Monitoring and Control System for Electrical Energy Consumption Based on The Internet of Things

Andi Syofian [a,1], Yugerita Firmance [a,2], Yultrisna [b,1*]
[a] Department of Electrical Engineering, Institut Teknologi Padang, Indonesia
[b] Department of Electrical Engineering, Politeknik Negeri Padang, Indonesia

yultrisna@pnp.ac.id,
* corresponding author

ABSTRACTS

Electrical energy consumption in the household sector is frequently uncontrolled, particularly when electronic devices are used. That is the tendency of users to forget to turn off or unplug the electronic device from the socket. In that case, modifications are made to the socket so that it can be controlled remotely via a smartphone. The hardware design uses the NodeMCU ESP8266 as a microcontroller combined with the PZEM-004T sensor module for electrical magnitude. Relay modules are used to secure the circuit in cases of higher loads. So that in the system, all three sockets can be monitored simultaneously. While the software design uses MIT App Inventor and Thingspeak Platform as servers. The data is saved in CSV format, which can be converted to Google Sheets or Microsoft Excel. Data is stored in the form of the name of the electronic equipment, the time of use, as well as voltage, current, power, cos phi, and electrical energy used. So that users can regulate the use of electrical equipment at home and reduce the waste of electrical energy. The test results showed the average faults for voltage, current, power, cos phi, and energy were 0.06%, 5.32%, 5.67%, 0.7%, and 7%, respectively.

KEYWORDS

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App Inventor, NodeMCU ESP8266, PZEM – 004T Thingspeak , Smart control

1. INTRODUCTION

Electricity has become the main human need in everyday life. PLN (National Electric Company) static data for 2021 states that PLN's electricity customers amounted to 82,543,980 or 91.71%, of the total household sector of 75,701,985 [1]. The increasing number of PLN customers causes the need for electrical energy to increase. This is due to the large use of electronic devices. But it is not known in detail which electronic equipment consumes electrical power, and PLN also has a limit on the electrical power capacity in each residential house [2].

In monitoring the use of electrical power, PLN uses a kWh meter with a prepaid system. But the disadvantage of using this kWh meter is that it still does not use a monitoring system, so electricity users monitor it manually, and this manual method usually makes users very reluctant to monitor it [3].

And excessive use of electrical power can cause electrical voltage instability. So it can pose a threat to the safety of electronic equipment. When the electric voltage often goes up and down, causing a short circuit, a large electric current surge affects the performance of the electronic equipment [2].

In technological developments, especially in the field of IoT (Internet of Things), namely utilizing the internet so that it is faster and easier to get information to help humans in work and business in various aspects of life [4][5].

One application in everyday life is a smart socket. That is a socket that can be controlled using a smartphone application that is connected to an internet connection. Making it easier to manage the use of electrical appliances at home can save electrical energy [6][7]

Research [8] using a combination of the Arduino Nano CH340 and the Wemos D1 mini as a microcontroller. In controlling the socket using a 2-channel relay. The results of the research from the tool can save electricity consumption of Rp 53,320.99 or 36,908 kWh per month in the R-1/1300 VA power tariff group.

Research [9] used a combination of an Arduino Uno with a NodeMCU ESP8266 and PZEM -004T module to read the amount of electricity. Displaying the data using a 16 x 2 LCD on the device and an application on the user's smartphone. Where data is stored, it requires an additional SD card stored in txt format The research results show that the method developed can monitor energy consumption data for electrical loads with an error value of 0.54% in the measurement voltage and a current error value of 2.93%. measurements and experienced a delay in sending data to the monitoring application on average 3 seconds.

Research [4] focuses more on developing smart socket applications that use the Wemos D1 as its microcontroller and ACS712 sensor to read current and energy consumption from connected electronic devices.

The server used to store data is Firebase. The number of sockets that can be monitored is only one. The result of his research is that users can control the consumption of electrical energy from applications on smartphones that are displayed in the form of bar graphs.

Based on the literacy study above, the research has advantages over previous research. Specifically, being able to monitor the use of three sockets simultaneously for data processing using the Thingspeak server, where the data can be stored and downloaded at any time in CSV format that can be converted to Google Sheets or Microsoft Excel. As well as the application display, users can see the voltage, cos phi, current, power, and energy consumption of each socket. With this, it can help users manage electrical energy consumption and the use of electronic devices.

2. RESEARCH METHODOLOGY

2.1. Block Diagram System

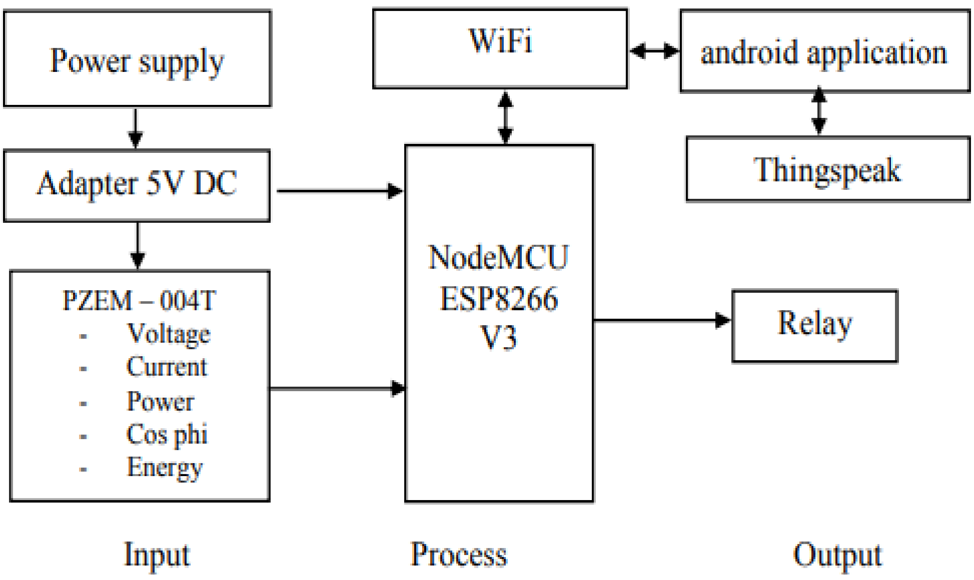

FIG 1. BLOK DIAGRAM SYSTEM

Figure 1 shows the entire system, starting from input, processing, and output. In the input of the design tool supplied from a PLN 220V AC power source, the AC is converted into 5V DC as the input voltage for the operation of the NodeMCU ESP8266. Voltage, current, power, cos phi, and energy will be measured by the PZEM – 004T module, also known as the smart sensor [10]. In the process, WI-FI serves as the communication medium of NodeMCU as well as NodeMCU as the control center of the circuit work system, which is used to control the entire circuit from input to all outputs [11]. While in the output, the data from the processing of the NodeMCU ESP8266 will be sent to the Thingspeak server and displayed in the user's Android application. And the relay will receive digital signals sent by NodeMCU ESP8266 so that it can connect and disconnect electricity and plug the circuit if there is more load on electronic devices [12][13]. The working principle of the tool in this research is shown in Figure 2.

Based on Figure 2, NodeMCU will start initializing all the components in this tool. After that, the user will determine the load that will be connected to the socket by creating the name of the connected device and pressing PB On in the application. After that, the PZEM-004T will read voltage, power current, cos phi, and energy. This data will be processed by NodeMCU and sent to the server to be displayed to the user application. Data stored on Thingspeak servers can also be downloaded in CSV format, which can be converted into Google Sheets or Microsoft Excel. When the OFF button is pressed, the relay status changes to 0 (off), and the electronic device turns off. The user will determine the relay or socket to be used via smartphone.

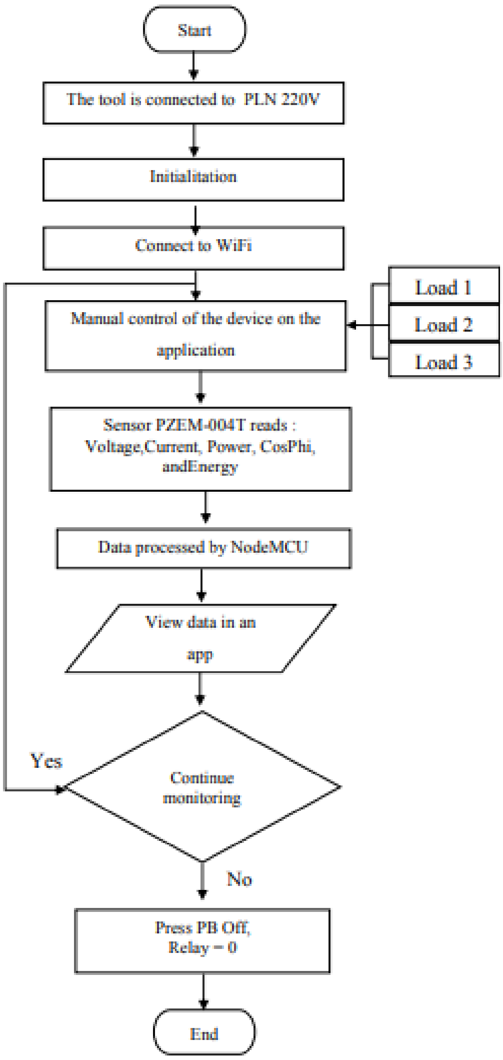

FIG 2. FLOWCHART OF THE WORKING PRINCIPLE OF THE SYNCHRONIZATION OF PLN METERING READINGS TOOL WITH THE CONTROLLING SYSTEM ON IOT-BASED SOCKETS

2.2. Hardware Design

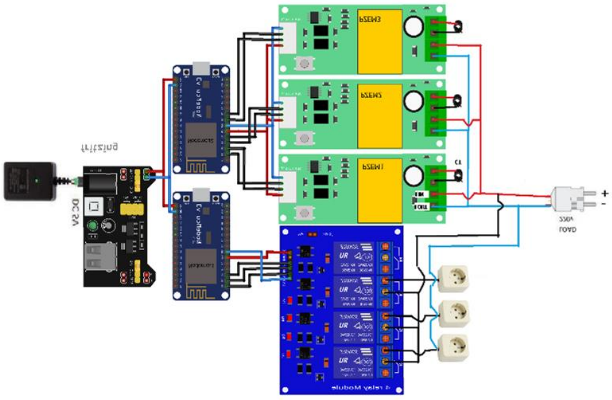

FIG 3. Schematic diagram for component connection

The schematic diagram is shown using two pieces of NodeMCU ESP8266 because one of the controllers is used as a client connected to the relay module, and another is used for wheel monitoring as a server connected to the PZEM-004T module.

2.3. Android App Display Design

The display in the application is an interface that functions to display data on the reading of electrical quantities read by the PZEM – 004T module. The app view was developed with MIT App Inventor 2. Specifically, an open-source web application with a user-friendly interface that can be accessed by Android users. In designing at MIT App Inventor, they use the method "Click & Drag".

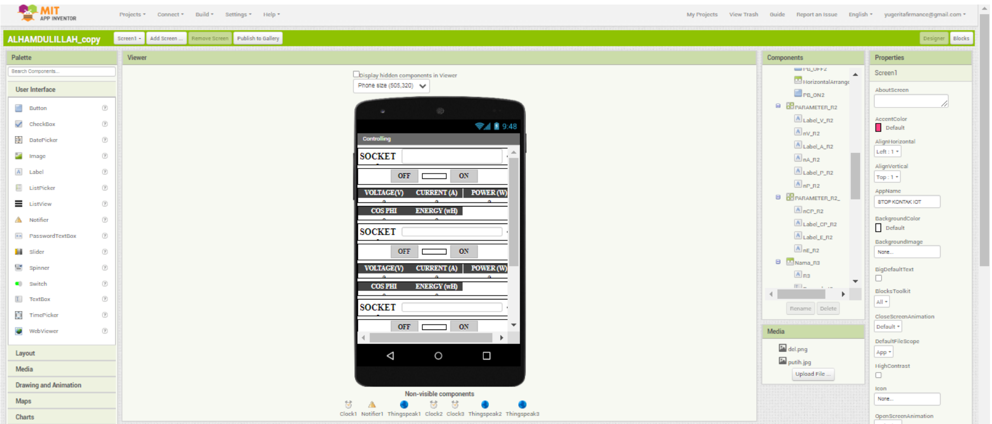

FIG 4. Android App Design Display

To get data from hardware, a database is needed that functions for connecting and storing data from monitoring design tools on a cloud server. So Thingspeak is used, which has the advantage that the data can be downloaded as a CSV file and converted into a Google Sheet or Microsoft Excel. In addition, it allows users to visualize and analyze data. MATLAB helps process and analyze data.

3. RESULTS AND DISCUSSION

Tests are carried out to determine the level of accuracy of the tool in reading electrical quantities such as voltage, current, power, and energy. By comparing the readings of the PZEM-004T module with a calibrated multimeter. The test uses three electronic devices that have different loads. While the energy test compared the number of three electronic devices read by the PZEM module – 004T with a digital kWh meter. Data collection is carried out every ten minutes for one hour. Figure 5 shows the connected system. All components are placed into a panel box with a dimension of 31 x 21 x 5.5 cm, and three sockets are placed on the outside of the panel box.

FIG 5. Tool design results

3.2. Software Development

Measurements can be monitored via smartphone. The parameters of measurement are voltage (V), current (A), power (W), cos phi, and electrical energy (Wh). The appearance of the application when it is running can be seen in Figure 6.

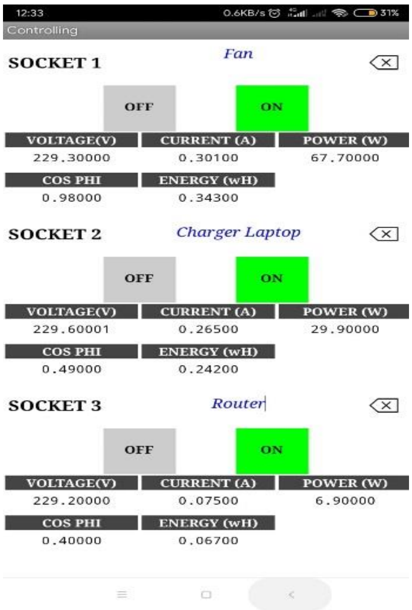

FIG 6. Application Display

And the monitoring data can also be seen on the Thingspeak server. Each socket's data is stored in one channel of server Thingspeak, as shown in Figure 7, which shows data from socket 3. In "Relay Status," if it is green, it indicates that at that time the socket is active; if it is not colored, then the socket is inactive or off.

FIG 7.. Appearance of one of the Thingspeak

Figure 8 shows the downloaded data from Thingspeak. The data stored is in the form of time when the socket is used, and the parameters measured are voltage (V), current (A), power (W), cos phi, and electrical energy (Wh). The status of the relay: 1 indicates the relay is on, and 0 indicates the relay is off. As well as the name of the electronic device that was monitored at that time. Making it easier for users to manage the use of electronic devices.

1	created_at	entry_id	Voltage (V)	Current (A)	Power (W)	Cosphi	Energy (Wh)	Status	Name of c
1652	2023-04-04T12:00:27+07:00	1651						1	Router
1653	2023-04-04T12:00:47+07:00	1652	231	0.038	0.39	3.4	0.063		
1654	2023-04-04T12:01:07+07:00	1653	231	0.036	0.37	3.1	0.063		
1655	2023-04-04T12:01:26+07:00	1654	231.10001	0.045	0.38	3.9	0.063		
1656	2023-04-04T12:01:46+07:00	1655	230.8	0.044	0.39	4	0.063		
1657	2023-04-04T12:02:05+07:00	1656	230.8	0.049	0.39	4.4	0.063		
1658	2023-04-04T12:02:25+07:00	1657	231	0.052	0.38	4.6	0.063		
1659	2023-04-04T12:02:44+07:00	1658	230.5	0.076	0.39	6.9	0.063		
1660	2023-04-04T12:03:04+07:00	1659	230.3	0.076	0.39	6.9	0.064		
1661	2023-04-04T12:03:23+07:00	1660	230	0.075	0.39	6.8	0.064		
1662	2023-04-04T12:03:43+07:00	1661	230.2	0.075	0.39	6.8	0.064		
1663	2023-04-04T12:04:03+07:00	1662	230.2	0.075	0.39	6.8	0.064		
1664	2023-04-04T12:04:22+07:00	1663	230.3	0.075	0.39	6.8	0.064		
1665	2023-04-04T12:04:42+07:00	1664	230.3	0.074	0.4	6.8	0.064		
1666	2023-04-04T12:05:01+07:00	1665	230	0.075	0.39	6.8	0.064		
1667	2023-04-04T12:05:21+07:00	1666	230	0.075	0.39	6.8	0.064		
1848	2023-04-04T13:01:42+07:00	1847	228.2	0.077	0.4	7.1	0.07		
1849	2023-04-04T13:02:02+07:00	1848	228.5	0.073	0.41	6.9	0.07		
1850	2023-04-04T13:02:21+07:00	1849	228.10001	0.073	0.41	6.9	0.07		
1851	2023-04-04T13:02:38+07:00	1850						0	

FIG 8. Data downloaded from Thingspeak

3.2. PZEM -004T Module Testing

The PZEM -004T module test compares the power current voltage reading and the PZEM – 004T read cos phi with the multimeter measurement

TABLE 1.. PZEM - 004T module testing

Burdens	Voltage (V)			Current (A)			Power (W)			Cos phi		
	PZEM -004T	Multi meter	Error %	PZEM -004T	Multi meter	Error %	PZEM - 004T	Data sheet	Error %	PZEM -004T	Multi meter	Error %
Fan	229.49	229.44	0.02	0.30	0.29	3.45	68.34	65.87	3.74	0.98	0.99	0.01
Charger Laptop	229.69	229.37	0.14	0.27	0.27	0	30.11	29.72	1.29	0.49	0.48	2.08
Router WI-FI	229.43	229.40	0.01	0.07	0.08	12.5	6.30	7.15	11.98	0.39	0.39	0
Average	0.06			5.32			5.67			0.7		

Based on the data in Table 2, the average voltage error ranges from 0.01-0.14% and the average current error ranges from 0–2.08%. Based on references, the error value is still within reasonable limits because it is less than 5%. The average current error ranges from 0–12.5%, and the average power error ranges from 1.29–11.98%. A fairly high error value occurs when testing Wi-Fi routers that have too little power, while for testing fans and laptop chargers that have large power, the average error is small. This is because the accuracy of the design tool in current readings increases as the power of electrical equipment increases. One of the causes of this error is the inaccuracy of the voltage provided in the real world. The supplied voltage value may not be exactly 220V. Another factor is the possibility of a current leak in the system that the current sensor fails to detect. The ambient temperature can also affect the accuracy of the sensor. If the temperature is getting higher, the resulting resistance will be even greater. That is, the greater the resistance, the stronger the current flowing in the circuit, which will be smaller as well. Following circuit theory, the strong relationship of electric current with resistance.

3.3. Testing of synchronization of energy readings with Digital kWhmeters

The test was carried out by adding up the energy used by the three electronic devices and comparing it with what was read by the kWh meter. Data retrieval is done every 10 minutes for 1 hour.

TABLE 2.. Energy reading testing between PZEM – 004T with digital kWhmeter

Time	design tools (Wh)			kWhmeter Digital (Wh)			Error%
	Initial meter	End meter	Difference	Initial meter	End meter	Difference	
10 minutes	0	0.014	0.014	37.265	37.252	0.013	7.69
20 minutes	0.014	0.022	0.008	37.252	37.243	0.009	11.11
30 minutes	0.022	0.030	0.008	37.243	37.234	0.009	11.11
40 minutes	0.030	0.021	0.009	37.234	37.226	0.008	12.5
50 minutes	0.021	0.013	0.008	37.226	37.218	0.008	0
60 minutes	0.013	0.006	0.007	37.218	37.211	0.007	0

Table 3 shows that in the initial minutes, there is a significant increase in energy consumption to 0.014 Wh. Within 20 to 30 minutes, power consumption begins to stabilize at 0.009. At minutes 40–60, there is a decrease in energy consumption. For more details, see the chart below:

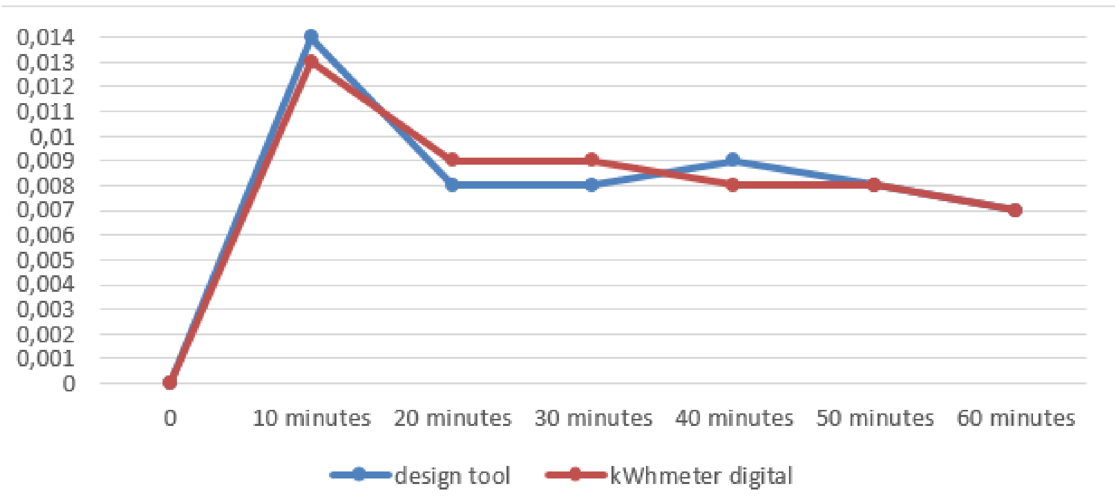

FIG 9. Comparison of energy consumption between design tools and digital kWhmeters

Table 3 shows that in the initial minutes there was a significant increase in energy consumption of up to 0.014 Wh. Within 20 to 30 minutes, power consumption started to stabilize at 0.009. At 40-60 minutes there was a decrease in energy consumption. For more details, see the graph shown in Figure 9.

4. CONCLUSIONS

The design tool is capable of monitoring and controlling three sockets simultaneously. The measurement data states that the average voltage error ranges from 0.01–0.14% and the average cosmic error ranges from 0–2.08%. The average current error ranges from 0–12.5%, and the average power error ranges from 1.29–11.98%. A fairly high error value occurred in tests of Wi-Fi routers that had too little power, while the average error for energy was 7%. And in data processing using Thingspeak, which can store and download the data, Thus helping users measure the consumption of electrical energy connected to the socket. For further research, it is necessary to add additional sensors, such as PIR or ultrasonic sensors that can detect human movement, to turn off electronic devices that are not directly used.

REFERENCES

[1] PT PLN, "Statistik PLN 2021," *Stat. PLN 2021*, vol. 01001–2206, no. Juni, pp. 49–58, 2021.

[2] A. W. O. Muhammed *et al.*, "Design and Implementation of an IoT Based Home Energy Monitoring System," *Proc. 5th Int. Conf. Inf. Technol. Educ. Dev. Chang. Narrat. Through Build. a Secur. Soc. with Disruptive Technol. ITED 2022*, no. November, 2022, doi: 10.1109/ITED56637.2022.10051192.

[3] M. Prathik, K. Anitha, and V. Anitha, "Smart energy meter surveillance using IoT," *Proc. Int. Conf. Power, Energy, Control Transm. Syst. ICPECTS 2018*, pp. 186–189, 2018, doi: 10.1109/ICPECTS.2018.8521650.

[4] K. ELORBANY, C. BAYILMIŞ, and S. BALTA, "A Smart Socket Equipped With IoT Technologies for Energy Management of Electrical Appliances," *Sak. Univ. J. Comput. Inf. Sci.*, vol. 4, no. 3, pp. 347–353, 2021, doi: 10.35377/saucis...863272.

[5] N. Nuryawan and M. Jannah, "Electrical Energy Monitoring and Control System In Boarding Rooms Based On The Internet of Things," *Int. J. Eng. Sci. Inf. Technol.*, vol. 2, no. 4, pp. 76–83, 2022, doi: 10.52088/ijesty.v2i4.335.

[6] M. H. Yaghmaee and H. Hejazi, "Design and Implementation of an Internet of Things Based Smart Energy Metering," *2018 6th IEEE Int. Conf. Smart Energy Grid Eng. SEGE 2018*, pp. 191–194, 2018, doi: 10.1109/SEGE.2018.8499458.

[7] A. Pandoh, A. S. Wasekar, S. Sarkar, and A. B. Thakur, "Smart Electricity Meter Monitoring and Prediction using iSocket," *2021 7th Int. Conf. Adv. Comput. Commun. Syst. ICACCS 2021*, pp. 211–216, 2021, doi: 10.1109/ICACCS51430.2021.9442011.

[8] A. W. Atmoko *et al.*, "ELECTRIC VAMPIRE REMOVER BERBASIS IOT UNTUK MENGATASI VAMPIR LISTRIK PADA," vol. 1, no. 2, pp. 115–124, 2021.

[9] E. Sorongan, R. Kango, and S. Suhaedi, "The Application of Energy Management Systems Using the Internet of Things to Improve the Efficiency of Electrical Energy Usage in the MSMEs Sector," *PROtek J. Ilm. Tek. Elektro*, vol. 10, no. 1, p. 26, 2023, doi: 10.33387/protk.v10i1.5042.

[10] Muliadi, M. Y. Fahrezi, I. S. Areni, E. Palantei, and A. Achmad, "A Smart Home Energy Consumption Monitoring System Integrated with Internet Connection," *2020 IEEE Int. Conf. Commun. Networks Satell. Comnetsat 2020 - Proc.*, vol. 5, pp. 75–80, 2020, doi: 10.1109/Comnetsat50391.2020.9328960.

[11] R. S. Hariharan, R. Agarwal, M. Kandamuru, and H. Abdul Gaffar, "Energy consumption monitoring in smart home system," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1085, no. 1, p. 012026, 2021, doi: 10.1088/1757-899x/1085/1/012026.

[12] I. Bagus, G. Purwania, I. N. S. Kumara, and M. Sudarma, "Application of IoT-Based System for Monitoring Energy Consumption," *Int. J. Eng. Emerg. Technol.*, vol. 5, no. 2, pp. 81–93, 2020, [Online]. Available: https://ojs.unud.ac.id/index.php/ijeet/article/view/60487.

[13] K. Luechaphonthara and A. Vijayalakshmi, "IoT based application for monitoring electricity power consumption in home appliances," *Int. J. Electr. Comput. Eng.*, vol. 9, no. 6, pp. 4988–4992, 2019, doi: 10.11591/ijece.v9i6.pp4988-4992.