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Applications of energy monitoring using the IoT

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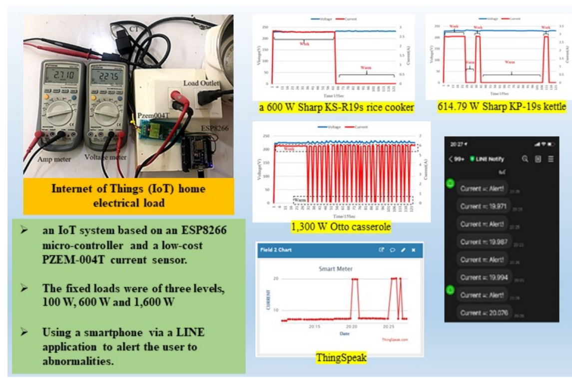
Abstract

This paper presents electrical energy measurement and monitoring for an Internet of Things (IoT) home electrical load. Energy monitoring included design, experimentation, and implementation of an IoT system for this purpose. The application used an IoT system based on an ESP8266 micro-controller and a low-cost PZEM-004T current sensor. The ESP8266 has general-purpose pins and a built-in Wi-Fi chip system. Electrical energy was displayed on a smartphone and the data was saved to a cloud system. Experimental results consisted of fixed and variable loads. The fixed loads were of three levels, 100 W, 600 W and 1,600 with respective average errors of 0.004%, – 0.31%, and – 0.57%. The current of the variable load was higher during heating and was reduced when the device was serving to keep its sample warm. Measurements of voltage, current and total electrical power data of various loads were recorded and displayed. These values were monitored using a smartphone via a LINE application to alert the user to abnormalities. The system has the advantages of being user-friendly, simple, and inexpensive.



Keywords: Energy monitoring; Internet of Things; IoT; ESP8266

1. Introduction

Currently, the Internet of Things (IoT) is widely used. The IoT is defined by the International Telecommunication Union (ITU) as a communication network that connects communication devices, electrical appliances, vehicles, buildings, or construction equipment. Software, sensors, and network interconnections are embedded in electronics to facilitate the devices, measure and store electrical readings or exchange information [1]. The term "Things" in the IoT term refers to an inclusive definition of communication devices and electric appliances such as fans, refrigerators, air conditioners, and rice cookers to aviation systems, water supply valves, small, embedded circuit boards in livestock, smart-building design for electrical power management in buildings [2], or a monitoring systems of solar cell panels [3]. Various channels have been implemented to link IoT networks [4]. These include short-range devices such as Wi-Fi, Bluetooth, Z-Wave, and ZigBee. They also include mobile phone networks like NB-IoT and LTE-M, LPWAN, in addition to LoRaWAN, SigFox and Ingenu via a satellite network or application of the IoT to monitor electrical power for energy conservation and surveillance systems [5].

There are many research studies about IoT energy monitoring to determine the status of smart-electrical appliances in residences or buildings. They display the real-time status of equipment and immediately report energy usage. These studies [6 – 8] proposed smart-meter design systems for measuring energy. They were designed and developed on the GSM network to display results, collect data, manage power and report to users. Additionally, Primicanta, Mohd Yunus, and Awan [9] presented a technique using the GSM network with ZigBees to monitor power and provide data for energy management employing a sensor to measure electrical current and voltage with an inexpensive PZEM-004T. Measurements and results were displayed on an ESP8266 WeMos D1. Likewise, Chooruang and Meekul [10] suggested a communication system for voltage results using a Wi-Fi that sent and received information with an MQTT protocol which indicated power management and included a real-time display. Moreover, Patil, Patil, and Khude [11] introduced a system for electrical power monitoring using a smart meter consisting of an Atmega328p microcontroller and a Wi-Fi module. Their technique presented an electrical power monitoring unit and a money transfer system for paying electric bills via the Internet. Furthermore, a notification was sent to the user if their electricity consumption reached a pre-determined limit. Additionally, an electricity theft prevention system was improvised using the current balance method. Mathur and Kalbande [12] introduced the use of a NodeMCU, which is a four-channel relay module and a Blynk App to connect Android devices that used this module. This was done to quickly control, record and compute electrical power usage and send electric bills via a cloud system. Fernando and Perera [13] presented the use of a smartphone to display the results of electrical system measurements and inspection as well as the amount of electrical power used via Firebase to store data and support the user. Moreover, Mulliadi *et al.* [14] proposed a monitoring technique for the use of electrical power in a house using an ESP8266 micro-controller and a PZEM- 004T sensor. They discovered that the PZEM-004T could measure the current and voltage with an acceptably low error. Additionally, Velasquez, Tobar-Andrade and Cedeno-Campoverde [15] suggested a technique using a Fiware platform to collect electrical power and temperature data and send alerts in emergency cases via FIWARE-Orion and FIWARE-Draco.

The current research proposes applications of energy monitoring using the IoT with hardware, software, a NodeMCU ESP8266 and a PZEM-004T to measure the voltage and current, compute the electrical power, collect, and deliver the data concerning electrical power usage with the Blynk application, display real-time results and control the device via the Internet (Wi-Fi) using a LINE application. This was done to facilitate user monitoring during home emergencies and simultaneously send multiple messages to alert the user to anomalies. After this introductory section, research materials and methodology, results and discussion, and the conclusions are presented.

2. Materials and methods

Materials

The current research of energy monitoring using the IoT applied hardware, software, and applications, including a NodeMCU ESP8266. This is a micro-controller connected to a Wi-Fi through its board with a micro-USB port to supply power and upload the program via an Arduino IDE [16]. It was developed in the C/C++ programming language and is widely used in the IoT for communications among micro-controllers due to it low cost.

A PZEM-004T [17] is an AC digital power energy meter module that measures various electrical parameters such as current, voltage, power, energy, power factor (pf), and frequency. The maximum electrical current that can be measured is 100 A.

ThingSpeak [18] is an open-source application that serves as an API for IoT applications to store and extract data from the devices using the HTTP and MQTT protocols via the Internet or a local network. The data were recorded every 15 seconds then displayed on a website in real-time in various formats such as charts and tables. The recorded data can be exported as a csv file for analysis.

Blynk [19] is an application package for supporting IoT devices such as Arduino, ESP8266, ESP32, NodeMCU, and Raspberry Pi. It provides for real-time display of data and controls devices via the Internet. Blynk is a freeware application that supports IOS and Android applications.

LINE Notify [20] is a service of the LINE application. It is used to send messages or automatic notifications to a group or a private account via an API of a LINE user's account. An access token is generated from the LINE Notify user's account page and put on the Arduino IDE program. A message can then be sent to the user.

Energy Monitoring Using the IoT System

Energy monitoring using the IoT was done to continuously examine the voltage, current, power and energy of particular devices. In this research, a PZEM-004T was used as a tool to measure such parameters by connecting it with a NodeMCU ESP8266 unit, which is a board with built-in Wi-Fi capability. It displayed the results on the Blynk app and continuously recorded data on ThingSpeak for later analysis. The designed IoT system could be applied and alerts sent to the LINE application on the user's smartphone when a specified current was exceeded or abnormalities occurred. A block diagram of this system is shown in Fig. 1.

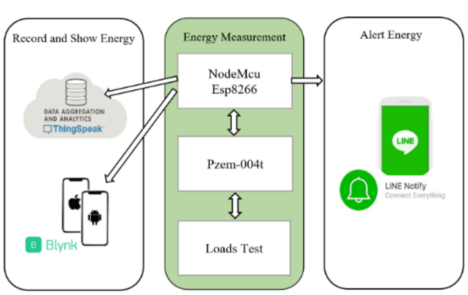


Fig. 1 Block diagram of the IoT system.

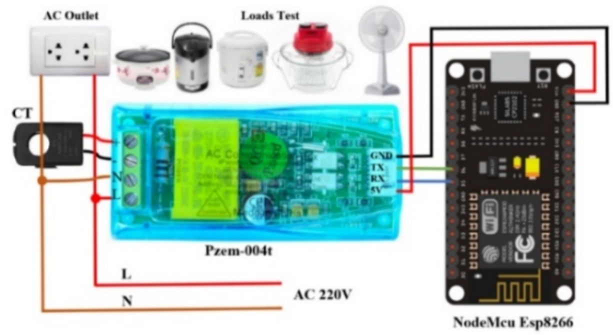


Fig. 2 Connection layout of the devices and loads in the energy measuring experiment**.**

An IoT system was applied to energy monitoring. It included several kinds of equipment and functions. A NodeMCU ESP8266 enabled the device to receive Internet signals, making it appropriate for use with the IoT to measure voltages, currents, power, and energy. A PZEM-004T is a sensor to measure electrical parameters of interest. This system is shown schematically in Fig. 2. The D5 and D6 legs of the NodeMCU ESP8266 were connected to the PZEM-004T. D5 is connected to the RX and D6 to the TX of the PZEM-004T to capture data. The PZEM-004T was applied for energy measurements. One side was connected to a current transformer (CT) by hanging Line 1 of an AC line and plugging it into an AC outlet to test the various loads. By connecting a load to an AC outlet, current flowed through the CT and the voltage, current, power and energy were displayed. The NodeMCU ESP8266 was uploaded via Arduino to link and display data from the PZEM-004T, which was then transferred to a display on a smartphone via Blynk or on ThingSpeak for a website. The data were recorded every 15 seconds. Furthermore, the data could be exported for analysis. The alert system for excessive current would immediately send this information to LINE Notify on the user's LINE application.

Experimental Methods

The design steps of the IoT energy monitoring experimental system are shown in Fig. 3. This figure presents experiments with high energy loads that are regularly applied in residences. There were two types of loads with six kinds of equipment.

Additionally, experiments were conducted with variable loads, in which the current alternately decreased to nearly zero then rose again during operation.
These loads included a 600 W rice cooker, a 614.79 W kettle and a 1,300 W casserole. The PZEM-004T was used to measure these loads along with a GW Instek GDM-461 digital multimeter. This system measured the voltage and current with an accuracy ±(0.8%+10 digits) [21]. The results were displayed and compared to determine the voltage error, as shown in Eq. (1).

$$\text{Error}=\frac{\text{Measurrer}_{\text{mult}}\text{-Measure}_{\text{iot}}}{\text{Measurrer}_{\text{mult}}}\times 100 \qquad (1)$$

This error is referred to the measurement error of the voltage with the PZEM-004T and digital multimeter. $\text{Measure}_{\text{mult}}$ are the measured results with a GW Instek digital multimeter, model GDM-461. $\text{Measure}_{\text{iot}}$ are the voltages measured by the IoT and PZEM-004T sensor.

Figure 4 shows the function of the IoT system, which transferred the results via the LINE application. The PZEM-004T was connected to the total load to display voltage, current, and power. The system was designed to record the data on ThingSpeak and display it on the Blynk application. When there was an abnormal current level, an alert was sent via LINE Notify to the user's LINE account. The system installation is shown in Fig. 5.

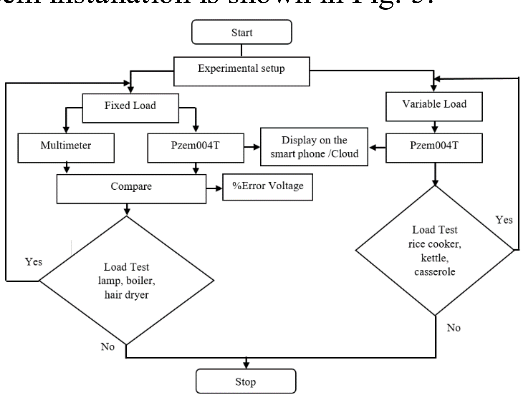


Fig. 3 Experiment steps of energy measuring using the proposed IoT.

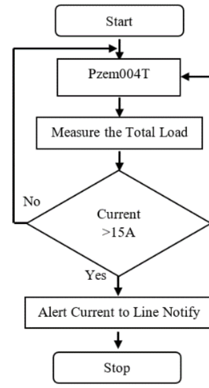


Fig. 4 The function of the proposed system delivering the results via the LINE application.

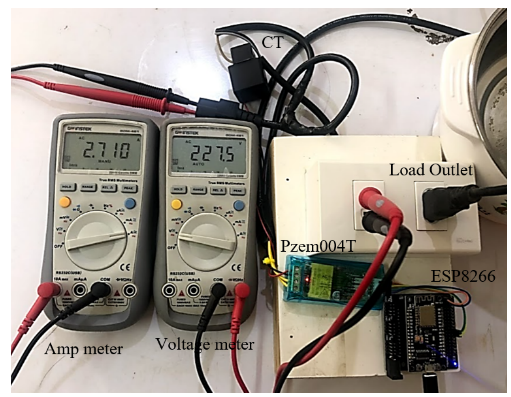


Fig. 5 Installation of the proposed system for testing with the loads.

3. Results and Discussion

This section presents the results obtained from the proposed system tested with fixed and variable loads, as well as the load system installed in a house (Fig. 4).

Results of the Fixed Load Test

There were three types of loads in the experiment, a 100 W lamp, a 600 W shabu pot, and a 1,600 W hairdryer. As shown in Table 1, the 100 W Philips lamp was tested by measuring and reading the voltage, current, and power using a PZEM-004T and GHW Instek digital multimeter (GDM-461) every 10 minutes and recording the results.Minimum and maximum voltages were measured with the PZEM-004T. They were 231.20 V and 231.90 V, respectively, while the average voltage was 231.53 V. Moreover, the minimum and maximum voltage measured with the digital multimeter were 231.20 V and 231.80 V, with an average voltage of 231.54 V. The voltage error averaged 0.004%. The results illustrated that both measuring tools were highly reliability, as they had errors of less than ± 2%. Table 2 shows the experimental voltage, current, and power readings with a 600 W Otto shabu potboiler using a PZEM-004T and GHW Instek digital multimeter, GDM-461 measured every 10 minutes. The minimum and maximum voltage were 230.50 V and 231.30 V, respectively. The average voltage was 230.84 V. Furthermore, the minimum and maximum voltages measured using the digital multimeter were 229.50 V and 230.70 V, respectively. The average voltage was 230.12 V with an average voltage error of – 0.31%. Table 3 shows the experimental voltage, current, and power readings with a Philips 1,600 W hairdryer from the PZEM-004T and GHW Instek digital multimeter (GD-461) measured every 10 minutes. The minimum and maximum voltages, measured with the PZEM-004T were 225.60 V and 227.50 V, respectively, while the average voltage was 226.55 V. Additionally, the minimum and maximum voltages measured with the digital multimeter were 223.40 V and 226.20 V with an average voltage of 225.28 V and a voltage error of – 0.57%.

Table 1 Fixed load experiment with a 100 W Philips lamp.

No.	PZEM-004T			Digital Multimeter			Error Voltage
	V(V)	I(A)	P(W)	V(V)	I(A)	P(W)	(%)
1	231.30	0.44	103.50	231.20	0.44	101.73	– 0.04
2	231.20	0.44	103.60	231.30	0.44	101.77	0.04
3	231.70	0.44	103.10	231.80	0.44	101.99	0.04
4	231.60	0.44	103.00	231.60	0.44	101.90	0.00
5	231.70	0.44	103.20	231.80	0.44	101.99	0.04
6	231.70	0.44	103.00	231.60	0.44	101.90	– 0.04
7	231.90	0.44	103.30	231.60	0.44	101.90	– 0.13
8	231.30	0.44	103.90	231.40	0.44	101.82	0.04
9	231.60	0.44	103.00	231.50	0.44	101.86	– 0.04
10	231.30	0.44	103.20	231.60	0.44	101.90	0.13
Average	**231.53**	**0.44**	**103.28**	**231.54**	**0.44**	**101.88**	**0.004**

Table 2 Fixed load experiment with a 600 W Otto shabu pot boiler.

No.	PZEM-004T			Digital Multimeter			Error Voltage
	V(V)	I(A)	P(W)	V(V)	I(A)	P(W)	(%)
1	231.10	2.74	633.00	229.50	2.73	626.54	– 0.70
2	230.50	2.74	631.50	230.10	2.74	630.47	– 0.17
3	230.90	2.74	633.40	230.40	2.74	631.30	– 0.22
4	230.50	2.74	632.00	229.80	2.74	629.65	– 0.30
5	230.90	2.74	632.90	230.70	2.74	632.12	– 0.09
6	231.30	2.75	637.00	230.60	2.74	631.84	– 0.30
7	230.80	2.75	632.40	230.20	2.74	630.75	– 0.26
8	231.00	2.75	635.40	230.10	2.73	628.17	– 0.39
9	230.80	2.75	634.80	230.10	2.73	628.17	– 0.30
10	230.60	2.75	633.80	229.70	2.74	629.38	– 0.39
Average	**230.84**	**2.75**	**633.62**	**230.12**	**2.74**	**629.84**	**– 0.31**

Table 3. Fixed load experiment with a 1,600 W Philips hairdryer.

No.	PZEM-004T			Digital Multimeter			Error Voltage
	V(V)	I(A)	P(W)	V(V)	I(A)	P(W)	(%)
1	227.10	6.05	1378.20	224.80	5.99	1346.55	– 1.02
2	226.90	6.06	1376.30	223.40	5.97	1333.70	– 1.57
3	226.60	6.09	1375.50	226.10	6.03	1363.38	– 0.22
4	226.40	6.06	1377.20	225.00	5.99	1347.75	– 0.62
5	226.50	6.05	1376.20	225.40	6.00	1352.40	– 0.49
6	227.50	6.02	1363.60	225.90	6.02	1359.92	– 0.71
7	226.80	6.05	1377.10	226.20	6.04	1366.25	– 0.27
8	226.10	6.04	1365.40	224.70	5.99	1345.95	– 0.62
9	226.00	6.04	1364.10	225.20	6.00	1351.20	– 0.36
10	225.60	6.03	1365.70	226.10	6.02	1361.12	0.22
Average	**226.55**	**6.05**	**1371.93**	**225.28**	**6.01**	**1352.82**	**– 0.57**

Results of the Variable Load

Three types of loads were selected as high-power residential loads for the fixed load experiment and their voltage errors compared. It was found that the errors were minor, 0.004%, –0.31%, and –0.57%, respectively, for the Philips 100 W lamp, 600 W Otto shabu pot and the 1,600 W Philips hairdryer. The variable load test used a PZEM-004T connected to an ESP8266 and sent the data to ThingSpeak followed by export since continuous measurements were required to determine the load behaviour. Figure 6 shows the experimental data with a 600 W Sharp KS-R19s rice cooker. It was used to heat one litre of rice with 1.2 litres of water for 30 minutes. The data were recorded every 15 seconds (due to the limitations of ThingSpeak). In the beginning, the voltage was 227 – 233.40 V, while the electric current was 0.001 – 2.80 A. The electrical current was higher when there was a working load (heating). It was reduced when cooking was complete. After 30 minutes, the electric current was 0.001 A, which was the warming function. Figure 7 shows the experiment data with a 614.79 W Sharp KP-19s kettle filled with five litres of water operating for 30 minutes with data recorded every 15seconds. The voltage readings were 226.20-232.60 V, and the current was 0.001 – 2.89 A. In this case, the electric current was higher during the working load (heating), and it was reduced when it stopped working (warming). Consequently, the voltage and current fluctuated. Figure 8 shows the experimental data with a 1,300 W Otto casserole operated for 30 minutes with data recorded every 15 seconds. The voltage readings were 221.70 – 232.90 V, and the current was 0.13 – 6.04 A. This figure also shows that the electrical current was higher for the working load (heating), and it was reduced when it stopped working (warming). The variable loads were higher than the fixed type of loads.

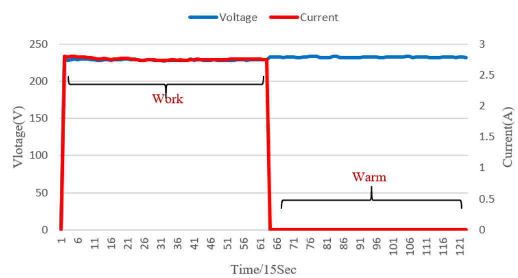


Fig. 6 Load measurements with a 600 W Sharp KS-R19s rice cooker for 30 minutes.

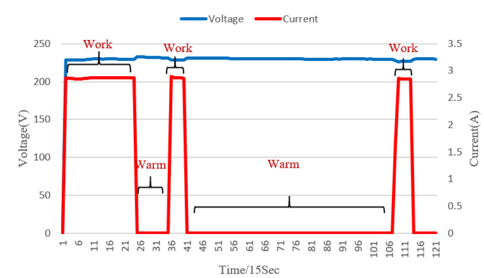


Fig. 7 Load measurements of the 614.79 W Sharp KP-19s kettle for 30 minutes.

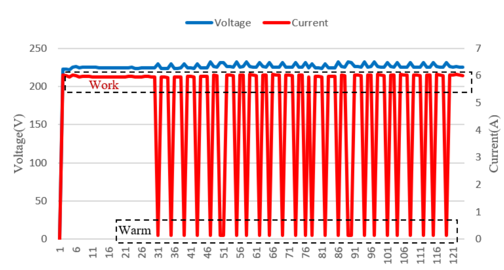


Fig. 8 Load measurement results for the 1,300 W Otto casserole for 30 minutes.

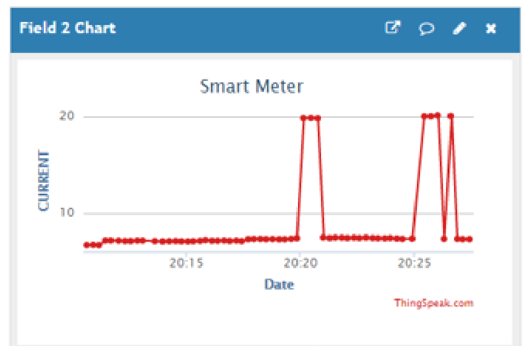
Application of the Total Load in a Residence

As shown in Fig. 4, the function of the proposed system was to send the measurement results via a LINE application by connecting the PZEM-004T to the total load to display the voltage, current, and energy and record the data on ThingSpeak and the Blynk app (Fig. 9(a)). An alert would be sent to the LINE application via the LINE notify service when a condition of excessive electrical current occurred. This experiment used a high energy load, which was an air conditioner and water heater operated simultaneously. Under this condition, an alert would be sent if the electrical current exceeded 15A, as shown in Fig. 9(b).

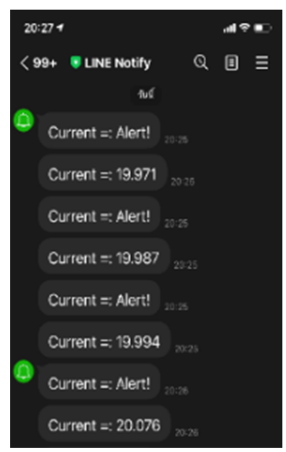
Discussion

The results of the fixed load experiment with a 1,600 W Philips hairdryer indicated that the minimum and maximum voltages were 225.60 V and 227.50 V, respectively, while the average voltage was 226.55 V. When measuring with a digital multimeter, the minimum and maximum voltages were 226.20 V and 225.28 V, respectively, with an average voltage error of –0.57%. Thus, the voltage error of the presented loads was under 1%, which is an acceptable value. The variable load data was measured using the PZEM-004T connected to the NodeMCU ESP8266, and the data were sent to ThingSpeak before being exported. In this case of the Sharp KS-R19s rice cooker, the voltage was 227.20 – 233.50 V and the current was 0.001 – 2.80 A. The results were used to determine the relationship between the voltage and current as well as the behavior of the load through the process. Using the Sharp KP-19s kettle as a load, the voltage was 226.20 – 232.60 V, while the current was 0.001 – 2.89 A. The kettle turned itself off when the water temperature was 90 – 98 °C and would function again when the temperature decreased to under 90 °C. Last, the voltage of the Otto casserole was 221.70 – 232.90 V and the current was 0.13 – 6.04 A. The current of the casserole load was up to 6.04 A.

Finally, the application reported the total load in a model house. The proposed system delivered the results via the LINE application by connecting the PZEM-004T to the total load and displaying the voltage, current, and energy. The system recorded the data on ThingSpeak and displayed it on the Blynk application. When excessive current was detected, an alert that included a message and the abnormal values was sent via the LINE Notify service. In the experiment, high energy loads from simultaneous operation of an air conditioner and water heater, produced alerts when the current was higher than 15 A (Fig. 4). Additionally, the system would inform the user who was not at home of an intruder or electricity theft.



(a) Display of the results on ThingSpeak.



(b) Alert of the current exceeding 15A on LINE Notify.

Fig. 9 The results on ThingSpeak and the alert on the smartphone.

4. Conclusion

The current research proposed and tested an energy monitoring and alert application of the IoT using a NodeMCU ESP8266 micro-controller and a PZEM-004T sensor on a smartphone with data recording on a cloud system. Alerts of abnormal energy use were sent on a LINE application. The research results presented measurements and recorded voltages, currents, and energy of the loads with high energy alerts via a LINE application to inform the user of abnormalities. This technique employed a facile design and development using an IoT configuration that is simple and inexpensive. Future research should develop a system that is more compact and user-friendly. Moreover, it would be applied to allow users monitor their homes for theft prevention as a smart house. Standards for all types of electrical devices in the home can be developed. Also, over a long period of time, monitoring electric power usage can be used to predict future energy consumption and user behavior.

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