Indonesian Journal of Electrical Engineering and Computer Science
Vol. 30, No. 3, June 2023, pp. 1259~1268
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v30.i3.pp1259-1268

Design and fabrication of an IoT-based smart electrical meter for residential energy management

Thanh Ba Nguyen, Tri Cao Nguyen
Department of Electrical and Electronic Engineering, Institute of Engineering and Technology, Thu Dau Mot University, Thu Dau Mot, Vietnam

Article Info

Article history:

Received Aug 28, 2022
Revised Jan 27, 2023
Accepted Jan 31, 2023

Keywords:

ESP32
Internet of things
PZEM 004T
Residential energy management
Smart electrical meter

ABSTRACT

Transparency in electricity measurement and efficient use of electricity are issues of concern to households. Electricity customers want to have confidence in their utility company's electricity meters installed at their houses. This study designs and constructs an internet of things (IoT)-based smart electric meter to measure electricity and remotely control domestic appliances. This device can monitor, calculate electricity bills and remotely control the appliances via the internet; electrical quantities are displayed in real-time on the Blynk app, liquid crystal display (LCD) screen and Google Sheet. The device is also capable of emailing the electricity user. The proposed system is designed and developed based on ESP32, a LCD, a PZEM 004T, four relays and a DC source. The results show that the device works stably and the device’s error is less than 5%. This research makes it possible for users to conveniently monitor their power consumption while enhancing their energy-saving awareness.

Corresponding Author:

Thanh Ba Nguyen
Department of Electrical and Electronic Engineering, Institute of Engineering and Technology
Thu Dau Mot University
Thu Dau Mot, Binh Duong, 75109, Vietnam
Email: thanhnb@tdmu.edu.vn

1. INTRODUCTION

In recent decades, the world economy in general has made great progress, leading to increasing demand for energy [1], [2]. There is a significant contribution from the area of residential buildings [3]. People are also looking for efficient energy management solutions for this area. In many countries, they still use traditional electric meters, electromechanical meters or electronic meters. These types of meters require staff to visit the meter location in each household for power readings and other administrative tasks [4], which causes more work for them as well as difficulty in ensuring transparency in measurement. These problems will be solved if an internet of things (IoT)-based smart meter is utilized instead.

Nowadays, IoT is becoming the new technology trend [5], [6]. IoT environment is increasingly being researched for information security, so it is safer for users [7]. IoT aims at providing life easier and more convenient by monitoring various activities, including energy management [8]. The IoT enables a lot of smart solutions for various problems and saves energy to a great amount. Real-time monitoring helps households reduce more energy consumption than monitoring through monthly electricity bills [9], [10]. There have been a great number of studies on electrical energy meters using IoT [11]. The statistics of the different technological and functional aspects found in the literature review are illustrated in Table 1.

To know electrical quantities, it is necessary to measure two fundamental quantities which are voltage and current. For electric current, there are two basic techniques: intrusive and non-intrusive. The ACS712 sensor from allegro micro systems (USA) is an example representing the first technical group; and the current sensor STC-013 of YHDC (China) is an example representing the second group. For voltage, there are the following techniques: i) AC/AC step-down transformer and voltage divider, and ii) ZMPT101B sensor.

Table 1. Smart energy meter technologies comparisons

Ref.	Technologies			Functions					
	Sensor	Microcontroller	Communication	Remote Control	Timing	Alert	Billing	Display	Google Sheets
[12]	ACS712 ZMPT101B	Arduino Uno, ESP8266	WiFi	Yes	No	No	Yes	Mobile App	No
[13]	ACS712 ZMPT101B	Arduino Uno, ESP8266	WiFi	No	No	Email	Yes	Web (Adafruit)	No
[14]	ACS712 ZMPT101B	Arduino Uno, Raspberry Pi	WiFi	Yes	Yes	Email	Yes	Mobile app, Web	No
[15]	ACS712 ZMPT101B	Arduino Uno, ESP8266	WiFi	No	No	No	No	Blynk app	No
[16]	ACS712 ZMPT101B	ESP8266	WiFi	No	No	No	Yes	Mobile app	No
[17]	ACS712 ZMPT101B	ESP32	WiFi	No	No	Mob. App	No	Blynk app	No
[18]	ACS712 ZMPT101B	ESP32	WiFi	No	No	No	No	Web (Ubidots)	No
[19]	ACS712 ZMPT101B	Arduino Uno, Raspberry Pi, LoRa Shield	LoRa	Yes	Yes	Yes	No	Mobile app, Web	No
[20]	ACS712 ZMPT101B	-	WiFi	Yes	No	No	Yes	Web, Mobile, LCD	No
[21]	ACS712 ZMPT101B	Arduino Mega, ESP8266, ZigBee Module	ZigBee	No	No	No	Yes	Web, Android app, LCD	No
[22]	ACS712 ZMPT101B	Arduino Mega, ESP8266	WiFi	Yes	No	No	No	ThingSpeak, Blynk App, LCD	No
[23]	ACS712 ZMPT101B	Arduino Uno ESP8266	WiFi	No	No	No	Yes	Web (Adafruit), LCD	No
[24]	ACS712 ZMPT101B	Aruino Nano, ESP8266	WiFi	No	No	No	No	Web (ThingSpeak)	No
[25]	PZEM-004T	ESP8266	WiFi	No	No	Email	No	Web (Grafana)	No
[26]	PZEM-004T	ESP8266	WiFi	Yes	No	No	No	Web (local host)	No
[27]	PZEM-004T	Arduino Uno, ESP8266	WiFi	Yes	No	Email, Mob. App	No	LCD, Mobile App	No
[28]	PZEM-004T	Raspberry Pi, Lora gate	Lora	Yes	No	No	No	Web ThingsBoard, Mobile	No
[29]	SCT-013 CT, Volt. transformer	Arduino Uno, ESP8266	WiFi	Yes	No	No	No	Mobile app	No
[30]	-	Arduino Uno, GSM module	GSM	No	No	SMS	No	LCD	No
[31]	-	Arduino Uno, GSM module	GSM	Yes	No	SMS	Yes	LCD	No
[32]	-	ARM7, ZigBee Module	ZigBee	No	No	SMS	Yes	LCD	No
Proposed paper	PZEM-004T	ESP32	WiFi	Yes	Yes	Email, Mob. App	Yes	LCD, Mobile App	Yes

After obtaining the current and voltage in one of the above ways, calculations are required to get the electrical parameters like active power, and power factor. This adds to the processing time of the processor. Instead of using the solution of individual sensors, using the PZEM004T module makes it easier and more convenient. This module helps to measure and calculate quantities of voltage, current, power factor, active power and energy. In the investigated studies, the ACS712 current sensor and a ZMPT101B voltage sensor were used in the studies [12]-[24]; the PZEM004T module used in the studies [25]-[28]; SCT-013 current transformer (CT) and AC/AC step-down transformer and voltage divider used in the research [29].

In order for the device works properly and fully perform its designed functions, a central processor is required. With IoT devices, there is also a need for an additional component that sends data over the wireless network to end-user applications. To perform both of these functions (data processing and communication) there are two main technical solutions: i) using two separate microcontrollers, and ii) using microcontrollers with built-in functions. Currently, the microprocessors commonly used in research include Arduino, ARM, Raspberry Pi, ESP8266 and ESP32. Arduino microcontrollers have 3 main product families: Nano, MKR and Classic. Arduino Uno is used in projects [12]-[15], [19], [23], [27], [29]-[31] and Arduino Mega used in projects [21] and [22] are microcontrollers of the classic family and belong to the group of technical solutions i) which means that communication modules are not integrated into. Despite using the same solution i) as above, the article [28] uses a Raspberry Pi microcontroller while the article [32] uses the ARM7 microcontroller which is a product of Arm Holdings Ltd. ESP8266, developed by Espressif Systems, is a microcontroller with an integrated WiFi module and is widely used in IoT projects [33]. ESP32 is an upgraded version of ESP8266 with more features and processing speed [34]. ESP8266 is used in projects [16], [25], [26]; ESP32 is used in projects [17], [18] which are in the solution group ii).

Regarding communication technology, there are different communication methods such as WiFi, LoRaWAN, Zigbee, and GSM [35]. As mentioned in the literature review, most smart metering systems use WiFi communication networks, [12]-[18], [20], [22]-[27], [29] while only few systems use LoraWan [19], [28], Zigbee [21], [32], or GSM [30], [31]. Communication over WiFi is realized in short range and suitable for household applications while the remaining methods are suitable for projects that need longer signal transmission distances.

For the functions of the surveyed meters, in general, these smart meters have basic functions such as measuring and displaying quantities such as current, voltage, power and energy. In addition, some projects add some features such as controlling the device remotely; controlling timer settings; sending alerts to users via email, SMS, mobile app, or both email and mobile app; calculating electricity bills. To display the collected and calculated data, some studies have solutions such as displaying on liquid crystal display (LCD), on the website, on mobile applications, or a combination of the two or all three of the above solutions. For example, the research team [12] presented a smart meter with the functions of remote control, electricity bill calculation and parameter display via a mobile application. Moreover, the research team [13] implemented a power meter that can calculate electricity bills, send alerts to users via email and display the data on the website via the Adafruit IO application. The research of the group [14] presents a device that can be remotely controlled, set the timing, calculate the bills, send email notifications, and display data via website and mobile app. In general, in those studies, each of the surveyed studies lacked certain features, especially not being able to export data through the Google Sheets application, a popular application of Google. Google Sheets is user-friendly, easy to access and process data anywhere and can be accessed by many people at the same time.

Following the previous studies, the motive for this research is to design and build a smart power meter with more features. This device is not only capable of measuring current, voltage, power and energy; calculating electricity bill calculation and presenting real-time display on Mobile App and LCD; but also emailing and sending data via Google Sheets. In addition, the device can control and schedule the switch remotely via a mobile phone. The device can send data via Google Sheets, which is a new feature compared to the previous studies. Furthermore, this device can make a contribution to conserving energy and help households calculate their bills.

The remains of this paper are organized as follows: The design of the proposed system in section 2. The main contents involving the implementation and experimental results are given in section 3. Finally, the conclusions are described in section 4.

2. METHOD

The development process of the proposed system includes the following steps: hardware design, software design and testing and evaluation of device features. After testing the features of the device with stable operation, the complete prototype will be built. The device's hardware is designed from today's common electronic components. Software programming includes programming for the ESP32 microcontroller and applications on Blynk application. The details of these processes are presented in the sections.

2.1. Hardware design

The system proposed in this paper consists of the main blocks as shown in Figure 1. The major components of the device are the power PZEM-004T module, ESP32, relay, LCD and source module. The hardware design for the smart energy meter is presented in Figure 2. PZEM-Z004T module as shown in Figure 3 is used to detect voltage, current, active power, frequency, power factor and energy [26], [36]. PZEM-004T is chosen for its ease of use and great performance [37]. Specifications of PZEM004T are described in Table 2. The device communicates with the ESP32 using the universal asynchronous receiver and transmitter (UART) protocol.

ESP32 as shown in Figure 4 is a low-cost microcontroller with many outstanding features. The module supports SPI, UART, I2C and I2S communication standards. It is capable of connecting with many peripherals such as sensors, amplifiers, and SD cards. ESP32 supports both Wi-Fi as well as bluetooth connectivity [38]. Table 3 describes the specifications of the ESP32 module.

The relay module used in this paper is shown in Figure 5. This is a 4-channel 5 V relay and the driving current of each channel is 15-20 mA. This relay can be applied to control high-power devices. The relay's operating current is below AC 250 V 10 A or DC 30 V 10 A. The relay can communicate with the microcontroller to control the device programmatically.

In this project, the LCD module used is 20×4 type. The components in the circuit are fed by the power module. The power module used in this study has a brand name of Hi-Link, it can convert 220 V AC to 5 V DC power. Hi-Link is chosen because of its popularity and cheap price.

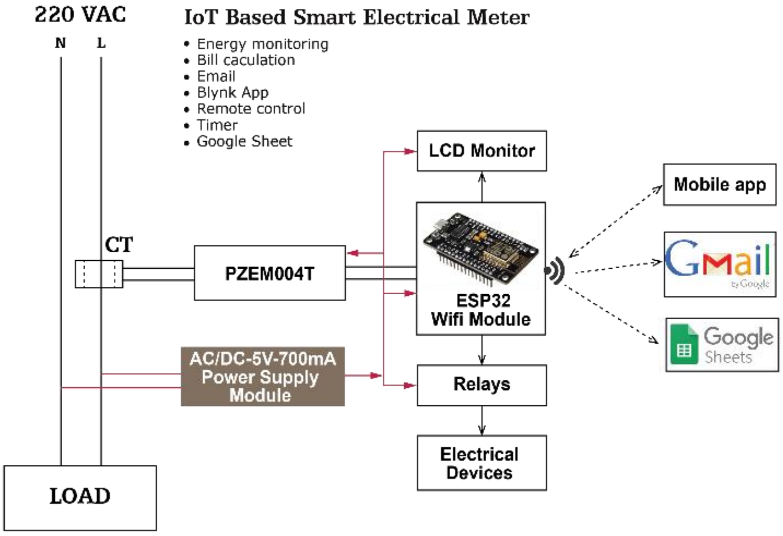


Figure 1. General block diagram of the proposed device

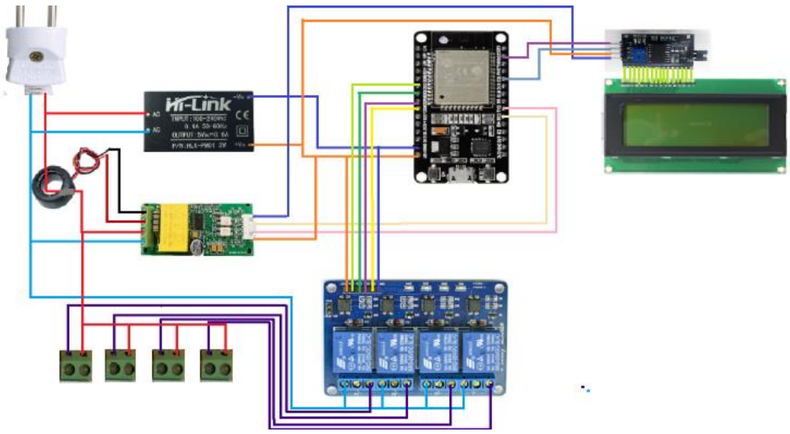


Figure 2. Connection diagram of main devices

Table 2. Specifications of PZEM004T

Parameters	Specifications
Voltage supply	5 V DC
Operating voltage	80–260 V AC/50–60 Hz
Operating current	0-100 A
Rated power	100 A/22000 W
Measurement accuracy	1.0

Table 3. Specifications of ESP32 module

Parameters	Specifications
Microcontrollers	ESP-WROOM-32
GPIO	30
Peripheral	UART, SPI, I2C, I2S, Capacitive Touch GPIOs, PWM, ADC, DAC
Flash memory	4 MB
SRAM	520 KB
Clock speed	240 MHz
Wi-Fi	802.11b/g/n Wi-Fi transceiver
Bluetooth	Bluetooth 4.2/BLE
Supply	5 V DC

Figure 3. The PZEM-Z004T module

Figure 4. ESP-WROOM-32

Figure 5. Relay module

2.2. Software design

Software design includes writing programs that can read electrical data, calculate electricity bills, control equipment, display the data on the Blynk application, export data via Google Sheet and send emails. The Blynk mobile application is used to monitor, control and display real-time electricity data. The interface of the mobile application is shown in Figures 6-8. Blynk application displays energy consumption, electricity bill, power capacity, current, voltage and frequency. The mobile interface of the control unit is shown in Figure 8. The devices' control interface has a drop box for device selection and an ON/OFF button. The interface also allows setting the ON/OFF timer for each device by selecting the time picker.

In Vietnam, the selling price of electricity to households is calculated based on tiered pricing as shopwn in Table 4. Accordingly, the more electricity a household uses, the higher the electricity price will be. Therefore, when the consumption is high, the mobile application will display a warning and email to the householder as shown in Figure 9.

The data exported to Google Excel are depicted in Figure 10. The displayed values include voltage, current, capacity, power factor, bill and cumulative energy. The data are taken every an hour, users can get the data for particular time periods. Google Sheet, which is an online application from Google, is popular with many people. Therefore, when the data are exported to Google Sheet, it is very convenient for data statistics.

Figure 6. Monitor unit interface

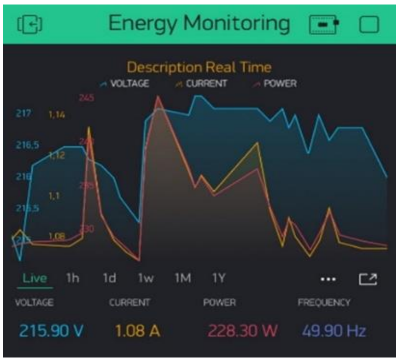


Figure 7. Real-time display of electrical quantities

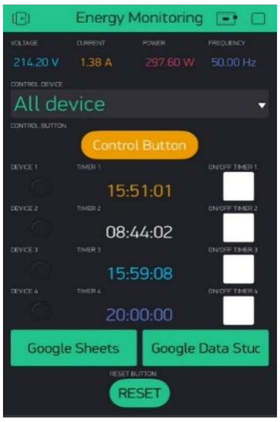


Figure 8. Control unit interface

Table 4. Electricity tariffs of urban areas in Vietnam [39]

Segment Tariff	Price per unit (VND/kWh)
From 0 to 50 kWh	1,678
From 51 to 100 kWh	1,734
From 101 to 200 kWh	2,014
From 201 to 300 kWh	2,536
From 301 to 400 kWh	2,834
Above 401 kWh	2,927

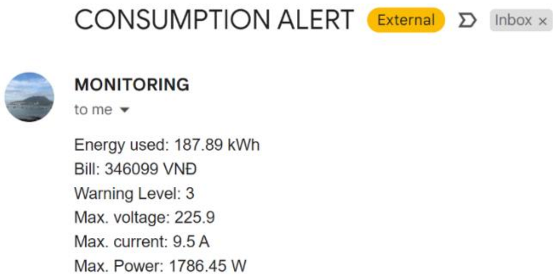
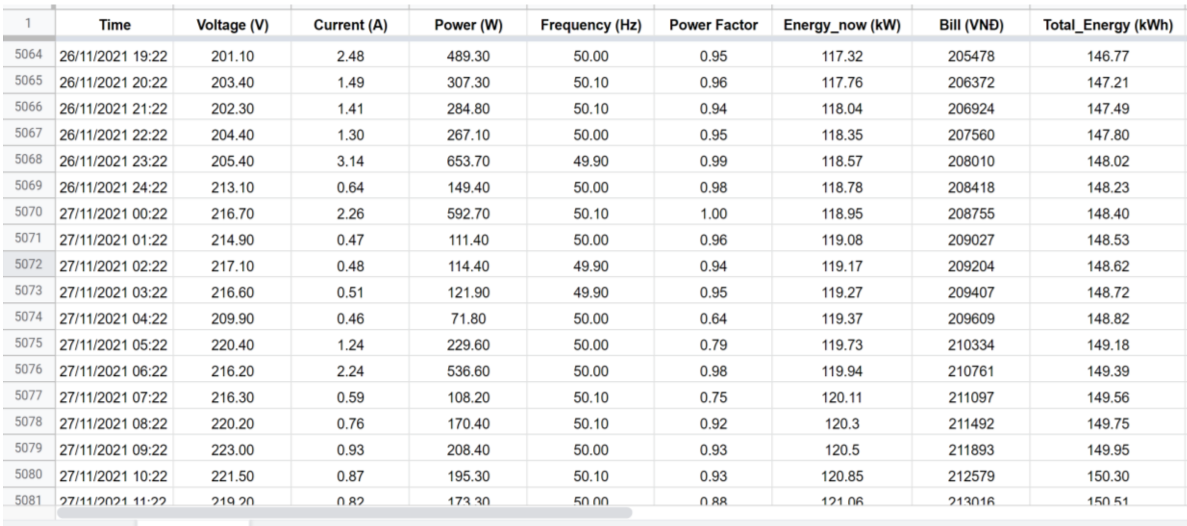


Figure 9. An email alert sends to the household



1	Time	Voltage (V)	Current (A)	Power (W)	Frequency (Hz)	Power Factor	Energy_now (kW)	Bill (VNĐ)	Total_Energy (kWh)
5064	26/11/2021 19:22	201.10	2.48	489.30	50.00	0.95	117.32	205478	146.77
5065	26/11/2021 20:22	203.40	1.49	307.30	50.10	0.96	117.76	206372	147.21
5066	26/11/2021 21:22	202.30	1.41	284.80	50.10	0.94	118.04	206924	147.49
5067	26/11/2021 22:22	204.40	1.30	267.10	50.00	0.95	118.35	207560	147.80
5068	26/11/2021 23:22	205.40	3.14	653.70	49.90	0.99	118.57	208010	148.02
5069	26/11/2021 24:22	213.10	0.64	149.40	50.00	0.98	118.78	208418	148.23
5070	27/11/2021 00:22	216.70	2.26	592.70	50.10	1.00	118.95	208755	148.40
5071	27/11/2021 01:22	214.90	0.47	111.40	50.00	0.96	119.08	209027	148.53
5072	27/11/2021 02:22	217.10	0.48	114.40	49.90	0.94	119.17	209204	148.62
5073	27/11/2021 03:22	216.60	0.51	121.90	49.90	0.95	119.27	209407	148.72
5074	27/11/2021 04:22	209.90	0.46	71.80	50.00	0.64	119.37	209609	148.82
5075	27/11/2021 05:22	220.40	1.24	229.60	50.00	0.79	119.73	210334	149.18
5076	27/11/2021 06:22	216.20	2.24	536.60	50.00	0.98	119.94	210761	149.39
5077	27/11/2021 07:22	216.30	0.59	108.20	50.10	0.75	120.11	211097	149.56
5078	27/11/2021 08:22	220.20	0.76	170.40	50.10	0.92	120.3	211492	149.75
5079	27/11/2021 09:22	223.00	0.93	208.40	50.00	0.93	120.5	211893	149.95
5080	27/11/2021 10:22	221.50	0.87	195.30	50.10	0.93	120.85	212579	150.30
5081	27/11/2021 11:22	219.20	0.82	173.30	50.00	0.88	121.06	213016	150.51

Figure 10. Electrical quantities displayed on Google Sheet

2.3. Working principle

The proposed control and monitoring algorithm on the devices is shown in Figure 11. At the initial point, the system is booted and connected to Wi-Fi. The data taken from the PZEM 004T are sent to ESP32 microcontroller. ESP32 plays the role of the central processing unit and Wi-Fi signal transmitter. Electrical quantities including current, voltage, power, power factor, frequency and energy are sent to the ESP32 microcontroller. When receiving the data, ESP32 will calculate the cost of the consumed electricity according to the electricity tariff regulated by EVN in Table 4. The data from the ESP32, after being processed, are exported to the Blynk app, Email and Google Sheet. Google Sheet is a free application of the Google Company which is popular with many people. From there, the collected data will be easily processed according to the needs of the user.

Figure 12 depicts the flowchart of the algorithm for controlling remote devices via the relays. When the system is connected to Wi-Fi and there is an ON/OFF command on the Blynk app, these relays can be opened and closed remotely. There are four relays; therefore, four devices can be controlled. The ON/OFF button of these devices can also be controlled by timing.

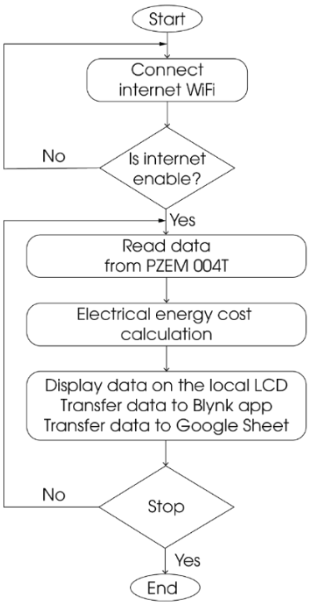


Figure 11. The proposed algorithm for measuring electrical quantities

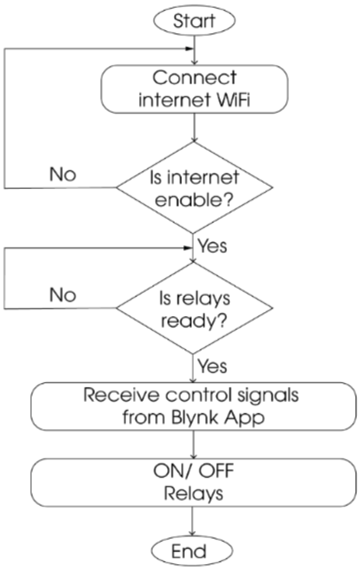


Figure 12. The algorithm for controlling the relays

3. RESULTS AND DISCUSSION

Figure 13 depicts the installation of the internal components of the proposed device. An LCD is attached to the device to monitor electricity indicators and electricity bills in a convenient manner. Figure 14 shows an IoT-based smart meter installed for testing. Figure 15 describes the test of a remote control device and the setting of the on/off timers for the device. Figure 16 depicts the test with a refrigerator and the results are shown in Table 5.

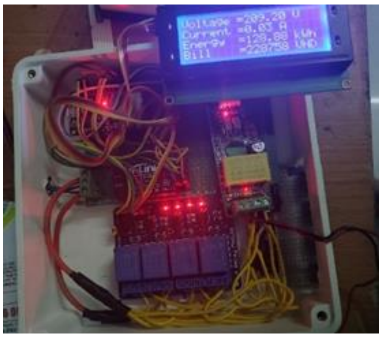


Figure 13. Internal configuration of the device

Figure 14. The experimental setup

Figure 15. Testing device controls

Figure 16. Tested with a refrigerator

Table 5. Test results with the refrigerator

Refrigerator	Multimeter	IoT Meter	Error (%)
U (V)	211	211.6	0.28
I (A)	0.52	0.53	1.90

To compare the device accuracy, the results are referenced with the commercial multimeter and electric meter installed by Vietnam Electricity (EVN) for consumers. The test results with the welding rod are shown in Table 6. The test results with the refrigerator show that the voltage error is 0.28%, and the current error is 1.90%; the test results with the welding rod load show that the error of voltage is 0.049%, and the error of current is 5%. This error level is lower than that of some studies like [18], [26]. In these two projects, the error of voltage measurement is 1.16% and 0.616%; the error of measuring current is 17.6% and 21.027%, respectively.

Table 7 describes the test results with the household's load. The value of the measured IoT meter is compared with the EVN's kWh meter installed for the household. The data are collected from the two meters once a day at the same time. The test results show that the maximum energy measurement error is 4.69% which is slightly lower than that of the study [32] 5%.

Table 6. Test results with the welding rod

Soldering iron	Multimeter	IoT Meter	Error (%)
U (V)	203.9	204	0.049
I (A)	0.19	0.2	5.00

Table 7. Test results with the household

Date	EVN Meter (kWh)	Proposed Meter (kWh)	Error (%)
07/11/2021	0	0	0.00
08/11/2021	7.9	8.0	1.27
09/11/2021	11.3	11.5	1.77
10/11/2021	6.8	7.0	2.94
11/11/2021	6.4	6.5	1.56
12/11/2021	5.4	5.6	3.70
13/11/2021	7.0	7.2	2.86
14/11/2021	6.9	7.0	1.45
15/11/2021	5.1	5.3	3.92
16/11/2021	6.8	6.9	1.47
17/11/2021	6.4	6.7	4.69
18/11/2021	7.0	7.3	4.29
19/11/2021	7.9	8.2	3.80
20/11/2021	6.9	7.2	4.35
21/11/2021	6.6	6.7	1.52
22/11/2021	8.9	9.3	4.49
23/11/2021	6.6	6.7	1.52
24/11/2021	7.5	7.8	4.00
25/11/2021	7.2	7.4	2.78
26/11/2021	6.9	7.2	4.35
27/11/2021	6.8	7.0	2.94
28/11/2021	5.4	5.6	3.70
29/11/2021	6.0	6.2	3.33
30/11/2021	5.3	5.5	3.77
01/12/2021	5.8	6	3.44
02/12/2021	6.1	6.3	3.28
03/12/2021	6.0	6.2	3.33
04/12/2021	5.7	5.9	3.51
05/12/2021	6.5	6.8	4.62
06/12/2021	6.1	6.3	3.28

4. CONCLUSION

Power monitoring that helps increase the transparency in the measurement of electrical quantities is an essential need not only for households but also for electricity companies. This study has designed and built an IoT power meter that can monitor electrical quantities such as current, voltage, capacity, power factor, frequency, and electricity and calculate electricity bills; switch off the electrical equipment remotely via a mobile phone; send emails; send parameters via Google Sheet. The device is compact and easy to install. The device works stably, the error when measuring energy is less than 5%. This device is useful for households to monitor and manage energy more efficiently. In the future, it is expected that the system will be expanded with more features as well as machine learning algorithms will be applied to effectively manage energy for households.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Thu Dau Mot University in Vietnam for its support. This research is funded by Thu Dau Mot University, Binh Duong Province, Vietnam under grant number DT.21.1-065.

REFERENCES

[1] T. Ahmad and D. Zhang, "A critical review of comparative global historical energy consumption and future demand: the story told so far," *Energy Reports*, vol. 6. pp. 1973–1991, Nov. 01, 2020, doi: 10.1016/j.egyr.2020.07.020.

[2] X. Zhang, H. Zhang, and J. Yuan, "Economic growth, energy consumption, and carbon emission nexus: fresh evidence from developing countries," *Environmental Science and Pollution Research*, vol. 26, no. 25, pp. 26367–26380, Jul. 2019, doi: 10.1007/S11356-019-05878-5.

[3] H. Do and K. S. Cetin, "Residential building energy consumption: a review of energy data availability, characteristics, and energy performance prediction methods," *Current Sustainable/Renewable Energy Reports*, vol. 5, no. 1, pp. 76–85, Jan. 2018, doi: 10.1007/S40518-018-0099-3.

[4] M. Kathiresh and A. M. Subahani, "Smart meter: A key component for industry 4.0 in power sector," in *Internet of Things for Industry 4.0,* Singapore, Springer, 2020, pp. 177–196, 2020, doi: 10.1007/978-3-030-32530-5_12.

[5] P. K. Malik *et al.*, "Industrial internet of things and its applications in industry 4.0: state of the art," *Computer Communications*, vol. 166, pp. 125–139, Jan. 2021, doi: 10.1016/j.comcom.2020.11.016.

[6] R. Singh, A. Gehlot, V. Jain, and P. K. Malik, *Handbook of Research on the Internet of Things Applications in Robotics and Automation*, 1st Ed. IGI Global, 2019.

[7] P. Verma *et al.*, "A novel intrusion detection approach using machine learning ensemble for IoT environments," *Applied Sciences*, vol. 11, no. 21, pp. 10268, Nov. 2021, doi: 10.3390/app112110268.

[8] N. H. Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of things (IoT) and the energy sector," *Energies*, vol. 13, no. 2, pp. 494, Jan. 2020, doi: 10.3390/en13020494.

[9] S. K. Vishwakarma, P. Upadhyaya, B. Kumari, and A. K. Mishra, "Smart energy efficient home automation system using IoT," in *Proc. of the 4th International Conference on Internet of Things: Smart Innovation and Usages (IoT-SIU)*, India, April 2019, pp. 1-4, doi: 10.1109/IoT-SIU.2019.8777607.

[10] S. S. V. Dam, C. A. Bakker, and J. D. M. V. Hal, "Home energy monitors: impact over the medium-term," *Building Research and Information*, vol. 38, no. 5, pp. 458–469, Sep. 2010, doi: 10.1080/09613218.2010.494832.

[11] W. Yaïci, K. Krishnamurthy, E. Entchev, and M. Longo, "Recent advances in internet of things (IoT) infrastructures for building energy systems: a review," *Sensors*, vol. 21, no. 6, Mar. 2021, doi: 10.3390/S21062152.

[12] S. Somantri, I. Yustiana, and A. Nugraha, "Electrical consumption monitoring and controlling system based on IoT and mobile application," in *Proceeding of International Conference on ICT for Smart Society (ICISS)*, Indonesia, November 2020, pp. 1-5, doi: 10.1109/iciss50791.2020.9307556.

[13] V. S. M *et al.*, "Internet of things based smart energy meter with fault detection feature using MQTT protocol," in *Proceedings of the 8th International Conference on Advanced Computing and Communication Systems (ICACCS*), India, March 2022, pp. 1592-1596, doi: 10.1109/ICACCS54159.2022.9785026.

[14] M. O. Agyeman, Z. Al-Waisi, and I. Hoxha, "Design and implementation of an iot-based energy monitoring system for managing smart homes," in *Proceeding of the Fourth International Conference on Fog and Mobile Edge Computing (FMEC)*, Italy, June 2019, pp. 253-258, doi: 10.1109/FMEC.2019.8795363.

[15] S. Khalid, M. Sarfraz, V. Singh, Aafreen, and A. Allahloh, "A novel model for IoT-based meter using ATmega328P microcontroller and google cloud store," in *Lecture Notes in Mechanical Engineering*, Singapore, Springer, 2021, pp. 639–648, doi: 10.1007/978-981-15-5463-6_57.

[16] Y. Maulana, R. Darmawan, L. Kamelia, E. Mulyana, M. R. Effendi, and M. I. Pamungkas, "The development of the home electrical power consumption system prototype in real-time," in *Proceeding of the 7th International Conference on Wireless and Telematics (ICWT)*, Indonesia, August 2021, pp. 1-5, doi: 10.1109/ICWT52862.2021.9678420.

[17] A. Othman and N. H. Zakaria, "Energy meter based wireless monitoring system using blynk application via smartphone," in *Proceeding of the 2nd International Conference on Artificial Intelligence in Engineering and Technology (IICAIET)*, Malaysia, September 2020, pp. 1-5, doi: 10.1109/IICAIET49801.2020.9257827.

[18] F. Jonathan and T. W. O. Putri, "Prototype of home power monitoring tool for electrical outlet using ESP32," in *Proceeding of International Conference on ICT for Smart Society (ICISS)*, Indonesia, August 2021, pp. 1-5, doi: 10.1109/ICISS53185.2021.9533189.

[19] S. Z. R. Hussain, A. Osman, M. A. Moin, and J. A. Memon, "IoT enabled real-time energy monitoring and control system," in *Proceeding of the 9th International Conference on Smart Grid (icSmartGrid)*, Portugal, 29 June 2021 - 01 July 2021, pp. 97-102, doi: 10.1109/ICSMARTGRID52357.2021.9551208.

[20] M. O. Onibonoje, "An IoT design approach to residential energy metering, billing and protection," in *Proceeding of International IOT, Electronics and Mechatronics Conference (IEMTRONICS)*, Canada, April 2021, pp. 1-4, doi: 10.1109/IEMTRONICS52119.2021.9422580.

[21] S. S. Chowdary, M. A. A. E. Ghany, and K. Hofmann, "IoT based wireless energy efficient smart metering system using zigbee in smart cities," in *Proceeding of the 7th International Conference on Internet of Things: Systems, Management and Security (IOTSMS)*, France, December 2020, pp. 1-4, doi: 10.1109/IOTSMS52051.2020.9340230.

[22] V. V. Gavhane, M. R. Kshirsagar, G. M. Kale, S. Katangle, S. B. Deosarkar, and S. L. Nalbalwar, "IoT based energy meter with smart monitoring of home appliances," in *Proc.of the 6th International. Conference for Convergence in Technology* (I2CT), India, April 2021, pp. 1-5, doi: 10.1109/I2CT51068.2021.9417886.

[23] H. Mubarok and A. Ardiansyah, "Prototype design of IoT (Internet of Things) - based load monitoring system," in *Proceeding of the 3rd International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, Indonesia, December 2020, pp. 377-382, doi: 10.1109/ISRITI51436.2020.9315454.

[24] J. Y. Lin, H. L. Tsai, and G. H. Lu, "Development of wireless AC power-monitoring module," in *Proceeding of the 8th International Conference on Applied System Innovation (ICASI)*, Taiwan, April 2022, pp. 1-4, doi: 10.1109/ICASI55125.2022.9774467.
[25] K. Chooruang and K. Meekul, "Design of an IoT energy monitoring system," in *Proceeding of the 16th International Conference on ICT and Knowledge Engineering (ICT&KE)*, Thailand, November 2018, pp. 1-4, doi: 10.1109/ICTKE.2018.8612412.
[26] A. I. Satriananda, L. Kamelia, M. R. Efendi, and A. Kusnawan, "The prototype of smart power meter at home based on internet of things," in *Proceeding of the 7th International Conference on Wireless and Telematics (ICWT)*, Indonesia, August 2021, pp. 1-3, doi: 10.1109/ICWT52862.2021.9678480.
[27] T. D. Nguyen, V. K. Tran, T. D. Nguyen, N. T. Le, and M. H. Le, "IoT-based smart plug-in device for home energy management system," in *Proceeding of the 4th International Conference on Green Technology and Sustainable Development (GTSD*), Vietnam, November 2018, pp. 734-738, doi: 10.1109/GTSD.2018.8595615.
[28] N. M. Khoa, L.V. Dai, N. A. Toan, and D. D. Tung, "A new design of IoT-based network architecture for monitoring and controlling power consumption in distribution grids," *International Journanl of Renewable Energy Research*, vol. 11, no. 3, pp. 1460-1468, 2021, doi: IJRER.V11I3.12337.G8293.
[29] K. Khanchuea, and R. Siripokarpirom, "A multi-protocol iot gateway and WiFi/BLE sensor nodes for smart home and building automation: design and implementation," in *Proceeding of the 10th International Conference of Information and Communication Technology for Embedded Systems (IC-ICTES)*, Thailand, March 2019, pp. 1-6, doi: 10.1109/ICTEmSys.2019.8695968.
[30] C. Santhosh, S. V. A. Kumer, J. G. Krishna, M. Vaishnavi, P. Sairam, and P. Kasulu, "Iot based smart energy meter using GSM," *Materials Today: Proceedings*, vol. 46, no. 9, pp. 4122-4124, 2021, doi: 10.1016/j.matpr.2021.02.641.
[31] J. Deny, A. B. Narasimha, R. G. V. Reddy, and S. Sathish, "Electricity monitoring and auto bill generation using IoT", in *Proceeding of the 3rd International Conference on Signal Processing and Communication (ICPSC)*, India, May 2021, pp. 695-698, doi: 10.1109/ICSPC51351.2021.9451738.
[32] V. Preethi, and G. Harish, "Design and implementation of smart energy meter," in *Proceeding of International Conference on Inventive Computation Technologies (ICICT)*, India, August 2016, pp. 1-5, doi: 10.1109/INVENTIVE.2016.7823225.
[33] A. Gehlot, R. Singh, P. K. Malik, L. R. Gupta, and B. Singh, *Internet of Things with 8051 and ESP8266*, 1st Ed., CRC Press, 2020.
[34] A. Maier, A. Sharp, and Y. Vagapov, "Comparative analysis and practical implementation of the ESP32 microcontroller module for the internet of things," in *Proceeding of Internet Technologies and Applications (ITA)*, UK, September 2017, pp. 143-148, doi: 10.1109/ITECHA.2017.8101926.
[35] K. Ahuja, and A. Khosla, "Network selection criterion for ubiquitous communication provisioning in smart cities for smart energy system," *Journal of Network and Computer Applications*, vol. 127, pp. 82-91, 2019, doi: 10.1016/j.jnca.2018.11.011.
[36] N. M. Khoa, L. V. Dai, D. D. Tung, and N. A. Toan, "An advanced IoT system for monitoring and analysing chosen power quality parameters in micro-grid solution," *Archives of Electrical Engineering*, vol. 70, no.1, pp. 173-188 2021, doi: 10.24425/aee.2021.136060.
[37] R. Khwanrit, S. Kittipiyakul, J. Kudtonagngam, and H. Fujita, "Accuracy comparison of present low-cost current sensors for building energy monitoring," in *Proceeding of International Conference on Embedded Systems and Intelligent Technology and International Conference on Information and Communication Technology for Embedded Systems (ICESIT-ICICTES)*, Thailand, May 2018, pp. 1-6, doi: 10.1109/ICESIT-ICICTES.2018.8442066.
[38] H. Kareem and D. Dunaev, "The working principles of ESP32 and analytical comparison of using low-cost microcontroller modules in embedded systems design," in *Proceeding of the 4th International Conference on Circuits, Systems and Simulation (ICCSS)*, Malaysia, 26-28 May 2021, pp. 130-135, doi: 10.1109/ICCSS51193.2021.9464217.
[39] T. B. Nguyen and P. H. Van, "Design, simulation and economic analysis of a rooftop solar PV system in Vietnam," *EAI Endorsed Transactions on Energy Web*, vol. 8, no. 35, 2021, doi: 10.4108/eai.27-1-2021.168504.

BIOGRAPHIES OF AUTHORS

Thanh Ba Nguyen received the bachelor's degree in Electrical and Electronics Engineering in 2005 and the master's degree in Power Systems Engineering in 2008 from Ho Chi Minh City University of Technology and Education, Vietnam. He is currently working as a Lecturer at Institute of Engineering and Technology, Thu Dau Mot University. He has total teaching experience of 14 years. His research areas include energy management, renewable energy, smart grid and IoT. He can be contacted at email: thanhnb@tdmu.edu.vn.

Tri Cao Nguyen received the bachelor's degree in Electrical Engineering from Ho Chi Minh City University of Technology in 2009 and master's degree in Electrical Engineering in 2012 from Ho Chi Minh City University of Technology and Education, Vietnam. He is currently working as a Lecturer at Institute of Engineering and Technology, Thu Dau Mot University. His research areas include IoT and smart automation. He can be contacted at email: tricn@tdmu.edu.vn.