is 25.60 Watts, with a kilowatt-hour (kWh) reading of 0.7686 as measured by the PZEM-004T module, and an electricity cost per kWh of IDR 1,152.83.

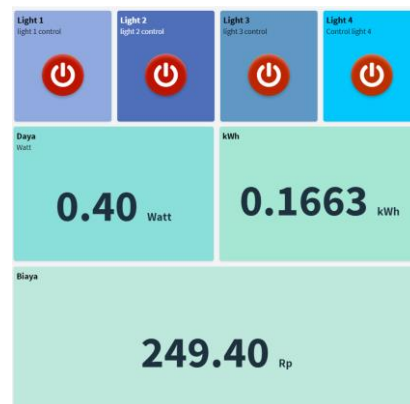
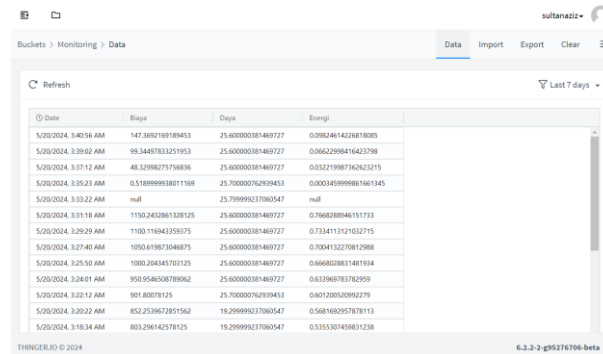


Figure 15. Measurement Display When All Lamps Are OFF

As shown in Figure 15, even when all lamps are turned OFF, a small amount of power is still detected. This occurs because the device includes internal components—specifically the PZEM-004T

sensor and the relay control circuit—which remain active even when the lamps are switched off. As a result, the system continues to consume a small amount of electrical power.



Date	Bytes	Data	Energy
5/20/2024 3:40:56 AM	147.3652169189453	25.600000381469727	0.08624614225618085
5/20/2024 3:39:02 AM	95.3448783251953	25.600000381469727	0.06622998416423798
5/20/2024 3:37:12 AM	48.3298275736836	25.600000381469727	0.032219987362623215
5/20/2024 3:35:23 AM	0.518999938011169	25.700000762939453	0.000340999661661345
5/20/2024 3:33:22 AM	null	25.79999923790547	null
5/20/2024 3:31:18 AM	1150.2432861328125	25.600000381469727	0.7668288846151733
5/20/2024 3:29:29 AM	1100.116943358375	25.600000381469727	0.7334113121032715
5/20/2024 3:27:40 AM	1050.619873046875	25.600000381469727	0.7004132270812988
5/20/2024 3:25:50 AM	1000.204345730125	25.600000381469727	0.6668028831481934
5/20/2024 3:24:01 AM	950.9548508789862	25.600000381469727	0.633969783782959
5/20/2024 3:22:12 AM	901.80078125	25.700000762939453	0.601300520992279
5/20/2024 3:20:22 AM	852.253967851562	19.29999923790547	0.5681682957878113
5/20/2024 3:18:34 AM	803.296142578125	19.29999923790547	0.5353307459831238

Figure 16. PZEM-004T Measurement Results Displayed in Thingier.io Data Buckets

Figure 16 presents the measurement results from the PZEM-004T module as displayed in the data buckets feature of Thingier.io. The data includes the month, date, year, time, electricity cost (IDR), power (Watts), and energy consumption (kWh).



Figure 17. Condition When Power is Connected (Relay OFF)



Figure 18. Condition When Power is Disconnected (Relay ON)

The purpose of the relay testing is to verify whether the relay operates according to the programmed commands. When the relay button on the Thingier.io website is pressed, the relay functions to disconnect the connected electrical current. When the button is pressed again, the current is reconnected. The outcomes of this test can be observed in Figures 17 and 18.

IV. Conclusion

Based on the results of this research on the design of a NodeMCU and PZEM-004T-based lamp power control and monitoring system, it can be concluded that the system was successfully developed. The average control delay for switching the lamps was 1.71 seconds, while the average error rate in power measurement was 0.10%. The sensor was capable of detecting power consumption (in Watts), energy usage (in kWh), and electricity cost (in IDR), and was able to transmit the data in real time to the Thingier.io website. This platform served as the control and monitoring interface, accessible through smartphones or personal computers. The integration of the NodeMCU's Wi-Fi module greatly facilitates remote access, enabling users to control and monitor the system anytime and from anywhere. However, one limitation of the system is its dependency on a stable Wi-Fi connection to ensure continuous operation.

Despite the success of this prototype, the system still presents several areas for improvement. Therefore, the authors propose the following recommendations: First, the device should be developed for broader applications, such as implementation in larger-scale environments including office buildings and industrial settings. Second, the system could be enhanced by adding automated control features that allow the NodeMCU to manage lamp brightness or operational schedules based on real-time energy consumption data, contributing to more efficient energy use. Lastly, while Thingier.io was utilized as the web-based control platform, it is

recommended that a custom mobile application be developed to provide a more secure, efficient, and user-friendly experience.

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