Design of an IoT Energy Monitoring System

Conference Paper · November 2018

DOI: 10.1109/ICTKE.2018.8612412

Komkrit Chooruang
Nakhon Phanom University

Design of an IoT Energy Monitoring System

Komkrit Chooruang
Faculty of Engineering
Nakhon Phanom University
Nakhon Phanom, Thailand
komkritc@npu.ac.th

Kraison Meekul
Faculty of Engineering
Nakhon Phanom University
Nakhon Phanom, Thailand
blackmeekul@gmail.com

***Abstract*— In this paper, we design and implement a low-cost IoT energy monitoring system that can be used in many applications, such as electricity billing system, energy management in smart grid and home automation. The design is based on a low-cost PZEM-004T, using non-invasive CT sensors, SD3004 electric energy measurement chip and ESP8266 Wemos D1 mini microcontroller for retrieving data from sensor nodes and sending data to server via internet. The experimental results showed that the developed energy monitoring system can successfully record the voltage, current, active power and accumulative power consumption.**

***Keywords*— Internet of Things (IoT), energy meter, energy monitoring system.**

I. INTRODUCTION

The Internet of Things (IoT) is becoming more widely used technology nowadays. It is often used to refer to the growing network for connected devices, or “things”, that are capable of exchange data over on a low bandwidth network. IoT is being used in various areas, such as automotive industry, logistics, healthcare, smart grid and smart cities.

Recently, electric energy consumption growth has risen significantly and thus, needed greatly increased energy supply in the coming decades due to increasing population and economic development. This is leading to a demand-supply deficiency [1]. In many developed countries, automatic meter reading (AMR), advanced metering infrastructure (AMI) or smart energy meter with real-time energy information report have been implemented at the household level [2-4]. Thus, consumers will be able to see their usage in real-time, eventually encouraging them to use less energy to save money [5]. In addition, studies [6-8] have suggested that more energy can be saved or decreased in household level with real-time energy consumption feedback as compared to conventional indirect feedback like monthly bills. However, those smart meters are usually high cost and require large amounts of investments on communication medium infrastructure; hence in many developing countries, these might not be an efficient and affordable solutions.

II. RELATED WORK

Several studies have proposed the design of smart energy meter. In [9-11], their design were based on GSM network and employed database management to provide energy usages information for their customers. In [12], ZigBees combined with GSM based was proposed, in such system the energy metering nodes use the ZigBees communicate with the central node and send data to central computer via GSM.

In this work, we have developed an IoT low-cost energy monitoring system that utilize Wi-Fi, and MQTT (Message Queuing Telemetry Transport) protocol. The developed system can provides detailed measurement of energy usage and the patterns of energy consumption. Hence, the users can understand their electricity usage patterns and then can adapt their behavior to reduce their energy profile.

III. SYSTEM OVERVIEW

A. System Overview

The system comprises of energy monitoring nodes that use the Peacefair PZEM-004T, low-cost energy meter using a non-invasive CT (current transformer) sensor, the SD3004 energy measurement chip and microcontroller for measuring the voltage, current, active power and accumulative power consumption. The measured data will then be submitted to server via MQTT in JSON (JavaScript Object Notation) format. The Raspberry Pi 3 model B was chosen to run as a local server. Thus, users can access to get information of their energy consumption via web application locally or via Internet. The system overview is shown in Fig.1.

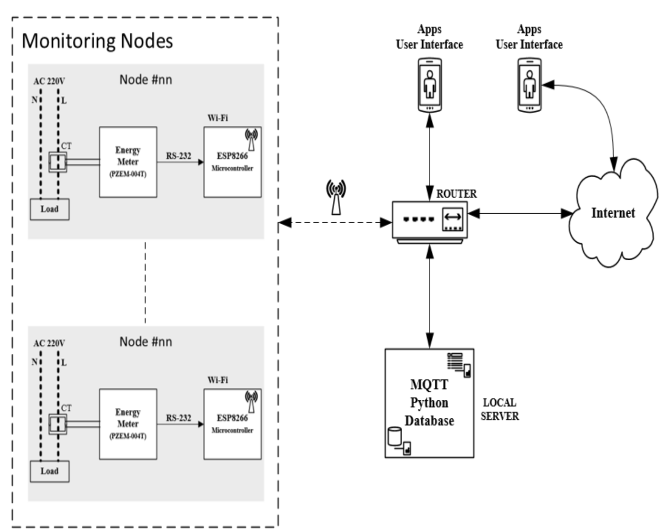

Figure 1. System overview.

978-1-5386-7159-7/18/$31.00 ©2018 IEEE

B. Energy Monitoring Nodes

In order to monitor energy usages, we utilize the PZEM-004T; it made by Peacefair Electronics. Its operation is based on the principle of current transformer. It uses a precision AC current transformer coil as a sensing part that has the output of 100A/100mA.

The PZEM-004T provides RMS voltage, RMS current and calculates active power and total energy usage over time or accumulative power consumption. The PZEM-004T uses SD3004 energy measurement SoC chip from SDIC microelectronics. It has very good measurement accuracy. Fig. 2 illustrates simple diagram of the developed IoT energy monitoring node.

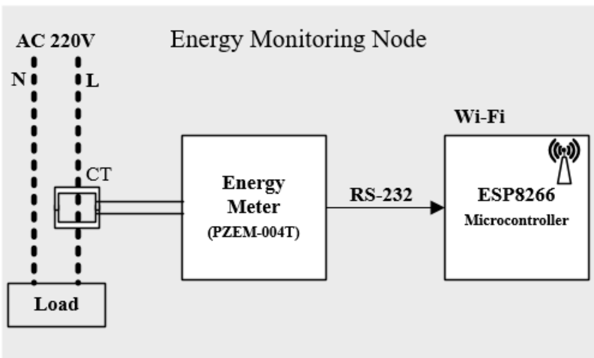

Figure 2. Diagram of IoT electric energy monitoring module.

In order to send measured data from the PZEM-004T to the network or the internet, we employed the ESP8266 Wemos D1 mini to communicate with the PZEM-004T via RS-232. Fig. 3 illustrates the prototype of energy monitoring node in which the PZEM-004T is connected with the Wemos D1 mini via RS-232 port. The firmware for Wemos D1 mini was developed using the Arduino software environments. The main function of the Wemos D1 mini is used to collect energy data from the PZEM-004T and send recived data to the server wirelessly, through Wi-Fi. The data will be sent to the server approximatly every 20 seconds. The JSON format is a lightweight data-interchange format and easy to understand. Therefore, JSON format is used for transmitting structured data over network connection via MQTT. The JSON data used in this system is represented in Fig. 4.

Figure 3. Prototype of energy monitoring node.


```
{
  "id":"emeter-node-01",
  "voltage":224.80,
  "current":2.66,
  "power":394.00,
  "accum":76939.00
}
```


Figure 4. JSON structured data format.

C. Energy Calcuation

Energy consumed per day can be determined in (1). The energy E in kilowatt-hours (kWh) per day is equal to the power P in watts (W) times number of usage hours per day t divided by 1000 watts per kilowatt:

$$E_{(\mathrm{kWh/day})} = P_{(\mathrm{W})} \times t_{(\mathrm{h/day})} / 1000_{(\mathrm{W/kW})}$$

(1)

For example, if we use desktop computer that requires power consumption of 300 watts and we use it for 8 hours per day. By following (1), thus this desktop computer will consume the electric energy per day at 2.4 kWh or 72 kWh per month. Hence, performing the calculation in (1), the energy consumptions are automatically stored and calculated in database on the server.

D. Local Server

The Raspberry Pi 3 model B is responsible to run server software packages at local network, the software include MQTT broker, Python, database server using InfluxDB, and data visualization.

E. MQTT Communication Protocol

MQTT is a publish/subscribe protocol, which is very simple and lightweight messaging, designed for constrained devices and low-bandwidth, unreliable networks. It is a good solution for our design since it provides an easy communication between the server and many IoT nodes [13-16]. The central server is so called a broker, and sensor nodes can subscribe to the topic and the topics are created automatically. It can also publish the data to topics of any kind of data. The broker then distributes the data to any node that has subscribed to that topic. The publishing can be done at 3 quality of service levels (QoS). In our setup, we use the Eclipse Mosquitto software that run as a broker on our local server, the Raspberry Pi 3.

F. Software

Since, the sensor data are constructed data type as MQTT messages that will be published to a self-hosted MQTT broker. Therefore, we wrote python scripts to subscribe to that MQTT topics and then stores all messages in time series data in the InfluxDB database [17]. The InfluxDB is a time series database. It is optimized for queries in the time domain. InfluxDB has been used for storing sensor data as time series. The main reason for this is that it allows to use the Grafana [18] for analyzing the data. Grafana is a web-based data visualizing tool that can connect to InfluxDB. Using the Grafana, we can setup custom dashboards, alerts and notifications from the data sets. Grafana has a web frontend that is very responsive.

energy monitoring system. It can be seen that in Fig. 7, the energy profile of the electric kettle was successfully recorded in the database system. According to the graph, it consumed electric energy around 1500 watts in boiling state and took about 3 minutes to boil water. Hence, this kind of energy tracking can be very useful as a tool to understand the energy consumptions behavior of appliances or electrical machines.

IV. Experimental Results

In this section, we demonstrate the operation of the developed IoT energy meter. It was experimentally implemented at our laboratory. Fig. 5 depicts the user-interface dashboard; the dashboard of the sensor node-1 was used as an example. The dashboards were created by using the Grafana. The dashboard consists of the gauges that indicate the active values of voltage, current and power. The graphs represent the measured energy data as a function of time. The energy were captured from the energy sensor node and then sent to the server. Each sensor has a unique ID and will send data every 20 seconds throughout the day, thus multiple sensor nodes can be deployed and data can be displayed simultaneously on the dashboard.

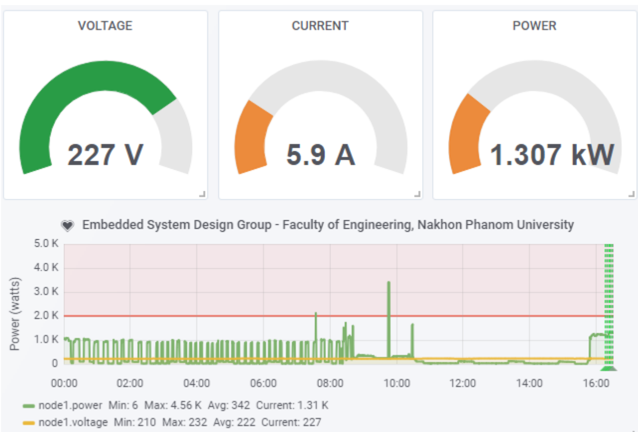

Figure 5. The dashboard of the developed energy monitoring system.

Fig. 6 shows the accuracy test in which the known load currents were varied and the measured currents from the sensor node were recorded. It can be seen that the reading accuracy of the measuring node was acceptable with the error less than 5%.

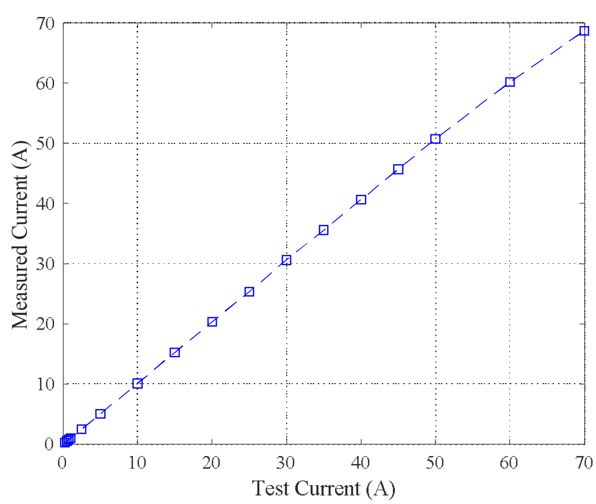

Figure 6. Result of the accuracy test.

An electric kettle, was used to demonstrate the energy profile tracking operation of the system. In this test, we want to track the energy profile of electric kettle using our developed

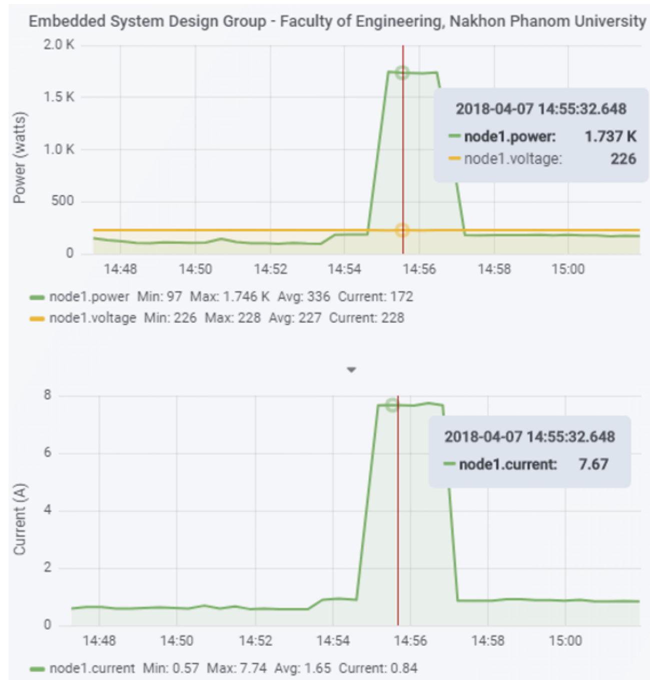

Figure 7. Energy consumption profile of the electric kettle.

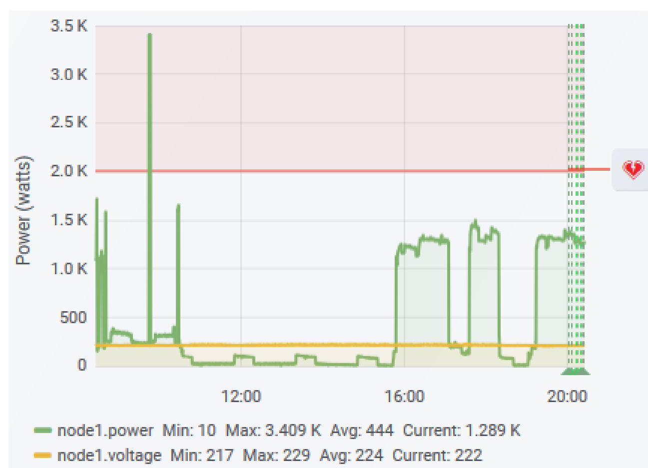

Figure 8. Energy monitoring and alert notification.

Fig. 8 illustrates the application of the developed system that will monitor the power consumption and compare the power reading with alert threshold. The alert threshold can be configured on the software. If the power consumption is above the alert threshold, the software will send notification via email.

V. Conclusion

The design of a low-cost IoT energy monitoring system is presented. This proposed system is suitable for energy monitoring and tracking applications. The sensor node is based on low-cost energy meter, PZEM-004T, CT sensors and ESP8266 Wemos mini microcontroller. The Raspberry pi 3 model B is used to serves as local server and store data in InfluxDB, a time series database. The experimental results showed that the developed energy monitoring system can successfully monitor voltage, current, active power and accumulative power consumption.

In future work, this system could be further developed to get more insight on energy usage profile and learn to automatically detect which appliance is in use.

References

[1] S. M. Amin and B. F. Wollenberg, "Toward a smart grid: power delivery for the 21st century," IEEE Power and Energy Magazine, vol. 3, no. 5, pp. 34-41, 2005.

[2] F. Benzi, N. Anglani, E. Bassi, and L. Frosini, "Electricity Smart Meters Interfacing the Households," IEEE Transactions on Industrial Electronics, vol. 58, no. 10, pp. 4487-4494, 2011.

[3] A. Zaballos, A. Vallejo, M. Majoral, and J. M. Selga, "Survey and Performance Comparison of AMR Over PLC Standards," IEEE Transactions on Power Delivery, vol. 24, no. 2, pp. 604-613, 2009.

[4] R. Rashed Mohassel, A. Fung, F. Mohammadi, and K. Raahemifar, "A survey on Advanced Metering Infrastructure," International Journal of Electrical Power & Energy Systems, vol. 63, pp. 473-484, 2014

[5] A. M. Vega, F. Santamaria, and E. Rivas, "Modeling for home electric energy management: A review," Renewable and Sustainable Energy Reviews, vol. 52, pp. 948-959, 2015.

[6] E. Taktak and I. B. Rodriguez, "Energy Consumption Adaptation Approach for Smart Buildings," in 2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA), 2017, pp. 1370-1377.

[7] M. Beaudin and H. Zareipour, "Home energy management systems: A review of modelling and complexity," Renewable and Sustainable Energy Reviews, vol. 45, pp. 318-335, 2015.

[8] K. Athira, A. R. Devidas, M. V. Ramesh, and V. P. Rangan, "User centered energy management scheme for smart buildings," in 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2017, pp. 1296-1302.

[9] H. G. R. Tan, C. H. Lee, and V. H. Mok, "Automatic power meter reading system using GSM network," in 2007 International Power Engineering Conference (IPEC 2007), 2007, pp. 465-469.

[10] M. Wasi-ur-Rahman, M. T. Rahman, T. H. Khan, and S. M. L. Kabir, "Design of an intelligent SMS based remote metering system," in 2009 International Conference on Information and Automation, 2009, pp. 1040-1043.

[11] L. Labib, M. Billah, G. M. S. M. Rana, M. N. Sadat, M. G. Kibria, and M. R. Islam, "Design and implementation of low-cost universal smart energy meter with demand side load management," IET Generation, Transmission & Distribution, vol. 11, no. 16, pp. 3938-3945, 2017.

[12] A. H. Primicanta, N. Mohd Yunus, and M. Awan, "ZigBee-GSM based Automatic Meter Reading system," in 2010 International Conference on Intelligent and Advanced Systems, 2010, pp. 1-5.

[13] M. A. Prada, P. Reguera, S. Alonso, A. Morán, J. J. Fuertes, and M. Domínguez, "Communication with resource-constrained devices through MQTT for control education," IFAC-PapersOnLine, vol. 49, no. 6, pp. 150-155, 2016.

[14] M. H. Amaran, N. A. M. Noh, M. S. Rohmad, and H. Hashim, "A Comparison of Lightweight Communication Protocols in Robotic Applications," Procedia Computer Science, vol. 76, pp. 400-405, 2015.

[15] K. Chooruang and P. Mangkalakeeree, "Wireless Heart Rate Monitoring System Using MQTT," Procedia Computer Science, vol. 86, pp. 160-163, 2016.

[16] HiveMQ. MQTT 101 – How to Get Started with the lightweight IoT Protocol. Available: https://www.hivemq.com/blog/how-to-get-started-with-mqtt

[17] InfluxData. The modern engine for Metrics and Events. Available: https://www.influxdata.com/

[18] G. Labs. Grafana; the analytics platform for all your metrics. Available: https://grafana.com/