ESTEEM Academic Journal
Vol. 18, March 2022, 48-60

The IOT Energy Monitoring System (EMOSY) using Energy Scavenging Concept

Nur Amalina Muhamad[1], Norhalida Othman[2], Ezril Hisham Mat Saat[3], Noor Hasliza Abdul Rahman[4] and Masmaria Abdul Majid[5]
[1,2,3,4,5]*College of Engineering, Universiti Teknologi MARA, Cawangan Johor, Kampus Pasir Gudang, 81750, Masai, Johor, Malaysia*
**corresponding author: [2]halida8142@uitm.edu.my*

ARTICLE HISTORY

Received
19 December 2021

Accepted
4 March 2022

Available online
31 March 2022

ABSTRACT

The adoption of an energy monitoring system to give customers information on their electricity consumption has received a lot of attention. Many technological solutions are now available due to advancements in electronics and computing. These solutions are important elements of a long-term future. Furthermore, with the rapid growth of information technology, particularly IoT, a better energy monitoring meter may be created by delivering real-time consumption data. This paper shows the development of a low-cost energy monitoring system which can store, analyze and display comprehensive energy consumption data. The IoT Energy Monitoring System named as EMOSY is developed using the energy scavenging concept. The ambient stray electric field is collected and converted from energy to power consumption using voltage detection circuit and Node MCU (ESP8266) as the microcontroller to retrieve data from sensor nodes and transfer it to a server via the internet. The database revealed that the built energy monitoring system can record electrical signals, power consumption, and electricity bills easily. This meter was placed near to the electrical devices then the device was switched on and off. The data will be sent and saved into the database. MySQL is used for data manipulation in database management and a cloud-based platform for website support has been used to see a real-time overview of how power is being consumed daily. This system was aimed to raise customer awareness of their energy consumption patterns by collecting data on their usage and being informed of their power usage.

Keywords: *IOT energy monitoring; Arduino; Electric field; Energy meter; Energy scavenging*

1. INTRODUCTION

Due to rising population and economic development, electric energy consumption has recently expanded dramatically, necessitating greater energy supply in the future decades. Energy monitoring is a technique that aids in the comprehension and visualization of energy consumption. The unmonitored energy leads to a demand-supply deficiency [1]. With the rapid advancement of information technology, especially the Internet of Things (IOT), it is now possible to create a more effective energy monitoring system by providing real-time consumption data. The application of IOT is widely embedded in multi sectors such as in agriculture for smart greenhouse technology [2-3], auto robots for collecting garbage [4], energy monitoring [5] and many more.

p-ISSN 1675-7939; e-ISSN 2289-934

Smart energy monitoring is critical for reducing the environmental impact of energy production. Many developed countries have implemented advanced metering infrastructure such as Automated Meter Reading (AMR) or smart energy meters with real-time energy information reports, at the household level [6-8]. AMR is a method that allows devices to be accessed remotely and collects electronic data provided by consumer units' meters. The information is subsequently collected electronically and communicated to the utility company by radio frequency, telephone, power line, or satellite connection [9]. A smart energy meter (SEM) is an electronic device with an energy meter chip for monitoring electric energy usage, data connection protocols, security features, a data display interface, and other characteristics [10]. The difference of smart meters from traditional energy meter devices is by its communication ability. Consumers may now view their energy usage in real time, which may encourage them to use less energy to save money by allowing energy monitoring [11-12]. Furthermore, studies demonstrate that real-time energy consumption feedback saves or reduces energy use at home level more effectively than typical indirect feedback like monthly bills [13-15].

S. R. Mohd Nasir et al. studies on the awareness and acceptance in using smart meters by energy customers in Malaysia [16]. The result shows regardless of demographic profiles and background, good awareness of smart living concepts was shown by positive feedbacks from the respondents towards the smart meter. Most of the respondents expect savings between 20% to 60% of electricity bills. To achieve this expectation energy savings using efficient appliances and adapting to smart living practices is essential. Hence, this shows the need of energy monitoring as a first step for saving electricity.

Besides that, another study has been conducted by Shamshiri, Meysam et al. on energy monitoring utilising an IoT-based Energy Management System (EMS) that use the industrial Modbus communication protocol. This IoT-enabled technology enables sub-metering-level monitoring of electricity usage. Furthermore, the half-hourly time series load profiles can provide useful information for the energy manager to take the appropriate energy-saving measures. However, in this project, various digital meters (Schneider, Siemens and Mikro) were purchased and embedded into the system and hence increasing the cost of energy monitoring system [17]. Claire Fulk, Grant Hobar, Kevin Olsen et al. proposed an energy monitoring system that is efficient, intuitive, and cost-effective for each room in a house. The energy monitoring system is low-cost since it does not depend on any smart meter. Current Transformer (CT) clamp was used as a circuit breaker connected to an AC lead [18]. The analog to digital converter (ADC) will convert the collected analog signal into digital signals. Then the converted data is sent to the Raspberry Pi Unit and then to the database.

However, many available smart meters are often expensive and require considerable investments in communication medium infrastructure, making them inefficient and unaffordable in many poor nations. To deal with this problem, the implementation of energy scavenging is applied to the EMOSY. Ambient energy scavenging is the process of extracting usable energy from natural and man-made sources that surround us in our daily lives. Energy scavenging is the collection of small amounts of ambient energy to power wireless devices [19-20]. Since IOT is now piloting smart technology, the usage of energy is also high. Batteries to power smart IOT technology are not well present nowadays due the environmental impact.

p-ISSN 1675-7939; e-ISSN 2289-934

IoT energy monitoring technology has an impact on human life with the purpose of lowering electrical energy usage. This project proposes a low-cost energy monitoring and control system based on IoT devices. The objective of the project is to develop of a low-cost IoT Based Energy Monitoring System using Arduino and electrostatic sensors as the detection mechanism of electrical current flow. The PHP, XAMP and MySQL language for energy monitoring system databases were then developed for capturing real-time processing data.

From the review, it is seen that the usage of electrostatic sensors has never been used for low-cost energy monitoring systems. This energy monitoring system will be placed besides electrical appliances of air conditioning and personal computer. The energy consumption data for each unit was collected and maintained in a cloud-based database that could be analyzed and reported on for energy conservation and analysis. This system can also be used to record and analyze data by connecting to a computer via WiFi. This technology is part of a global energy monitoring system that provides real-time energy usage statistics to assist individuals in saving money on their energy bills.

The novelty of this project is the application of energy scavenging concept for energy monitoring purposes. The concept of stray electric field, charge and current is embedded in the design of electrostatic sensors. The electrostatic sensor detects the intensity of this stray electric field and calculates it as electric potential. Around an electrified object, an electric field that is proportional in strength to the amount of charge is produced. The intensity of the electric field is then converted into electric potential. Electric potential is proportional to the intensity of the electric field, but as it moves away from an electrified object, the intensity of the electric field decreases. Therefore, the electrostatic sensor sets a distance between the electrified object and the sensor using a controller to get an optimum electrical signal. In addition, the sensor detects the signal to indicate the electrical appliance’s state either ON or OFF condition. It does not measure energy consumption of the appliances directly. However, if the period (time) of the devices turned ON are known and the power rating of the electrical appliances are also known, the estimated energy consumption of the electrical appliances can be calculated.

2. METHODOLOGY

The focus of EMOSY's development is on creating an energy monitoring system that is simple, low-cost, and reliable. Several key stages in the research's evolution are depicted below.

2.1 System Overview

The energy monitoring system comprises NodeMCU V3 ESP8266 as a microcontroller, electrostatic sensor, an antenna, a database, and a website monitoring page. This energy monitoring system is the best solution for a web-based energy monitoring system that detects the ON or OFF status of electrical appliances through an electric field. Then, the data will be transferred to the server for process monitoring and the energy consumption in the web database will be recorded. This prototype will be attached to the electrical appliances such as air-conditioning, and etc. The overview of the energy monitoring meter and the connection of EMOSY with electrical devices is shown in Figure 1.

p-ISSN 1675-7939; e-ISSN 2289-934

ESTEEM Academic Journal
Vol. 18, March 2022, 48-60

Figure 2 shows the flowchart of EMOSY. The sensor will detect electrostatic presence and will amplify the small current detected and send the amplified signal to the microcontroller's analog input. This analog input will be converted into digital form (10 bits ADC). These values will be sent and saved into the database together with the date and time of data captured. The microcontroller is programmed to read sensor values and send them to the database every 5 minutes. The shorter time of sampling will increase the efficiency of data capture, but it will also increase the amount of data stored in the database. Therefore, 5 minutes of time sampling has been selected in this research to minimize data storage while maintaining acceptable efficiency of data captured.

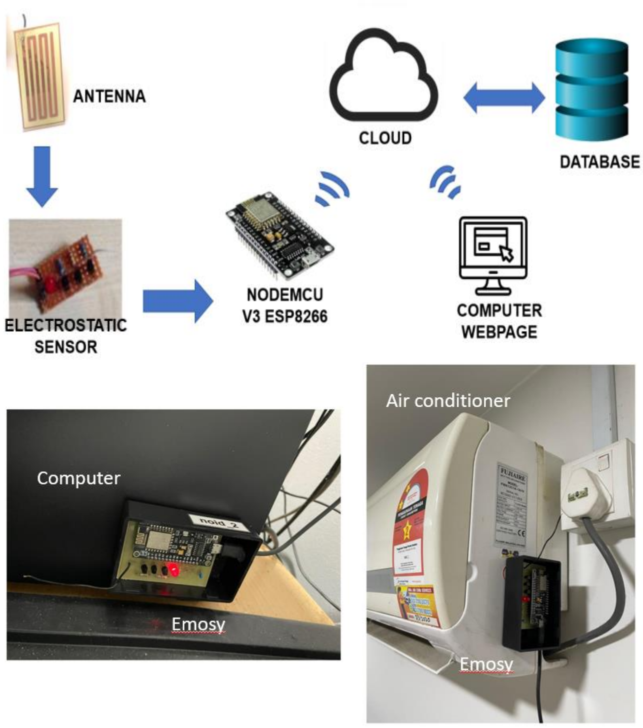

Figure 1: The Overview of Energy Monitoring Meter (top), connection of EMOSY with electrical devices (bottom)

p-ISSN 1675-7939; e-ISSN 2289-934

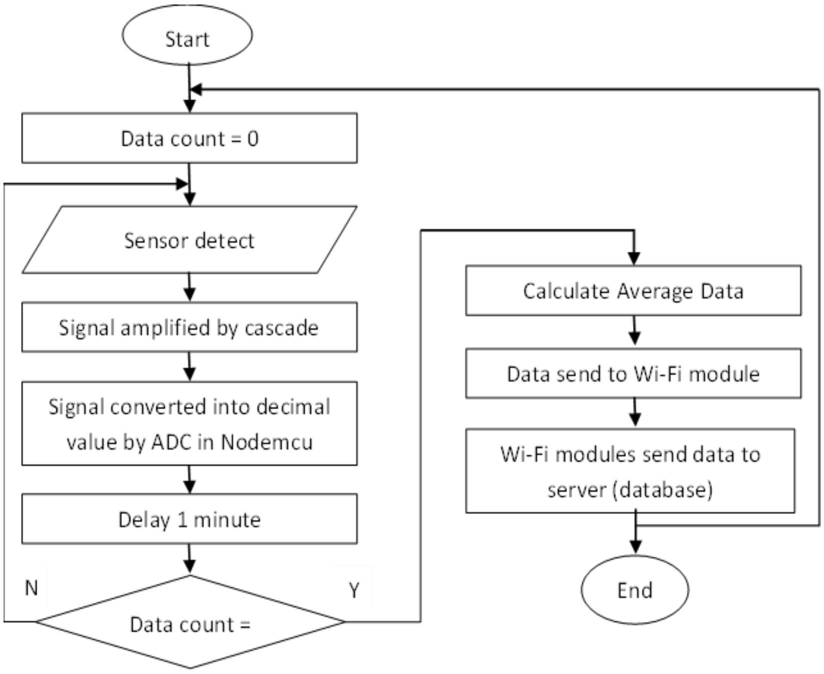

Figure 2: Flowchart of EMOSY

2.2 Electrostatic Sensor and Antenna

The electrostatic sensor records the intensity of the electrical appliances' electric field and calculates it as an electric potential. An electric field is generated around an electrical appliance, while the strength of this electric field is proportional to the amount of charge. Once the electrostatic is detected, it indicates that the electrical appliance is turned ON and vice versa. The higher reading indicates that the electrical appliance is in ON mode condition, while the lower reading is subjected to OFF mode condition.

For sensor development, the voltage detector concept is applied in this system. The non-contact voltage detectors have an antenna to pick up the leakage current on active live wires. The leakage current flows through the antenna and is fed to a very high gain amplifier. This system is based on the Darlington pair configuration in which three NPN 2N222 transistors are cascaded and connected with three resistors. The value of the ratio of the collector-emitter current to the base for this system is approximately 200. Figure 4 below shows the schematic diagram connection between transistors, resistors, and an antenna with NodeMCU. The amplifier output goes high when weak electrical signals are detected. The amplified voltage is connected to an LED to indicate the signal. The principle of this electrostatic circuit is to detect this changing electric field and indicate the presence of the voltage. The connection of the electrostatic sensor and antenna is shown in Figure 3.

p-ISSN 1675-7939; e-ISSN 2289-934

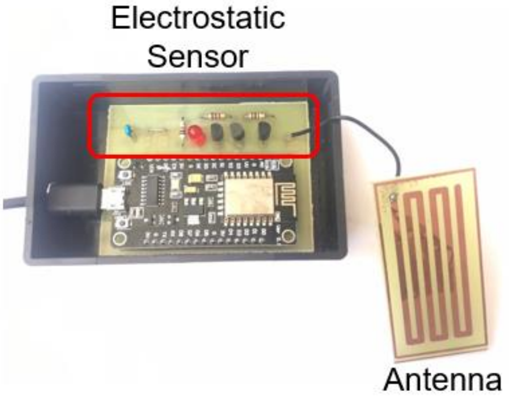

Figure 3: The connection of antenna and electrostatic sensor

Here, the basic concept of electric and magnetic fields (EMF) is used. EMF are found when there is electricity which include all electrical appliances equipment and wiring. AC power generates an electric field as well as a magnetic field. The distinction between an electric and magnetic field is that an electric field is created by voltage, but a magnetic field is created by current flowing via wires or electrical equipment. The presence of an electric field can be seen everywhere in the environment, but it cannot be seen with the naked eye. This is because all charged objects generate an electric field that travels into the space around them.

Therefore, a fabricated antenna is designed to detect the surrounding electric field. The antenna is connected to the base of the first NPN transistor as in Figure 4 below. This antenna will be placed close to the electrical appliances' supply to detect the electrostatic field. Then, an electric field will be produced and thus, voltage will be induced. This voltage will be amplified through the first transistor. This amplification process will be repeated through the third transistor. Lastly, the output signal after the third amplification process will be sent to the analog pin mode of NodeMCUV3 and will be converted into 10 bits digital form by Analog to Digital Converter (ADC) that is built in the NodeMCU.

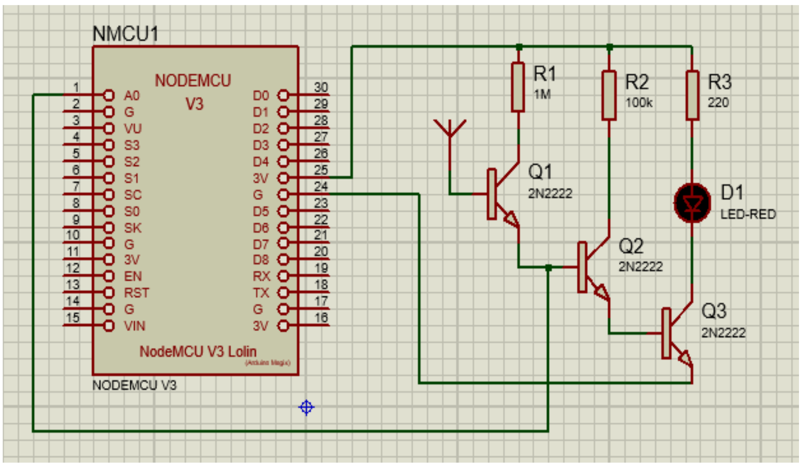

Figure 4: Schematic diagram of Darlington pair configuration with antenna

p-ISSN 1675-7939; e-ISSN 2289-934

2.3 NodeMCU V3 ESP8266

Figure 5 shows the NodeMCU V3 ESP8266 microcontroller. Every 5 minutes, the read data from the sensor is programmed into the NodeMCU V3 ESP8266 and sent to the database via a WiFi module. ESP 8266 is a WiFi module that has been built in the NodeMCU to send data or signals from the microcontroller to a web server's database. Prior to communicating with the database server, this WiFi module must be initialized using the local WiFi SSID and password. This data represents the strength of the electrical field of the electrical appliances in mode ON or OFF state. Furthermore, these data are set in multiple decimal value places ranging from 0 to 1024 depending on the distance between the antenna and the appliances' power supply unit.

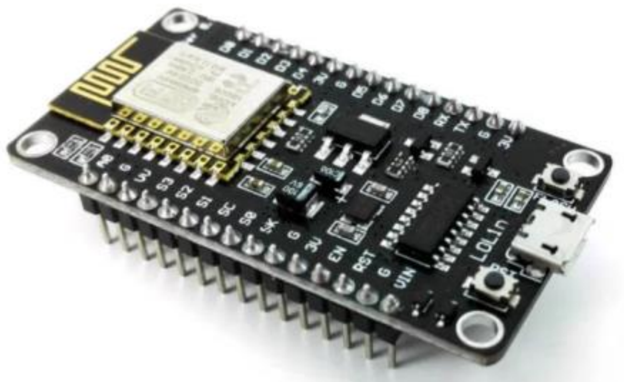

Figure 5: NodeMCU V3 ESP8266 microcontroller

2.4 Energy Calculation

Every electrical device has a manufacturer's rating. For example, the nominal power for a computer and aircond used in this project is 650 W/h and 750 W/h. If the power and usage time are known, the total energy consumption per day for these electrical appliances can be calculated in Equation (1).

$$E = p \times t \tag{1}$$

where:
E = energy
P = power in Watt (W)
t = electrical appliances usage hours per day (hr)

The tariff rates for power bills have been provided by Tenaga Nasional Berhad (TNB) Malaysia. This tariff is used to determine the estimated billing and the current rate for the domestic category is shown in Table 1. The minimum monthly charge is RM 3.00 set by the TNB Malaysia.

p-ISSN 1675-7939; e-ISSN 2289-934

Table 1: Tariff of Domestic Category in Malaysia

Tariff Category	Unit	Current Rate (RM)
1-200 kWh/ month	Sen/kWh	21.80
201-300 kWh/ month	Sen/kWh	33.40
301-600 kWh/ month	Sen/kWh	51.60
601-900 kWh/ month	Sen/kWh	54.60
901 kWh onwards/ month	Sen/kWh	57.10

3. RESULT AND DISCUSSIONS

In this paper, the energy monitoring system that has been developed in this project is able to monitor the power consumption and bill electricity of electrical devices. The device as shown in Figure 6 is small and portable as it can easily move and be installed on any electrical devices.

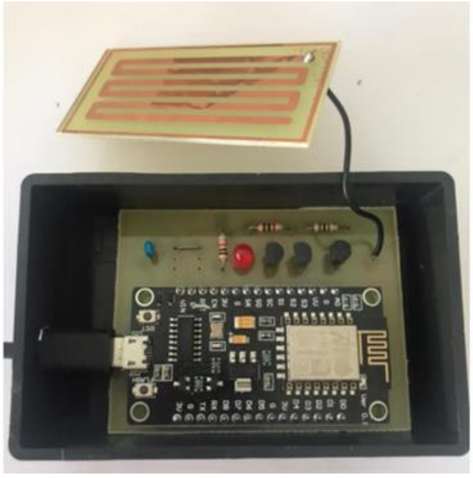

Figure 6: The prototype of energy monitoring system

The dashboard of an energy monitoring system is shown in Figure 7. As the fetching data was set, the data can be monitored in real time every 5 minutes. The dashboards were made with the PHP, XAMP, and MySQL programming languages. The dashboard consists of the value of energy consumption of each electrical device, total energy consumption, estimated electricity cost and real time sensor status. Each sensor is identified by a unique ID, and data is sent every 5 minutes throughout the day. The noid 1_ and noid_2 represent the energy monitoring of a computer and air conditioning, respectively. Multiple sensor nodes can be installed here, and the data can be shown on the dashboard.

Figure 8 shows the selection of the period of energy monitoring. The data can be seen from monthly, weekly and daily for each noid. The data statistics such as total signal reading, active signal detection, active time, estimated energy consumption, equipment activity and estimation cost can be determined. The graphs below show the energy data as a function of time as measured. The energy was captured and transferred to the server from the energy sensor node. Figure 9 and 10 show the captured data of noid_1 and noid_2. The red and orange line in the

p-ISSN 1675-7939; e-ISSN 2289-934

graphs indicate the threshold value of the electrical devices. A high threshold value indicates that the device is switched on, whereas a low threshold value implies that it is turned off. Hence, it is important to determine the threshold value of each electrical device because the electric field can be detected even if the equipment is switched off but not unplugged from the main power socket. However, the electric field strength will increase as the voltage rises. The threshold voltage for noid_1 is between 481 - 487 V while the threshold voltage for noid_2 is between 77 – 78 V. These values can be measured during installation of the sensor on the electrical appliances. Few testings needed to be done during installation by turning ON and OFF for a few minutes to see these threshold values.

The threshold value for appliances during ON state is higher compared to OFF state due to electrostatic power supply. Once these values have been identified, it can be set for each electrical appliance through the setting page on the website. Each device may have different low threshold and high threshold value depending on the electrostatic strength detected.

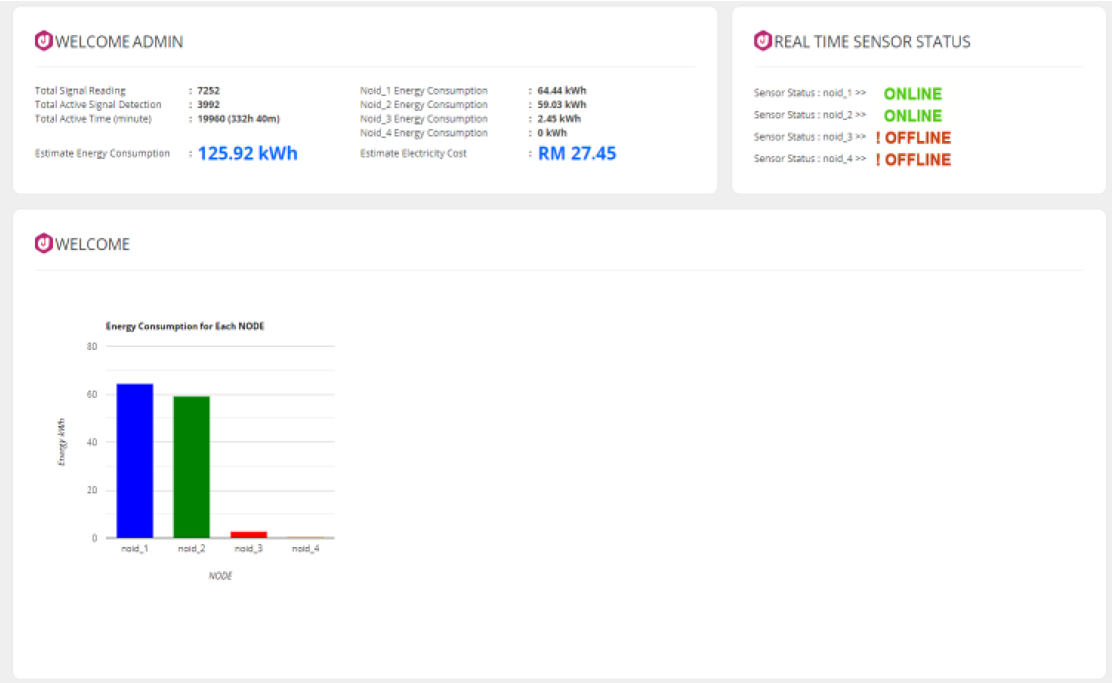

Figure 7: The dashboard of energy monitoring system

p-ISSN 1675-7939; e-ISSN 2289-934

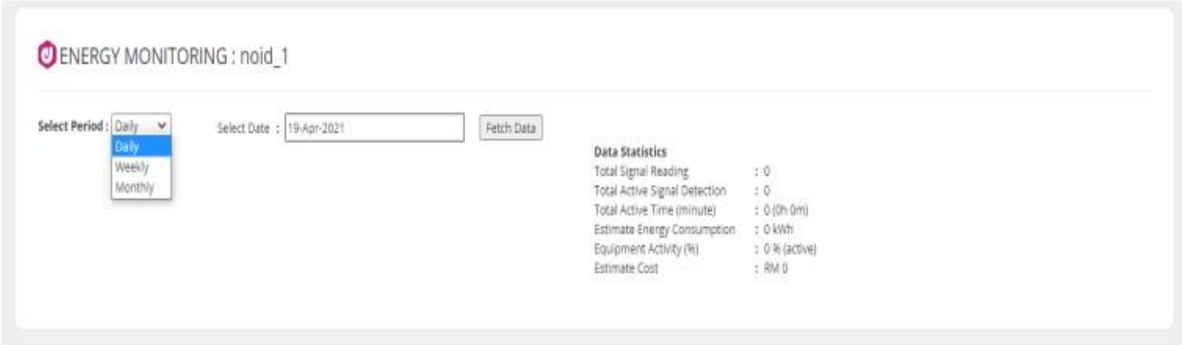

Figure 8: The selection period of energy monitoring

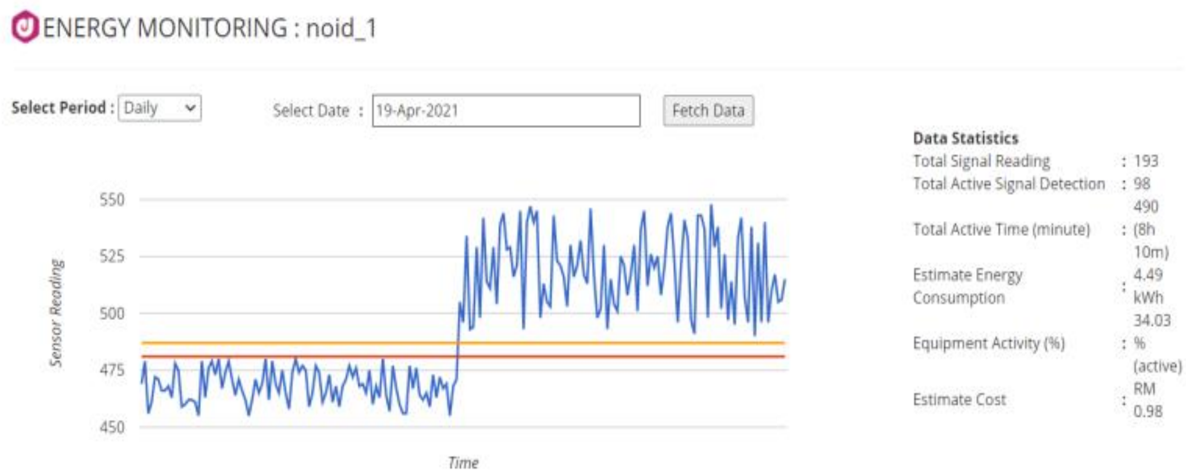

Figure 9: The captured data of noid_1

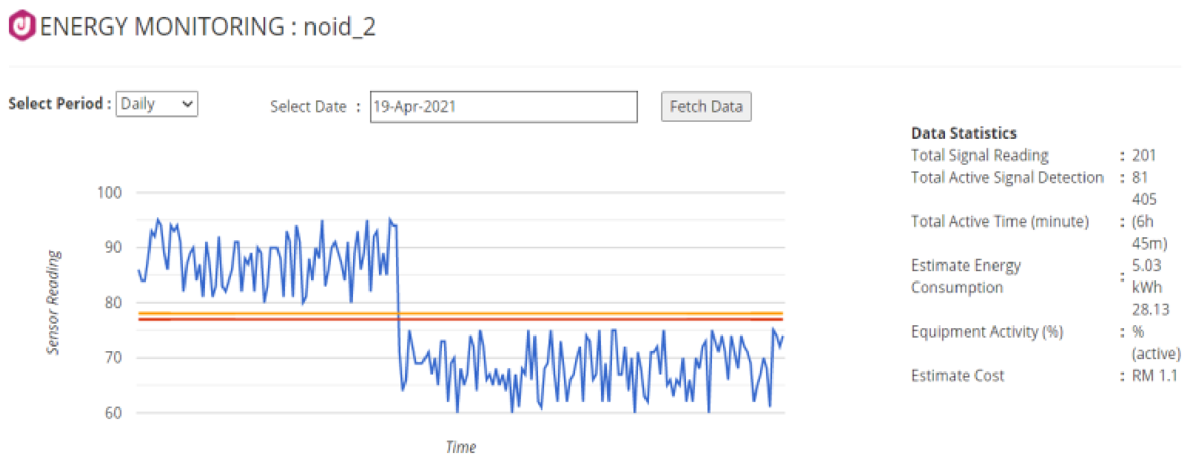

Figure 10: The captured data of noid_2

The sensor sends the analog value and the microprocessor converts the signal into digital form (10 bits ADC). The calculation of voltage detection value is shown in Equation (2).

p-ISSN 1675-7939; e-ISSN 2289-934

ESTEEM Academic Journal
Vol. 18, March 2022, 48-60

$$\text{Voltage detection value} = \left(\frac{\text{digital read}}{1024}\right) \times 5\text{V} \tag{2}$$

Hence, the total active signal detection and the total active time(min) shown in Figure 9 and 10 represents all the digital data for ON state mode of noid_1 and noid_2. Then, the power rating (W/h) for noid_1 and noid_2 was set to 650 W/h and 750 W/h for noid_2. This is the standard power rating for computers and air conditioning. The estimated energy consumption was then calculated by mulitiplying the power rating and the total active time. Finally, the estimated cost can be determined using the tariff rates by the TNB. Figure 11 shows the example of collected data in the database for every 5 minutes.

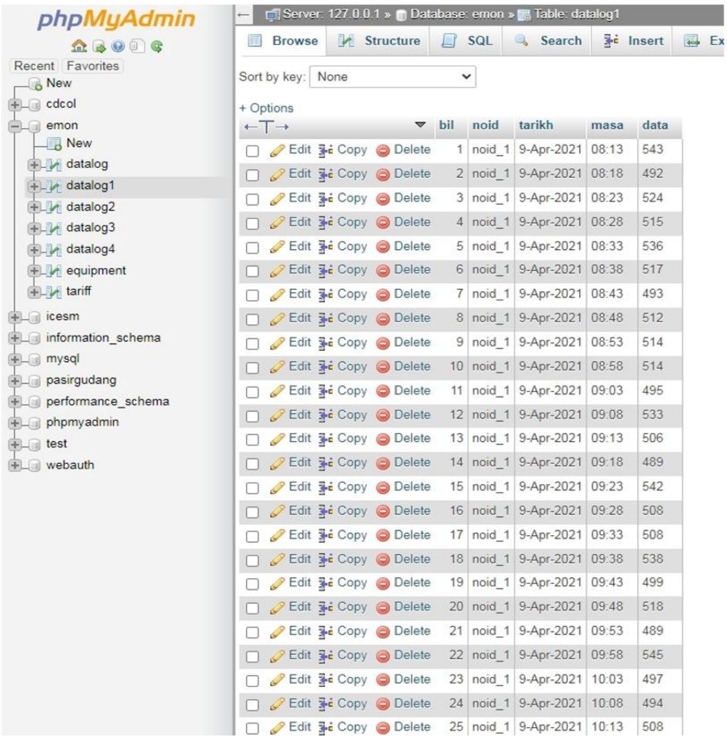

Figure 11: Data collection for every 5 minutes

4. CONCLUSION

This project proposes a low-cost energy monitoring meter based on IoT devices by using the energy scavenging concept. These smart Internet of Things devices capture and store energy usage data from each unit in a cloud-based database. Then, the energy conservation and the analysis can be analysed and produced. The energy usage profiles and detailed breakdown of which appliances contribute to the overall demand profile were useful to the users. Thus, this energy monitoring is essential for building energy efficiency because it provides valuable data for baseline studies and evaluations of the activities and actions that have been implemented. Hence, the cost effective for this project is low-cost compared to the available smart energy meter.

p-ISSN 1675-7939; e-ISSN 2289-934

ACKNOWLEDGEMENT

The authors are grateful for the financial support by the Universiti Teknologi MARA, UiTM Cawangan Johor, Kampus Pasir Gudang under 'Geran Bestari' (600-TNCPI 5/3/DDN (01) (012/2020).

REFERENCES

[1] S. Massoud Amin and B. F. Wollenberg, “Toward a smart grid: power delivery for the 21st century” *IEEE Power Energy Mag.*, vol. 3, pp. 34-41, 2005.

[2] N. Bafdal and I. Ardiansah, “Application of Internet of Things in Smart Greenhouse Microclimate Management for Tomato Growth” *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 11, no. 2, pp. 427–432, 2021.

[3] I. Ardiansah, N. Bafdal, E. Suryadi, and A. Bono, “Greenhouse monitoring and automation using arduino: A review on precision farming and Internet of Things (IoT)” *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 10, no. 2, pp. 703–709, 2020.

[4] S. Nuanmeesri and L. Poomhiranb, “Optimization Shortest One-Way Path for Energy Saving Auto Robot Collecting Floating Garbage using Fast Approximate Nearest Neighbor Search” *Int. J. Adv. Sci. Eng. Inf. Technol*., vol. 11, no. 2, pp. 457–464, 2021.

[5] I. Bagus, G. Purwania, I. N. S. Kumara, and M. Sudarma, “Application of IoT-Based System for Monitoring Energy Consumption” *Int. J. Eng. Emerg. Technol.*, vol. 5, no. 2, pp. 81–93, 2020.

[6] F. Benzi, N. Anglani, E. Bassi, and L. Frosini, “Electricity smart meters interfacing the households,” IEEE Trans. Ind. Electron., vol. 58, pp. 4487 – 4494, 2011.

[7] A. Zaballos, A. Vallejo, M. Majoral, and J. M. Selga, “Survey and performance comparison of AMR over PLC standards” *IEEE Trans. Power Deliv.*, vol. 24, pp. 604 – 613, 2009.

[8] R. Rashed Mohassel, A. Fung, F. Mohammadi, and K. Raahemifar, “A survey on Advanced Metering Infrastructure” *Int. J. Electr. Power Energy Syst.*, 2014.

[9] F. D. Garcia, F. P. Marafao, W. A. De Souza, and L. C. P. Da Silva, “Power Metering: History and Future Trends” *IEEE Green Technol. Conf.*, pp. 26–33, 2017.

[10] M. M. Rahman, Noor-E-Jannat, M. O. Islam, and M. S. Salakin, “Arduino and GSM based smart energy meter for advanced metering and billing system” *2nd International Conference on Electrical Engineering and Information and Communication Technology*, iCEEiCT 2015, 2015.

[11] N. M. Yoeseph, M. A. Safi’Ie, and F. A. Purnomo, “Smart Energy Meter based on Arduino and Internet of Things” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 578, no. 1, 2019.

[12] D. Lestari, I. D. Wahyono, and I. Fadlika, “IoT based Electrical Energy Consumption Monitoring System Prototype: Case study in G4 Building Universitas Negeri Malang” Proc. - 2017 *Int. Conf. Sustain. Inf. Eng. Technol. SIET 2017*, vol. 2018-Janua, pp. 342–347, 2018.

[13] E. Taktak and I. B. Rodriguez, “Energy consumption adaptation approach for smart buildings,” Proc. IEEE/ACS *Int. Conf. Comput. Syst. Appl. AICCSA*, vol. 2017-October, pp. 1370–1377, 2018.

[14] 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.

[15] K. Athira, A. R. Devidas, M. V. Ramesh, and V. P. Rangan, “User centered energy management scheme for smart buildings” *2017 International Conference on Advances in Computing, Communications and Informatics*, ICACCI 2017.

[16] S. R. Mohd Nasir et al., “Awareness and Acceptance in Using Smart Meter by Energy Customers in Malaysia” *Environ. Proc. J.*, vol. 5, no. SI2, pp. 35–41, 2020.

p-ISSN 1675-7939; e-ISSN 2289-934

[17] M. Shamshiri, C. K. Gan, K. A. Baharin, and M. A. M. Azman, "IoT-based electricity energy monitoring system at Universiti Teknikal Malaysia Melaka" *Bull. Electr. Eng. Informatics*, vol. 8, no. 2, pp. 683–689, 2019.

[18] C. Fulk, G. Hobar, K. Olsen, S. El-Tawab, F. Rahman, and P. Ghazizadeh, "Cloud-based Low-cost Energy Monitoring System through Internet of Things" *2019 IEEE Int. Conf. Pervasive Comput. Commun. Work. PerCom Work. 2019*, pp. 322–327, 2019.

[19] M. E. Kiziroglou and E. M. Yeatman, "Materials and techniques for energy harvesting" *Woodhead Publishing Limited*, pp. 541-572, 2012.

[20] F. Yang, L. Du, H. Yu, and P. Huang, "Magnetic and electric energy harvesting technologies in power grids: A review" *Sensors (Switzerland)*, vol. 20, no. 5, pp. 1–12, 2020.

p-ISSN 1675-7939; e-ISSN 2289-934