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DESIGN A MONITORING SYSTEM OF A SINGLE-PHASE ELECTRICITY METER BASED ON THE INTERNET OF THINGS

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ABSTRACT

This research aims to create systematic monitoring of a single-phase electricity meter that is accompanied by power monitoring features, the amount of electrical energy usage costs and relay control features using internet connections. The design has been carried out using PZEM-004T current and voltage sensors. The microcontrollers have been implemented by using ESP8266. This configuration is to reduce separate micro-controller. The embedded microcontroller and WiFi are made improvements from previous research. This embedded microcontroller is used to send data to the internet through WIFI. This monitoring system can then be accessed using the Cayenne interface. The test results of this tool show that the connection between the microcontroller and the Cayenne application works well through an internet connection. With this tool, users can see real-time data on the use of electrical energy and its cost, as shown in the cayenne dashboard. The voltage sensor test results show an average accuracy is 99.17%. The current sensor testing has an average accuracy rate of 96.9%. On average, the wattage delta between the cayenne dashboard and multimeter measurement is 2.16 watts.

Keywords: monitoring system, single-phase electricity meter, internet of things

INTRODUCTION

The current use of electric power only uses a KWH meter measuring instrument to see the power distributed by PLN (State Electricity Company). These tools cannot show a detailed amount of information about how much electricity is used. This can be a waste of electricity because there is no direct supervision of electricity consumption. Therefore, a tool is needed to monitor electric power's use directly, which can be monitored remotely using an android application through the Internet of Things (IoT) system [1].

The previous research that has been done is related to this research via SMS [2]. This method used ACS 712 current sensor, Arduino UNO microcontroller, and HP GSM. Further related research was based on Arduino Mega2560 Using the WEB [3], while the components used in this study were the Arduino Mega2560 microcontroller plus the ESP8266 WiFi module, with an Energy meter HR230 Modbus.

The development of the IoT concept in line with Android applications can be used to display electrical power parameters, especially electronic equipment. Such as the use of the Andromax M2Y modem, which is used as a medium for the control and monitoring system of electrical devices based on wireless networks [4]. Similar systems have also been created using third-party IoT applications such as Thing speak [5, 6]. The development of this system can also be done by integrating the concept of a Wireless Sensor Network (WSN), where several sensor points are embedded [6]. This system can be designed from the hardware side using voltage sensors, current sensors, LCDs, microcontrollers, WiFi modules, computers, and smartphones [7]. IoT-based monitoring systems can also be applied to smart homes [8, 9]. This system is implemented using communication protocols such as WSN and Power Line Communication (PLC). The home electrical device control system sends data from the controlled device via the internet on a smartphone. Such as the NodeMCU microcontroller is used to control the ON-OFF conditions of electrical equipment and can also send power data to the database server [10]. Using a web system, Nandi, Mungurwadi, and Mannur [11] demonstrate the instantaneous electrical equipment use. Real-time data aids in remotely monitoring and comprehending household consumption. Therefore, altering behavior is a viable method for managing consumption. The writers created a prototype. They utilized a variety of sensors, including the SCT-013. In the essay, it was easy to see that only the design aspects Immediately gathered data were displayed on the screen.

To continue and improve the previous research, the researcher made the main difference in this study: the microcontroller used. We only use one microcontroller module, namely NodeMCU ESP8266. This ESP8266 in this research is connected to WiFi and is a controller for energy meter consumption. In addition, the control of the load (light/ fan, etc.) can be managed by an Android cellphone/laptop. This solution reduces component and power consumption as well.

The electrical power consumption monitoring system is designed to obtain data related to measuring electrical parameters, including current, voltage, and power, in real time. The measurement of electrical power parameters is usually carried out using simple instrumentation, and the data collection process is still manual, so the data obtained cannot be obtained at any time, and the results are too long to obtain.

METHOD

This research went through several steps: device/sensor installation, application preparation, connectivity test, interfacing hardware to software, data reading test, measurement, and analysis. The application used in this study is an IoT dashboard that can be accessed with a web browser and built using Cayenne software. At the connectivity test step, it is ensured that all software and tools can function correctly.

The purpose of using IoT in this system is to simplify the calculation of the use of electrical energy while reducing energy waste and increasing the efficiency, security, and sustainability of the electric power system.

A. Hardware design

The working principle of the proposed system can be explained as follows (please refer to FIGURE 1):

1. The source of electricity voltage comes out from PLN. Voltage sensing by using the PZEM004 sensor.
2. The PZEM004 measures voltage and current. The data output goes to the Node MCU ESP8266 to process, and also the output voltage goes to the AC to DC converter so that it produces a DC voltage as a power source for the ESP8266,
3. Output Node MCU ESP8266 will connect to two relay channels to control (loads one and two). The loads will be tripped when the current event exceeds the set value.
4. The zero-crossing technique is used for sensing frequency.
5. Voltage and current signals are used for power factor estimation.
6. The Cayenne API needs to access by ESP8266 via the internet by accessing the cayenne web.
7. The power, voltage, current, power factor, and cost of power consumption can be monitored from the dashboard of the Cayenne application in the form of graphics or numeric.

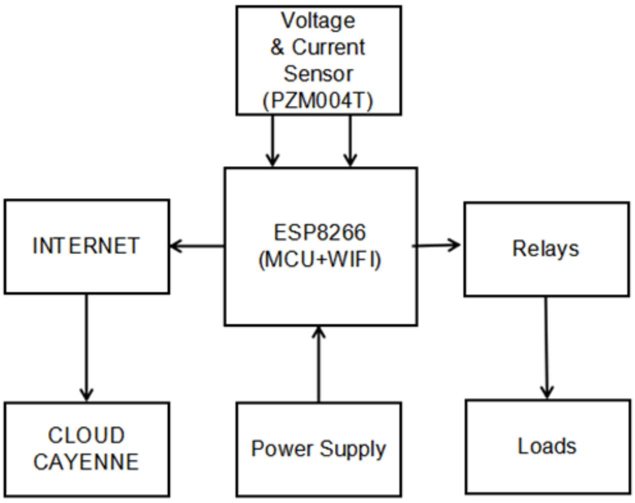


FIGURE 1. Block diagram proposed system.

Current sensors and voltage sensors are embedded. This sensor measures voltage and current. With these two parameters, we can obtain how much electrical power is being used. As a user interface, cayenne is designed to display data in real time. The PZEM004 sensor is specifically designed to measure current and voltage parameters with a maximum range of up to 100A with an output value of 0-100A. It can measure electrical voltages ranging from 80-260VAC with an active transformer system feature, is compatible with Arduino or AVR micro-controllers, and can be directly connected to a 220V power source. Arduino ESP8266, in this design, acts as a signal processor and performs power and cost calculations. Where the data is taken from the sensor which is an analog signal translator into a digital signal which will then be processed to transmit data according to the program code that was designed previously. ESP8266 is equipped with WiFi to communicate with the outside world/Internet, in this case, the Cayenne cloud.

B. Software design

The software design step can be divided into two parts, including the process in the database server section and the process in the application interface. The first stage of designing this system software is initialization by creating an IP address and host. Then make sure either the cayenne can connect or not. If it is not connected, then it is reconnected. It can receive data and send it to the database server if it is connected. If the data has been sent to the database server, then the data is stored in the table provided on the Cayenne database server. FIGURE 2 shows how the ESP8266 sends the data to the cloud and the user request to process and display result data to the cloud cayenne dashboard.

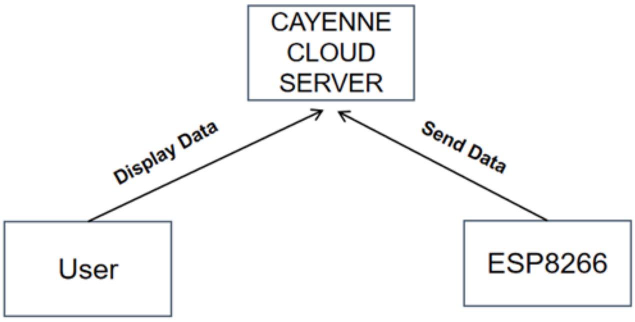


FIGURE 2. Request display and send data measurement result.

The second step is to perform initialization the form of a username field and password. After that, it will enter the dashboard, which can display a graph of the monitoring results. The data results will be sent to the database via an internet connection.

The flow of sending and accessing the data can be seen in FIGURE 2. The measurement data will be sent from the ESP8266 to the cayenne web server via an internet connection. Then the user can access the data measurements through the internet. There are two categories monitoring and controlling the appliances.

FIGURE 3 presents the monitoring system feature, where it first reads the current status and then calculates the current, voltage, and total power consumption. These estimations can be monitored in the Cayenne dashboard and the Cayenne mobile apps.

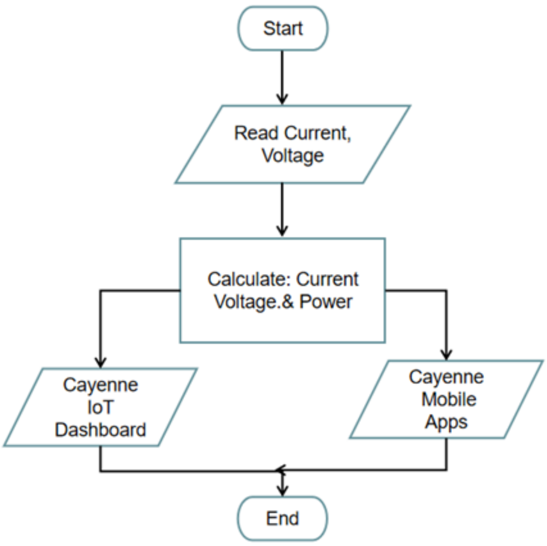


FIGURE 3. Flowchart of Monitoring

FIGURE 4 shows the flowchart of the control system feature, enabling the appliances to read the current and check its limit. If the expected current exceeds the limit, it sends the notifications to the relay operation.

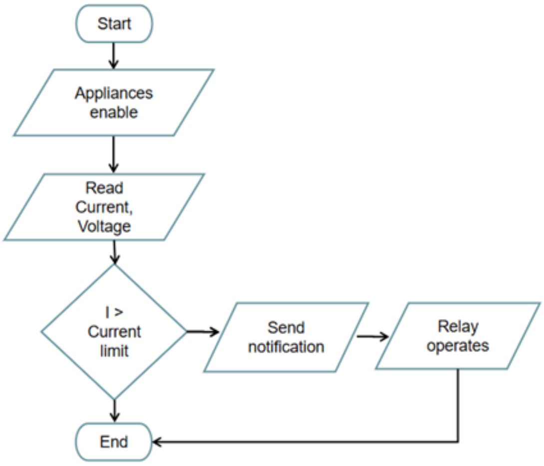


FIGURE 4. Flowchart of Monitoring

The Cayenne dashboard, as shown in FIGURE 5, will be displayed in the time, current, voltage, power, and graphs format. The software required is a C programming language compiler to program on the ESP8266. The compiler is contained in the software, namely Arduino IDE. The library used in the Arduino IDE is the esp8266wifi library.

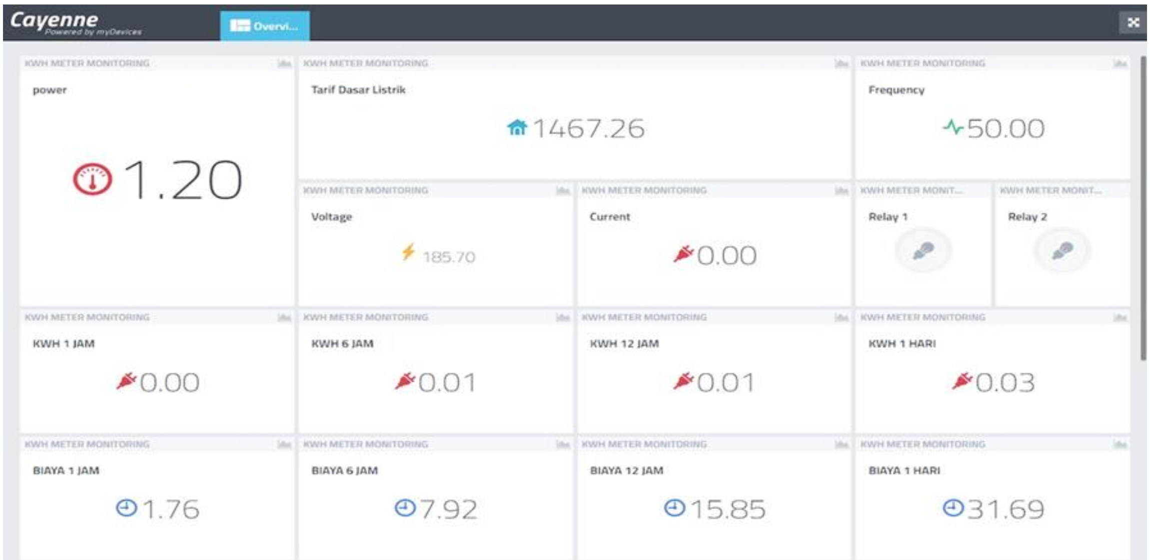
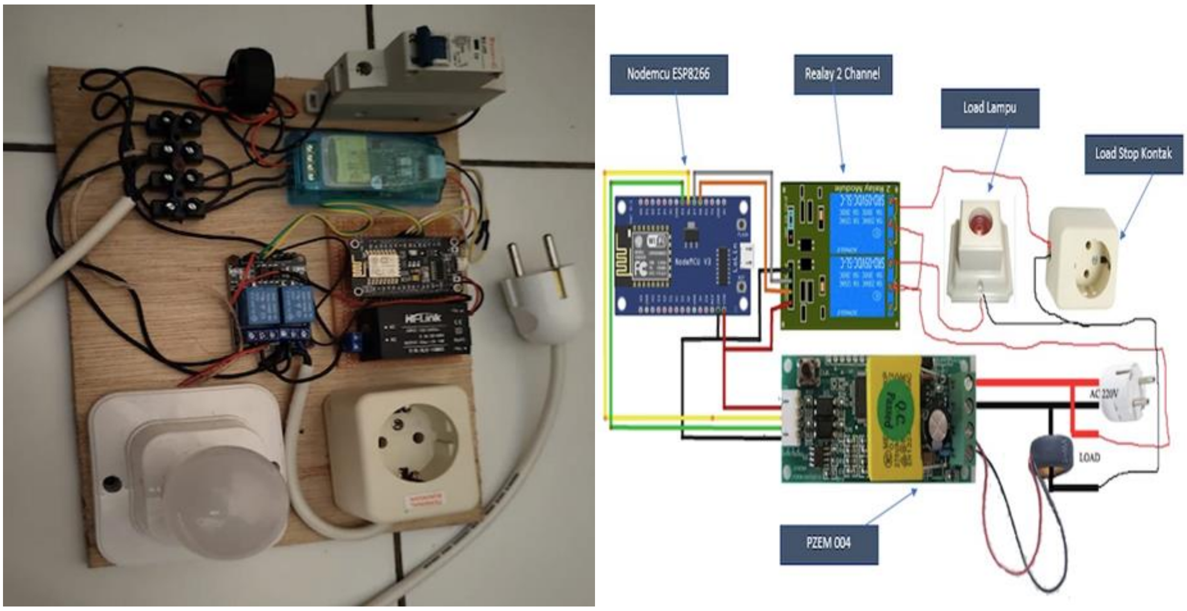


FIGURE 5. Cayenne dashboard of the proposed system.

The cayenne provides Application Programming Interfaces (API) to assist the process of collecting data and turning it into a form of information. The design of the Cayenne program is done by entering the variable ID and token code on the cayenne. Variable ID is used to read variables that have been created on the cayenne. The data displayed and stored in this study was only for 25 minutes. This system can only monitor for the next 25 minutes without saving data.

RESULT AND DISCUSSION

FIGURE 6 (a) and (b) show the proposed system monitoring hardware implementation. Furthermore, the system is tested to find out its performance. The current, voltage, and power will measure and compare among multimeter readings and dashboard reading from cayenne. Other measurements and checking also will be done for software integration.



(a) (b)

FIGURE 6. (a) The prototype of the single-phase electrical meter monitoring system, (b), The connection module of the single-phase electrical meter monitoring system.

PZM-004T Voltage Sensor Measurement

The measurement of the PZM-004T sensor is aimed to find out how much the voltage is based on manual measurement from a multimeter compared to the result in the cayenne dashboard. TABLE 1 shows the test results of the PZM-004T sensor. Based on the test results, the value obtained from the PZM-004T sensor reading is not too far off in accuracy compared to the measurement results from the Voltmeter. The average of accuracy is 99.17%. This result if we compare to [12]: the result is 98.2%, it is not much different. In comparison to [13], the average accuracy is 98%. Although a different type of voltage sensor can be caused the value differently. in terms of sensitivity of the sensor and other environmental parameters such as characteristics of appliances, voltage source, and also the speed of connectivity to server can become a factor.

The main system parameters used for the performance evaluation and calculation are discussed here. The residential voltage rating with the configuration where the voltage levels from the 220 - 240 Volt for a single-phase is quite stable as refers to a standard range of power electric company of single-phase electricity.

TABLE 1. Real-time voltage measurement from cayenne dashboard vs. volt meter.

Voltage Measurement			
Time	**Volt Meter**	**Sensor PZM-004T**	**Accuracy**
10:00	226.6	225.9	99.69%
10:15	220.4	219.3	99.50%
10:30	221.3	220.9	99.82%
10:45	218.5	219.6	99.50%
11:00	222.2	219.9	98.96%
11:15	223.7	219.4	98.08%
11:30	227.4	224.9	98.90%
11:45	220.4	218.7	99.23%
12:00	222.3	220.9	99.37%
12:15	217.5	221.6	98.15%
12:30	221.8	219.9	99.14%
12:45	223.5	222.8	99.69%
Average	**222.1**	**221.2**	**99.17%**

PZM-004T Current Sensor Measurement

Alike in the voltage sensor measurement, the current sensor measurement aims to find out how the readings from the current sensor are. The current sensor reading data is also compared with the Ampere meter measurement data. The PZM-004T current sensor test results are shown in TABLE 2. You may see the average accuracy from several measurements is 96,9%. This resulting number compared to [12] is 95.66%, and compared to [12] is 93%,

The crucial part of household appliances is not on the voltage but on the current view. Current is the electrical charge which carries flow in spesific time. A simple way of defining this concept is that current is a charge over time. Current can be categorized into direct current (DC) and alternating current (AC). The DC flows only in one direction, whereas the AC periodically changes in direction.

The root means square (RMS) current is used in the calculation because the AC constantly changes its value. The RMS current is calculated as follows:

$$I_{rms} = \frac{I\ max}{\sqrt{2}} \qquad (1)$$

where I_{rms} is the RMS of the current in Ampere, and I_{max} is the maximum value of current in Ampere.

The other important parameter in the proposed system is power consumption. The power is an electrical energy flow for the unit of time. It can also be multiplying voltage, current, and power factors. EQUATION 2 and EQUATION 3 show the formula for power.

$$P = V\ I\ Cos\ \theta \qquad (2)$$

$$Z = V\ I\ Cos\ \theta \qquad (3)$$

where

P = power in Watt, I = current in Ampere, cos θ = power factor, and Z is the system's impedance. Voltage and power factors are assumed in our proposed system, which is fixed to 220 Vac and 90%, respectively. This values are the nominal value for residential areas. All the values are followed the active power.

TABLE 2. Real-time current measurement from cayenne dashboard vs. ampere meter.

	Current Measurement		
Time	**Ampere Meter**	**Sensor PZM-004T**	**Accuracy**
15:00	1.43	1.41	98.6%
15:15	1.33	1.31	98.5%
15:30	1.39	1.33	95.7%
15:45	1.32	1.29	97.7%
16:00	1.35	1.31	97.0%
16:15	1.26	1.22	96.8%
16:30	1.29	1.23	95.3%
16:45	1.27	1.19	93.7%
17:00	1.28	1.25	97.7%
17:15	1.21	1.19	98.3%
17:30	1.25	1.21	96.8%
17:45	1.22	1.18	96.7%
Average	**1.3**	**1.3**	**96.9%**

ESP8266 Measurement

The accessing process of the ESP8266 WiFi Module with Cayenne was done in Web Server. The proposed system was tested with the cayenne. This system use the WiFi module receive and transmit the data from the PZM004 sensors and ESP8266. The beginning step was to sign up for the Cayenne account to own the system. Then, the channel is created to know the amount of data to be monitored. For the Arduino IDE, enter the esp8662wifi program. The IP addresses of computers with ESP8266 must be matched for a single network. If the ESP8266 works well, the Arduino IDE serial monitor will display connected. The ESP8266 test aims to determine whether the measurement results can be properly connected to the internet. FIGURE 7 show is the integration through Cayenne API.

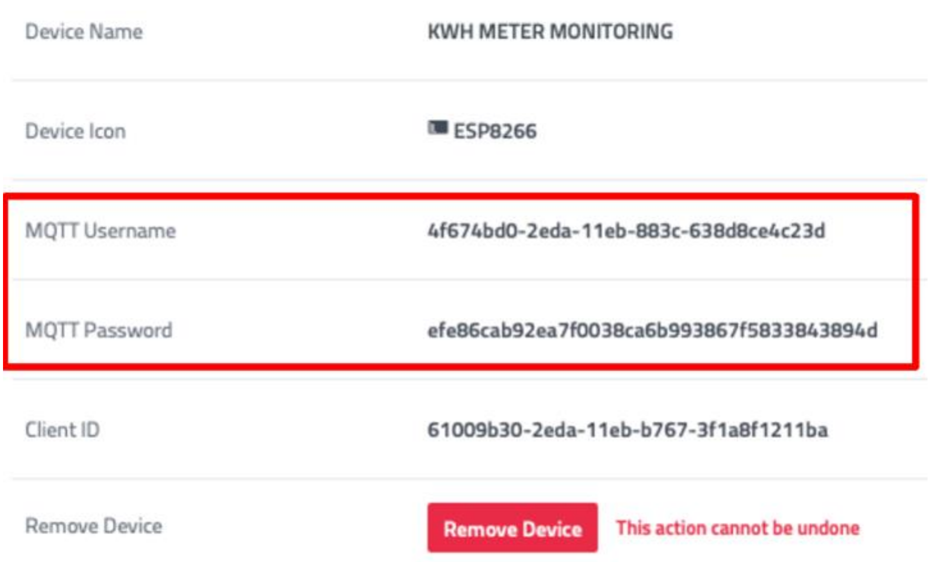


FIGURE 7. Cayenne API setting of the proposed system.

Cayenne Measurement

The cayenne interface testing is carried out to determine the displayed voltage, current, and power. The results of this interface device display can be seen in TABLE 3 based on the cayenne dashboard.

TABLE 3. Measurement result based on cayenne dashboard.

	Appliances	Relay 1	Relay 2 (LED 2.5w)	Cayenne Dashboard				
				Voltage (V)	Current (A)	Power Factor	Freq (Hz)	Power (watt)
1	Hair Dryer (350W)	ON	ON	229.1	0.83	0.84	50.00	153.96
2	Hair Dryer (350W)	ON	OFF	228	0.83	0.84	49.90	158.96
3	Hair Dryer (1400W, low mode)	ON	ON	228.3	1.39	0.56	50.00	177.71
4	Hair Dryer (1400W, low mode)	ON	OFF	227.8	1.32	0.57	50.00	171.40
5	Dispenser (350W)	ON	ON	229.7	1.63	1	50.00	374.41
6	Dispenser (350W)	ON	OFF	229.6	1.62	1	50.00	371.95
7	Hair Dryer (1400W), high mode	ON	ON	224.3	5.98	1	50.00	1341.31
8	Hair Dryer (1400W), high mode	ON	OFF	223.8	5.96	1	50.00	1333.85
9	Water pump (325W)	ON	ON	229	0.44	0.53	50.00	53.40
10	Water pump (325W)	ON	OFF	228.2	0.45	0.59	50.00	60.59

TABLE 4 is a manual measurement using a multimeter.

TABLE 4. Measurement result based on Multimeter.

	Appliances	Relay 1	Relay 2 (LED 2.5w)	Multimeter				
				Voltage (V)	Current (A)	Power Factor	Freq (Hz)	Power (watt)
1	Hair Dryer (350W)	ON	ON	229	0.81	0.83	50	153.96
2	Hair Dryer (350W)	ON	OFF	228	0.82	0.84	49.9	157.05
3	Hair Dryer (1400W, low mode)	ON	ON	227.9	1.38	056	50	176.12
4	Hair Dryer (1400W, low mode)	ON	OFF	227.8	1.32	0.57	50	171.40
5	Dispenser (350W)	ON	ON	229.6	1.62	1	50	371.95
6	Dispenser (350W)	ON	OFF	229.6	1.63	1	50	374.25
7	Hair Dryer (1400W), high mode	ON	ON	224	5.96	1	50	1335.04
8	Hair Dryer (1400W), high mode	ON	OFF	223.6	5.96	1	50	1332.66
9	Water pump (325W)	ON	ON	228.7	0.44	0.53	50	53.33
10	Water pump (325W)	ON	OFF	228.5	0.45	0.59	50	60.67

TABLE 5 is shown the delta between the cayenne dashboard and manual measurement. Variant appliances performed subsequent tests to determine whether the cayenne interface could display power data correctly. This comparison shows that the difference is 2.16 Watt as average from variant appliances load. This 2.16 Watt compared to [12] is 2.42 Watt, compared to [13] is 0.15 Watt. The proposed system has some improvements compared to previous research [12]. The [13] has Modbus SDM230, which has more accuracy and better sensitivity compared to PZM004.

TABLE 5. Delta Measurement Cayenne dashboard vs. Multimeter

	Appliances	Relay 1	Relay 2 (LED 2.5w)	Delta				
				Voltage (V)	**Current (A)**	**Power Factor**	**Freq (Hz)**	**Power (watt)**
1	Hair Dryer (350W)	ON	ON	0.1	0.02	0.01	0.00	5.77
2	Hair Dryer (350W)	ON	OFF	0	0.01	0.00	0.90	1.92
3	Hair Dryer (1400W, low mode)	ON	ON	0.4	0.01	0.00	0.00	1.59
4	Hair Dryer (1400W, low mode)	ON	OFF	0	0	0.00	0.00	0.00
5	Dispenser (350W)	ON	ON	0.1	0.01	0.00	0.00	2.46
6	Dispenser (350W)	ON	OFF	0	0.01	0.00	0.00	2.30
7	Hair Dryer (1400W), high mode	ON	ON	0.3	0.02	0.00	0.00	6.27
8	Hair Dryer (1400W), high mode	ON	OFF	0.2	0	0.00	0.00	1.19
9	Water pump (325W)	ON	ON	0.3	0	0.00	0.00	0.07
10	Water pump (325W)	ON	OFF	0.3	0	0.00	0.00	0.08
	Average			**0.17**	**0.008**	**0.001**	**0.09**	**2.16**

Real-time Measurement

TABLE 6 shows real-time monitoring with a load in the form of a 400W electric iron at 8.21 PM Jakarta time. The data displayed on the cayenne dashboard is in the form of voltage, current, and electrical power values. It takes to display the amount of electricity is about 2-3 seconds.

From TABLE 6, it is found that the voltage and current tables displayed on the cayenne each produce a value of 224.70 V and 1.76A. Thus, the power consumption displayed on cayenne is 395.47W.

TABLE 6. Real-time monitoring of electric iron (400W).

Time	Current (A)	Voltage (V)	Power (W)
20: 21: 10	1,77	223.45	395.51
20: 21: 12	1,75	225.55	394.71
20: 21: 14	1,76	224.70	395.47
20: 21: 17	1,78	221.65	394.54
20: 21: 19	1,73	220.95	382.24

CONCLUSION

The design monitoring system for the single-phase electricity meter has been successfully designed and implemented. The system is designed to monitor electrical power consumption in real time on the cayenne interface. The methodology and processes are designed and created to provide a valuable and crucial solution in a monitoring system. This research can be a learning medium about the use of the embedded module of microcontroller and WiFi connectivity. The proposed system was performed better in measuring and monitoring the current, voltage, and the power consumption. This is caused by the proposed system considered the system process design with the hardware selection of the ESP8266 WiFi module, PZM-004T current and voltage sensors, and relays. The overall communication done through the WiFi module to the data display on cloud servers, cayenne. The data are also monitored in real-time and historically stored in the cloud database. This system produces a 2.16 Watt difference between manual measurements and the cayenne dashboard. The average voltage accuracy rate is 99.17%, and the average current accuracy rate is 96.9%, which can display data in graphs and tables. System measurement data is displayed on the interface device every 2-3 seconds. Further research is needed to develop this system, such as optimizing sensor data retrieval to produce sinusoidal voltage and current signals.

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REFERENCES

[1] J. Jokanan *et al*., “Rancang Bangun Alat Monitoring Daya Listrik Berbasis IoT Menggunakan Firebase Dan Aplikasi,” *JURNAL TEKNIK ELEKTRO*, vol. 11, no. 1, pp. 47-55, 2022, https://doi.org/10.26740/jte.

[2] A. Tanjung *et al*., “Prototipe Sistem Monitoring Daya Pada Kwh Meter 1 Phase Dan Sistem Kontrol On/Off Via SMS Module,” *Tek Elektro Umr. Published online*, pp. 1-7, 2017.

[3] G. Herandy and B. Suprianto, “Monitoring Biaya Dan Pengukuran Konsumsi Daya Listrik Berbasis Arduino Mega 2560 Menggunakan Web,” *Jurnal Teknik Elektro*, vol. 8, no. 3, 2019.

[4] T. D. Hendrawati, Y. D. Wicaksono and E. Andika, “Internet of Thingns: Sistem Kontrol-Monitoring Daya Perangkat Elektronika,” *JTERA (Jurnal Teknologi Rekayasa)*, vol. 3, no. 2, 2018.

[5] I. S. Hudan and T. Rijanto, “Rancang Bangun Sistem Monitoring Daya Listrik Pada Kamar Kos Berbasis Internet of Things (IoT),” *Jurnal Teknik Elektro*, vol. 8 no. 1, 2019.

[6] D. Handarly and J. Lianda, “Sistem Monitoring Daya Listrik Berbasis IoT (Internet of Things),” *JEECAE (Journal of Electronic Control and Automatic Engineering)*, vol. 3 no. 2, 2018.

[7] I. G. P. M. E. Putra, I. A. D. Giriantari and L. Jasa, “Monitoring Menggunakan Daya Listrik Sebagai Implementasi Internet of Thing Berbasis Wireless Sensor Network,” *Majalah Ilmiah Teknologi Elektro*, vol. 16 no. 3, pp. 50-55, 2017.

[8] R. Bharathi, M. E. Madhushee and P. Kumari, “Power Consumption Monitoring System Using IoT,” *International Journal of Computer Application*, vol. 173, no. 5, 2017.

[9] D. Mocrii, Y. Chen and P. Musilek, “IoT-Based Smart Homes: A Review of System Architecture, Sofware, Communication, Privacy and Security,” *Internet of Things*, vol. 1, no. 2, 2018.

[10] F. Alfaris, A. Juaidi and F. Manzano, “Intelligent Homes’ - Technologies to Optimize the Energy Performance for The Net Zero Energy Home,” *Energy and Buildings*, vol. 153, pp. 262-274, 2017.

[11] Nandi *et al*., “IoT Based Single -Phase Energy Meter and Monitoring System,” *i-manager’s Journal on Embedded Systems*, vol. 7, no. 1, p. 37, 2018, 10.26634/jes.7.1.14568.

[12] R. Fernando, I. G. P. D. Wibawa and C. Ekaputri, “Sistem Kendali dan Monitoring Penggunaan Daya Listrik Pada Perangkat Listrik Rumah Berbasis IoT,” *E-Proceeding of Engineering*, vol. 5, no. 3, 2018.

[13] G. Herandy and B. Suprianto, “Monitoring Biaya Dan Pengukuran Konsumsi Daya Listrik Berbasis Arduino Mega 2560 Menggunakan Web,” *Jurnal Teknik Elektro*, vol. 8, no. 3, 2019.