A Low Cost Electricity Monitoring Wireless Sensor Network

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Abstract: As electricity price increases, the electricity consumption should be taken into account and managed wisely. For schools, universities, or industries having a number of buildings, each building should be equipped with a kWh meter. Installing a branded kWh meter in every building could be too expensive. This research aims to develop a low cost electricity monitoring system that consists a number of sensor nodes (SNs), a sink/gateway, and a server. The SNs and gateway are built based on Arduino boards. LoRa radio is used to establish communication between SNs and the gateway, while WiFi radio is utilized to perform communication between the gateway and campus internet network where the server is connected. Research activities includes SN and gateway prototype building, sensors calibration, data communication testing, link measurement, installation, and system running test. The system with five SNs has been built and installed at five buildings in the campus of Politeknik Negeri Samarinda. According the measurement during running test, the RSSI and SNR are mostly better than the value obtained in preliminary link test. Furthermore, the monitoring system does not give only electricity consumption pattern, but figures of installation problems, which is important for electrical installation improvement.

1 INTRODUCTION

In Indonesia, electricity tariff always increases almost annually. The tariff is increased to reduce the electricity subsidy for the middle to high classes, keep the service reliable, and to enhance the electrification (PT. PLN, 2021). Therefore, the electricity consumption must be managed properly to save the cost that may appear due to inadvisable use of electricity.

Electrical consumption is normally measured by a kilowatt hour meter (kWh meter) either analogue or digital. Customers rely on kWh meter to measure the electricity they have used during the past period. When they found that the amount of electricity in the previous period is high, they might consider to control the electricity consumption in the next period. For schools, universities, or industries having several buildings in their area, a kWh meter should be installed in every building. It is particularly important as each building may have different electricity consumption characteristic. Lack of kWh meter in every building could make electricity utilization policy becoming unsuitable.

Furthermore, rather than utilizing conventional kWh meter where people must visit periodically to read the electricity consumption such as in (Pasurono, 2013), people nowadays tend to use an integrated monitoring system where kWh meter installed in every building sends data report to a central station periodically. As such, no reader is required to observe the kWh meter. This trend rises due to the emerge of internet of things (IoT). Moreover, the integrated monitoring system is commonly able to measure other electrical parameters such as voltage, current, frequency, and power factor. Therefore, there will be more data to analyse the consumption characteristic. In this system, the data could be reported 24/7 with a certain period such every hour.

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The price of integrated system such as in (Eyedro, 2021) is USD 299 or over IDR 4 million per unit. It is just the price of sensor node and does not include the server, shipping, and installation. For industries, installing every building with such a unit may not be a problem as measuring the electrical load characteristic is required. The cost of metering procurement might not as high as the outcome of controlling the electricity consumption, where they could save the cost significantly. However, for many schools and universities, it could be very costly. Hence, a low cost electricity monitoring wireless sensor network developed in this research could be a solution.

The system developed in this research comprises a number of sensing units (ie. sensor node) that is installed next to main panel available in every building. The sensor node (SN) measures almost all electrical parameters and displays them on a liquid crystal display (LCD). The data of several parameters are also sent periodically to a gateway through wireless network.

Once accepting the data, the gateway forwards data to the server that is prepared for campus resources monitoring. Since the server connects to the campus internet network, the gateway should have an access to the campus internet as well. The server saves the data and could display it as a simple statistic form. Every person who has authority would be given an access to the data, and hence could monitor it from everywhere every time.

To compare with similar research, below are several research on Arduino based energy meter. In (Rajput, 2018) an energy meter is developed to provide prepaid system that utilizes GSM technology for data communication. Through this system, consumers are allowed to manage their electricity consumption by paying up front. Another research reported in (Mithya, 2019) builds energy meter that is able to send message to both customer and the electricity company through GSM. When electricity consumption is beyond a specific threshold, an alarm is sent. While both projects use GSM communication technology, a smart energy meter developed in (Kanakaraja, 2021) utilizes LoRa WAN as the communication system. The energy meter allows the user to monitor energy consumption every time from everywhere. All systems above generally focus on home energy meter and concern about single sensor node. In contrast, the system introduced in this paper focus on energy measuring network in institution local area with a number of sensor nodes.

2 SYSTEM DESCRIPTION

The architecture of the monitoring system network is shown in figure 1. That is similar with the common wireless sensor network (WSN) architecture described in (Akyildiz, 2002). A unit namely sensor node (SN) is built in a panel box and installed next to the main panel. Three current transformers and a number of cables from the SN's voltage sensors are installed in the main panel to measure voltage, current, power factor, frequency, active and apparent power, and electrical energy. All data are processed and displayed on SN's liquid crystal display (LCD). Since the main panel consists of three-phase installation, the SN measures parameters of every phase. The only three-phase parameter measured by SN is the energy in kWh unit. The SN does not only display its measurement results on LCD, but also send several data to the gateway as well. Such data are the active power of phase R, S, T, and the energy of three-phase. The purpose of sending the active power to the server is to observe the balance of the three-phase of every building, while the purpose of sending the three-phase energy is to measure the building electricity consumption. To avoid cabling complexity, the communication between SN and the gateway is established by wireless link.

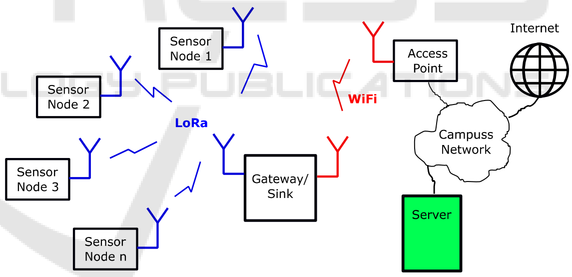

Figure 1: The architecture of monitoring system network

Long range (LoRa) radio technology (LoRa Alliance, 2015) is considered to establish the link between SN and the gateway as among other technologies such as WiFi (Digi Int., 2008) and Bluetooth (Wooley, 2020), LoRa is able to reach the longest distance, which is up to kilometres away. According its specification (LoRa Alliance, 2015), in the urban area LoRa could reach up to 5 km, while in rural area it is able to reach up to 15 km. In a specific condition (The Things Network, 2020), LoRa could even reach 832 km. In this case, a LoRa transmitter is brought by a balloon flying 83 km above the land, and as a consequence a line of sight (LoS) conditions is achieved. To work in LoRa protocols, both SN and the gateway are equipped with a LoRa transceiver.

The working frequency is 915 MHz to deal with the Indonesian government regulation of low power wide area network (LPWAN) where LoRa is included.

When the gateway has accepted data from SNs, it forwards the data to server. The server should have a connection to the internet to make it accessible to be monitored from everywhere at any time. In this research, the server connects to Politeknik Negeri Samarinda internet network. As a consequence, the gateway is equipped with a WiFi transceiver to communicate with the server. Currently, the gateway is located at the Electrical Department Laboratory where several access points (APs) are available to connect to.

All data coming from the gateway are collected by the server. A simple web based application controls, saves, and displays the incoming data. The application could be accessed from everywhere at any time by a person who has been given authority.

3 RESEARCH METHODS

Research activities is started by reviewing literatures pertaining electrical parameter sensors, Arduino based wireless sensor networks, communication protocols, LoRa and WiFi technologies, and server development. When significant information obtained from the literature is sufficient, the SN and gateway prototype are built. Along with the prototype building, the sensors are calibrated by comparing the measured parameter values with the value measured by correspond laboratory electrical metering.

The process is followed by data communication evaluation involving communication protocol test. Prior installation, link measurement is undertaken to observe the capability of communication system to provide communication link and network between SNs and gateway. Once the installation of five SNs, the gateway, and the server is accomplished, the system running test is performed.

4 RESULTS AND DISCUSSION

Sensor node (SN) consists of three PZEM-400T sensors including its current transformer, an Arduino Nano, a 915 MHz LoRa transceiver, 20 x 4 LCD display, and 3DR 5dBi antenna. The unit is powered by a 220 V AC to 12V DC mini power supply. All parts are installed into a panel box with the size of 35 x 25 x 12 cm^2 as shown in figure 2. The circuit diagram and other details are described in (Alfan, 2021). The accuracy of the SN measurement has been compared with HIOKI PQ3100 power quality analyser (Alfan, 2021), and shows that the error is less than 3 % for voltage, current, apparent power, active power, and frequency, while for power factor is 6.505 %.

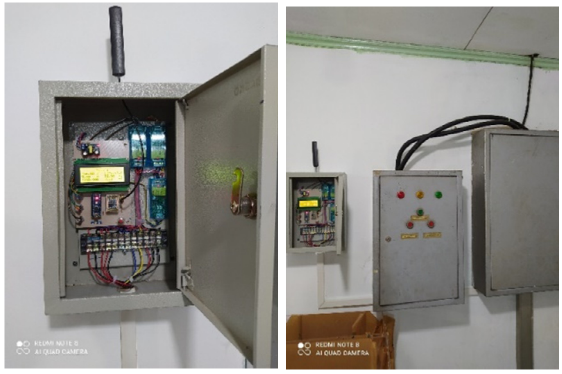

Figure 2: Sensor node.

The cost of a sensor node unit in this system is less than IDR 1 million including installation. It is about a quarter of the price of a sensor node unit in (Eyedro, 2021). With a large number of production, the cost could be cheaper.

Due to the requirement and convenient operation, several parts of the program in (Alfan, 2021) has been changed. For example, the parameters of every phase are displayed consecutively and automatically without pushing the push button as the previous design. Also, the length of data values is increased 1 byte into 2 bytes. Hence the data format becomes 1 byte of the destination address, 1 byte of the source address, 1 byte of message counter, 1 byte of packet length, 1 byte of data1 type, 2 bytes of data1 value, 1 byte of data2 type, 2 bytes of data2 value, 1 byte of data3 type, 2 bytes of data3 value, 1 byte of data4 type, 2 bytes of data4 value. The contents of every data are phase R, S, T active powers, and three-phase kWh respectively. This packet format is inserted into the LoRa data packet. The packet is sent every 30 minutes.

During installation, several cables from three-phase voltage sensor of SN are connected to phase R, phase S, phase T, Neutral bus bar respectively. Meanwhile, three current transformers (CTs) are clamped on their respective phase load cable/busbar with the CT cables are connected to the current sensor unit.

The gateway comprises of a Wemos board and a 915 MHz LoRa transceiver. Both are powered by a DC 12 V 5 A power supply and installed in a 35 x 25 x 12 cm^2 panel box as shown in figure 3. The LoRa transceiver is utilized to receive data transmitted by SNs. The data then are processed by the Wemos into the packet that is suitable with the WiFi packet format. Afterwards, the packet is sent to the server throughout the campus internet.

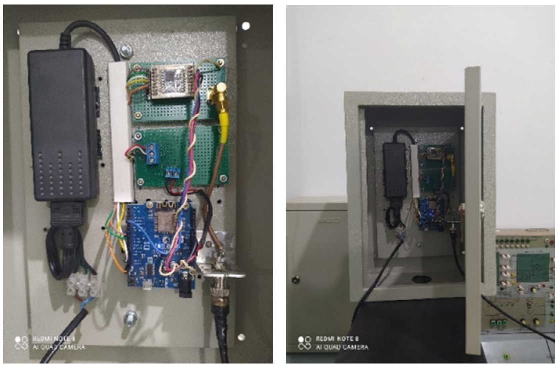

Figure 3: Gateway.

The server of the monitoring network takes a space of the Department of Electrical Engineering server. It is developed based on Laravel web framework. Currently, the web appearance is simple but quite effective. The server is also prepared for other resources monitoring such as water consumption and solar energy monitoring, where the monitoring system would be developed. The web display is shown in figure 4. This display could be accessed from everywhere as long as the internet is available.

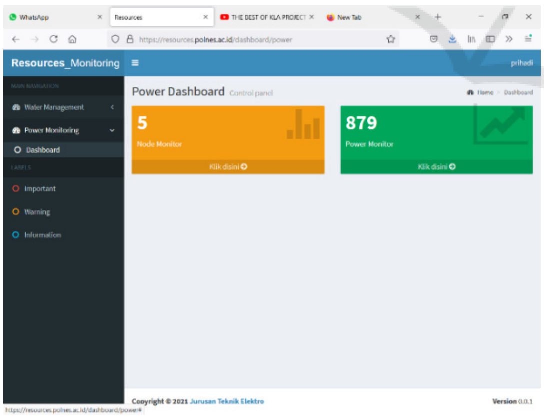

Figure 4: The display on web based server.

Prior the system installed in February 2021, a preliminary measurement of the link between several future SN locations and the gateway located at the laboratory of The Department of Electrical Engineering is undertaken. The results could be found in (Batong, 2021).

During the measurement, two LoRa transceivers are installed on a pole with the height of 6 meters. Each had their own Slim Jim antenna. A transceiver worked on the frequency of 433 MHz, while another work on 915 MHz. Both transmitted packet periodically. Two LoRa receivers where one worked on 433 MHz and another worked on 915 MHz are brought to five locations sequentially to measure received signal strength indicator (RSSI), signal to noise ratio (SNR), and packet loss. The result showed that for both frequencies and all SN locations the RSSI is above -120 dB. It means that all links are acceptable to establish LoRa data communication.

In February 2021, five units of SN are installed in two office buildings, two laboratories, and a workshop. These buildings are selected due to various distances and building functions. The different function is believed would give specific electricity consumption character that may be different from the character of other buildings.

Three locations where the SN installed has been observed in the preliminary measurement mentioned above. Hence, the result of the preliminary measurement could be compared with the current measurement provided by the installed SN. It is with the note that in the preliminary measurement (Batong, 2021), the gateway transmits packets to the SN, while in the current situation, the SN transmits packets to the gateway. The location on both situations is the same, which is at the laboratory of Electrical Department.

Furthermore, not all results in (Batong, 2021) will be used. For example, as the antenna used in SN unit is omnidirectional antenna, the comparison is only for this type of antenna. Moreover, since the operation frequency used in the current system is 915 MHz, to deal with the Indonesia government regulation, the comparison is only undertaken for this frequency. The averaged RSSI and SNR of preliminary result and the current measurement are shown in Table 1.

Table 1: The RSSI and SNR comparison of preliminary and current measurement.

Location	RSSI (dB)		SNR (dB)	
	Prelim.	Current	Prelim.	Current
Electrical Department Office	-113	-100	7.41	9
UPT Bahasa 2nd floor	-118	-116	4.08	0.25
Chemical Engineering Laboratory	-99	-89	8.41	8.75

It can be seen that the RSSI measured by the installed SN is even higher than the RSSI measured by the preliminary observation. It is possibly due to the use of metal panel box as the SN cover and the antenna grounding. Such metal box might reduce interference from outside the SN unit and improve the antenna radiation pattern.

Meanwhile, the SNR measured by the installed SN is commonly higher than the SNR measured in preliminary observation. The SNR value in UPT Bahasa that is only 0.25 dB is still reliable as the minimum limit of SNR according LoRa standard (LoRa Alliance, 2015) is -20 dB. However, during heavy rain, packet transmitted from SN in UPT Bahasa sometimes could not be accepted by the gateway. Thus, the LoRa transmitter power will be increased from the default (17 dB) into to the maximum (20 dB) through the program. Also, the antenna will be replaced by a higher gain antenna.

Several months after being installed, the electricity monitoring system could show the electricity consumption of the buildings. How much electricity every building uses is clear as shown in website menu (figure 5), the unit is kWh. By comparing such electricity consumption with the electrical equipment specification used in the building and people activities, it could be calculated whether the electricity utilization is normal or wasteful. If it is wasteful, a significant action might be required to reduce the consumption.

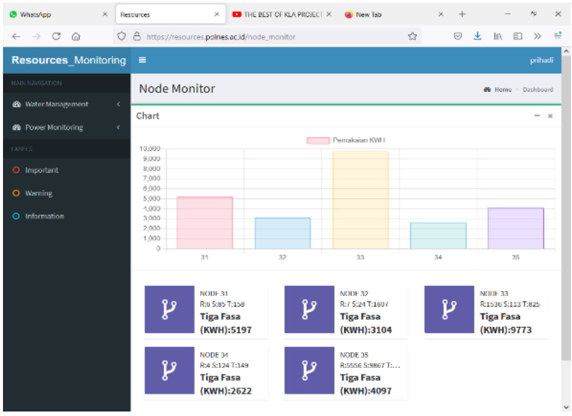

Figure 5: The display of buildings electricity consumption.

Since the active power of every phase is also sent to the server, the phase equilibrium can also be read to analyse whether the installation is proper or not. The display is shown in figure 6. The unit of active power is in watt, while the three-phase consumption is in kWh. In Politeknik, improper installation may occur as additional installation is undertaken without considering the phase load balance. As such, installation revision should be provided.

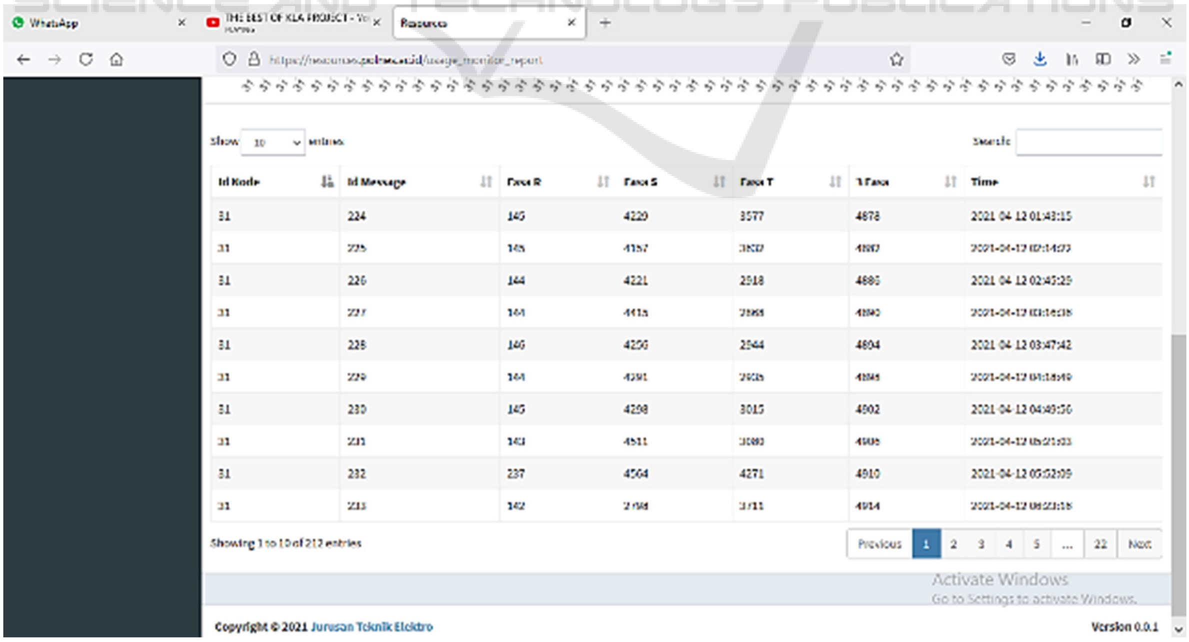

Figure 6: The display of individual phase active power.

4 CONCLUSIONS

It has been built and installed a low cost electricity monitoring wireless sensor network as a solution to measure the electricity consumption for every building in the campus of Politeknik Negeri Samarinda. Along with the electricity consumption report required by the Politeknik directorate, the system also gives the report of phase equilibrium that is required by electrical experts in Politeknik to revise and improve the installation. It is necessary to prevent electrical hazard or installation damage caused by the imbalance phase load. In brief, the integrated electricity monitoring system could make electrical resources utilization and maintenance more accountable, which is important to achieve the predicate of green technology campus

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