Electrical power submeter for quality and energy monitoring using Wemos microcontroller

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ABSTRACT

Voltage, current, and frequency are three electrical energy variables that need to be monitored because if they do not comply with established standards, they can cause damage to electronic devices that use electrical energy. The objective of this article is to develop a submeter that can be used for monitoring both energy consumption and three power quality variables. The system was developed by using commercially available instruments involving the PZEM 004t sensor, the Wemos D1 mini microcontroller, and the Blynk platform on the smartphone. The use of the Blynk platform enables the system to log the monitored variables continuously in the form of a spreadsheet file and send them via email in order to be downloaded and used for further analysis. The results of calibration tests carried out using varying loads showed that the developed system has voltage measurement results with a difference of 1.35% when compared to measurement results using a commercial multimeter, while the difference for current measurements is 0.85%.

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1. INTRODUCTION

In modern society, electrical energy is a basic need apart from the need for clothing, food and shelter because most of the equipment used by people daily uses electrical energy. Among all aspects, two important aspects to monitor regarding the use of electrical energy are the quantity of electrical energy used because it is related to bill payments and the quality of electrical energy because it is related to the safety of electrical equipment from the risk of damage. From the side of electrical energy companies, electrical energy monitoring needs to be carried out for energy management purposes including planning electrical energy generation capacity, detecting distribution disturbances and ensuring that the electrical energy distributed to consumers has quality variables that comply with standards so that it is safe. So far, electrical energy consumption monitoring by customers has been commonly carried out by using electricity meters, however electrical energy quality monitoring was still very rarely carried out.

Currently, a traditional metering system was provided and installed in every house or building by the energy company. This type metering system is mainly dedicated for recording the energy consumption and displaying it so that it can be checked by seeing it directly only for recording and billing purposes. If necessary, for example for further analysis, continuous monitoring of electrical energy consumption can be done manually, namely by looking directly at the electricity meter and then making manual records either on paper or using a spreadsheet application. This activity is labor and time consuming so that it is arguably inefficient. Development of monitoring systems or metering systems aimed for electrical energy management systems has attracted attention from researchers for example research reported in [1]–[4] and so on. Some of these publications called the developed system a smart meter because it has more features and functionalities than the traditional metering system.

In general the smart meter has four main components involving smart metering devices, databases, data communication systems, and control mechanisms [5]. The smart meter could be used for power quality monitoring [6] or energy consumption monitoring [2], [7]. The use of electrical energy smart meter which has data record and storage features allows to generate data for further analysis for example in energy consumption analysis for mitigating risk [8], household classification [9], household clustering [10], households characteristics [11] and self-energy consumption monitoring [12] which could be used for planning electrical energy use to increase energy efficiency [13]. Moreover, energy consumption monitoring would be useful for detecting the anomaly of energy usage which could be used as an initial indicator of the condition of people living in the building [14], [15].

Monitoring of electrical power quality can be done manually, namely by using a manual measuring instrument and then recording variable values related to electrical power quality for early warning of the safety of electrical equipment or for further analysis. Manual monitoring of power quality could not provide continuous monitoring, so that if the power quality does not conform to the standard, it could be known only after the home appliances or electrical instruments were broken. Electrical power quality is very important to monitor and has attracted attention of researchers as reviewed in [16].

Two main variables measured in the power quality monitoring are voltage, and current. Besides, the power factor is also an important variable to monitor [17]. Among these variables, voltage characteristics especially voltage fluctuations is the most monitored variable [18], [19]. Researchers were interested in the development of power quality monitoring systems, mostly for grid electrical power networks, for example research reported in [20], [21]. Power quality monitoring is very useful to be applied for a building or a house. A system for monitoring electrical power quality could be placed in the main meter or be embedded in a certain area of the building which is called a sub-meter [22]. Besides proactive measures to protect household appliances from poor quality power, researchers also proposed monitoring power quality as a basis of its tariff for customers [23]. Based on the research results above, in this article, a monitoring system that can be used to monitor electrical energy consumption and electrical energy quality at the same time was proposed. The objective of this publication is to develop a system for monitoring power consumption and electrical power quality in the form of a sub-meter that can be placed in an electrical installation line in a house or building after the main meter.

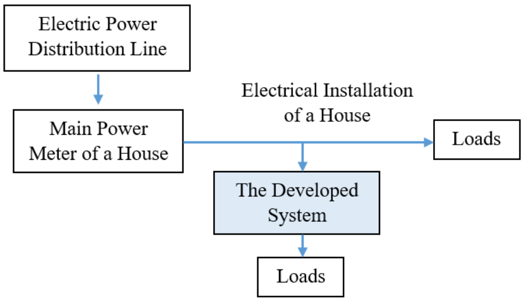
2. METHOD

2.1. General architecture

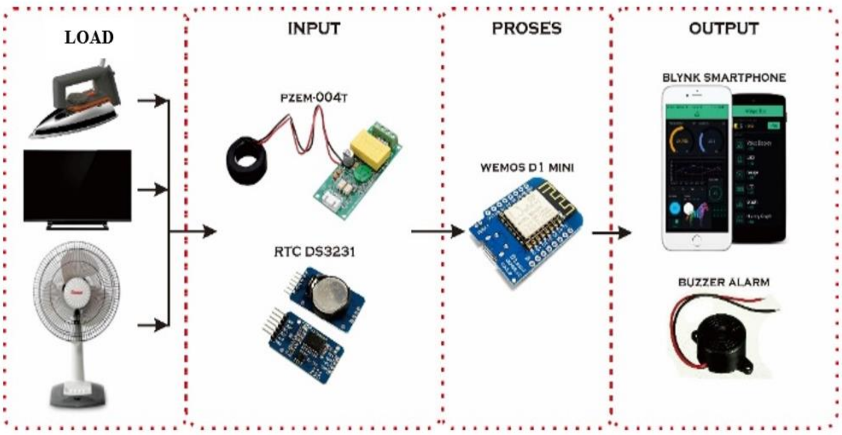
The general architecture of the developed system can be seen in Figure 1(a). The developed system is a sub-meter which was placed after the main meter in the electrical installation network in the house or building. The developed system was applied for one power line path in the house in which multiple home appliances were plugged in. By using this configuration, the proposed system just needs one sensor thus its architecture would be simpler than using one sensor for every home appliance monitored for example proposed in [24]. Placing a system like this makes it possible to monitor electrical energy consumption and electrical power quality in one part or one room of a house or building. The developed system consists of four general component categories, namely load, input, process, and output as can be seen in Figure 1(b).

The load group is electrical equipment or home appliances which are generally used in homes or buildings functioned as a load tester. In the input section, there is a PZEM 004t sensor component which is a multifunctional sensor that can measure current, voltage, power and alternating current (AC) electrical energy consumed. The sensor produces output using serial communication. The PZEM 004t sensor output is then sent to the Wemos D1 Mini microcontroller as the main processor for further computing. To process the PZEM 004t sensor output data, a real time clock (RTC) DS3231 module is needed because it is related to recording electrical energy consumption and electrical power quality at a certain time. The computational results by the Wemos D1 Mini microcontroller were then sent to the smartphone to be displayed using the Blynk platform and are also used to turn on the alarm buzzer. Wemos D1 microcontroller has an advantage compared to Arduino microcontroller used in [25] in which it can be connected to the computer networks via Wi-Fi directly without an additional device. Wemos D1 Mini microcontroller sent the data to the Blynk platform by using Wi-Fi. This architecture is simple because it does not need to build a separate hardware circuit for the data receiver such as if using other data communication systems for example long range (LoRa) [26], Antares [27], Zigbee [28] or to build a hardware of wireless sensor for every home appliances monitored if use wireless sensor network (WSN) as proposed in [29].

The developed system was able to monitor both power quality and energy consumption and the reading results could be read by using the Blynk application and then emailing the measured data. The destination email address should be provided in the Blynk platform first. Monitoring the electric energy consumption by using a smartphone has advantages such as the data could be monitored easily from everywhere since nowadays almost all people use smartphones [30]. The buzzer is used as a warning alarm if the voltage, current or frequency of the electrical power are lower or higher than the standard values. The normal voltage value on the system is determined at 180-230 V AC, while the normal frequency value is set at a frequency of 49–60 Hz following the specifications for household equipment used in Indonesia. If the voltage value is smaller than 180 V or greater than 230 V then the alarm buzzer will turn on. Likewise, if the frequency is smaller than 49 Hz or greater than 60 Hz then the buzzer alarm will be turned on.



(a)

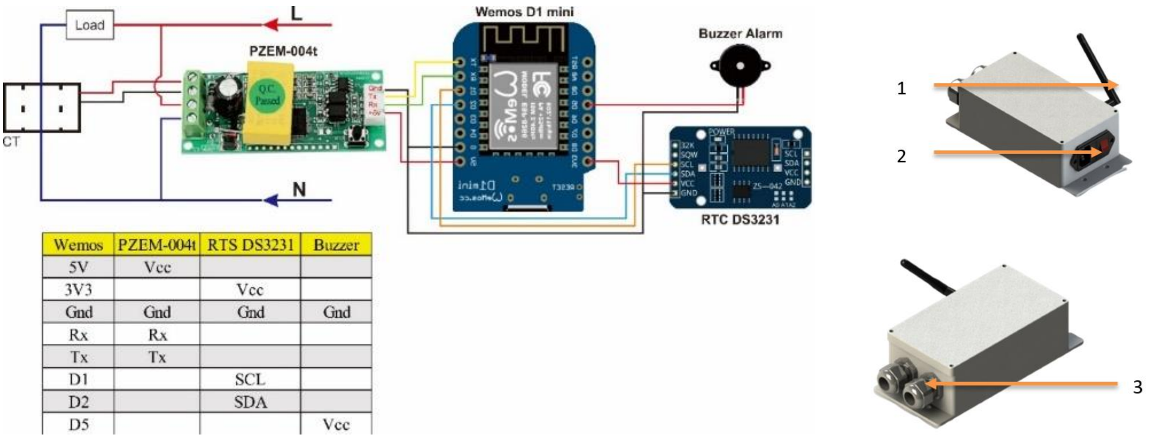


(b)

Figure 1. General architecture of the developed system: (a) the position of the developed system in the electrical installation of the house and (b) the developed system has four groups of components including loads, inputs, processes, and outputs

2.2. Hardware design

The schematic circuit of the hardware along with a summary of the connections between components can be seen in Figure 2(a). The Tx and Rx pins of the PZEM 004t sensor are connected to the Tx and Rx pins on the Wemos D1 mini microcontroller respectively to send data from the sensor to the microcontroller. PZEM 004t is a multipurpose sensor that has been used by researchers in developing monitoring systems for example in the micro-concentrator photovoltaic (micro-CPV) system monitoring [31]. The technical specifications of the PZEM 004t sensor can be seen in Table 1. There is a DS3231 RTC module where the serial clock line (SCL) and serial data line (SDA) ports are connected to ports D1 and D2 of the Wemos D1 Mini microcontroller respectively. This RTC component is used to store date and time data with high accuracy which is integrated with the AT24C32 serial electrically erasable programmable read only memory (EEPROM) for other data storage purposes. To protect the hardware circuit from impacts, water splashes and dust, the hardware circuit was placed in a box made of waterproof acrylonitrile butadiene styrene (ABS) thermoplastic box material with dimensions of 16 cm (length) × 9 cm (width) × 6 cm (height). Figure 2(b) shows the 3D image of the container box of the developed system. The parts of the box that are visible from the outside are as follows: i) part number 1 is the antenna, ii) part number 2 is the power supply connector along with the on/off switch, and iii) part number 3 is the input-output stop connector contact.



Wemos	PZEM-004t	RTS DS3231	Buzzer
5V	Vcc		
3V3		Vcc	
Gnd	Gnd	Gnd	Gnd
Rx	Rx		
Tx	Tx		
D1		SCL	
D2		SDA	
D5			Vcc

(a) (b)

Figure 2. Hardware construction: (a) schematic circuit of the developed system and (b) box for containing hardware circuit of the developed system

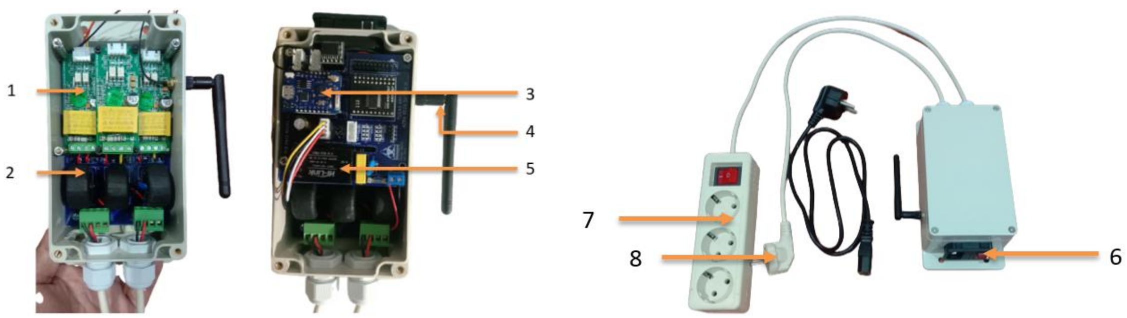
Table 1. Technical specification of PZEM 004t sensor

Parameter	Measurement Range	Resolution	Inaccuracy
Voltage	80 – 260 V	0.1 V	±0.5%
Current	0-100 A	0.02 A	±0.5%
Power	0-23 kW	0.1 W	±0.5%
Energy	0-9999.99 kWh	1 Wh	±0.5%
Frequency	45-65 Hz	0.1 Hz	±0.5%
Power factor	0.00-1.00	0.01	±0.1%

3. RESULTS AND DISCUSSION

3.1. Obtained system

The obtained hardware of the system can be seen in Figure 3 with hardware arrangement inside the box was shown in Figures 3(a) and 3(b) while the complete obtained system was shown in Figure 3(c). Number 1 is the PZEM 004t sensor. Number 2 is the coil from the PZEM 004t sensor. Number 3 is the Wemos D1 mini microcontroller. Number 4 is the antenna. Number 5 is a Hi-Link component that is used as a power supply for the Wemos D1 mini microcontroller. This component can change the voltage from AC 220 V to DC 5V. Number 6 is the AC power supply socket for the system circuit. Number 7 is the socket used for loads. Number 8 is the AC input socket from the power line for the load.



(a) (b) (c)

Figure 3. The obtained system: (a) hardware arrangement inside the box (lower part), (b) hardware arrangement inside the box (upper part), and (c) complete obtained system

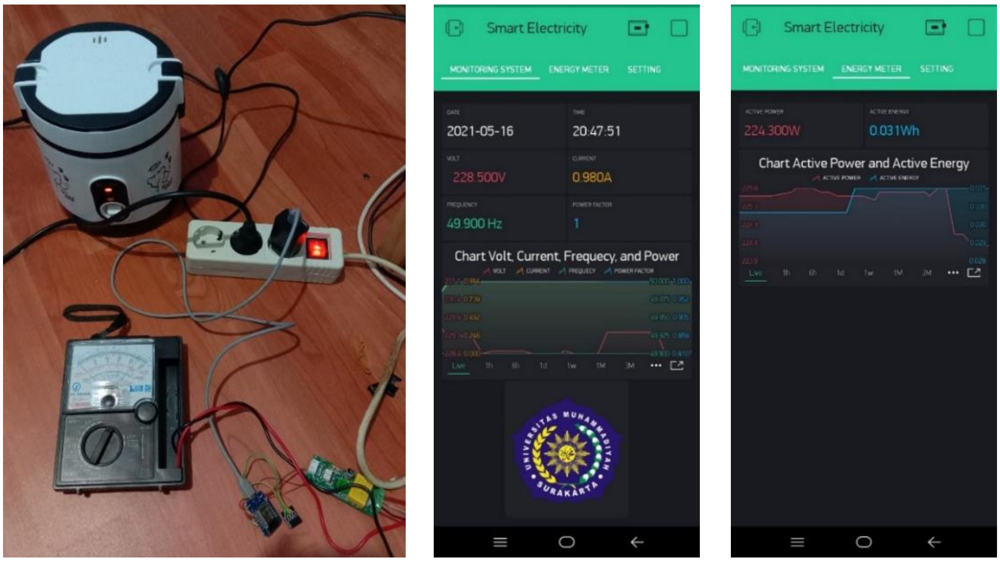
3.2. Calibration testing

The calibration test was carried out by comparing the results of measuring voltage and electric current by using the developed system to the measuring results using a commercial multimeter widely used. Calibration testing was carried out using several types of electrical equipment which were widely used by people daily as a load. The load was applied to the provided socket connected to the developed system. The measurement results were displayed in the Blynk platform of the smartphone. One example of a test setting in the experimentation is depicted in Figure 4. Figure 4(a) shows the actual configuration of calibration testing by using a rice cooker as a load in which the measurement results of the developed system were compared to that of a commercial multimeter. Figure 4(b) shows the display of monitored variables namely voltage, current, frequency, power factor, time and date of the Blynk platform. Figure 4(c) shows the energy consumption monitoring feature of the Blynk platform which displays active power and energy consumption. All monitored variables in the Blynk platform were equipped with numerical and graphics to give clear information to the user. The difference in measurement results between using the developed system and using commercial measuring instruments was calculated using (1) and (2), where Δ is the absolute difference value, $\Delta(\%)$ is the difference value in percent, x_m is the measured value by using a commercial multimeter, and x_s is the measured value by using the developed system.

$$\Delta = |x_m - x_s| \quad (1)$$

$$\Delta(\%) = \frac{|\Delta|}{x_m} \, x \, 100\% \quad (2)$$

The experimental results of voltage and current measurements using six loads are summarized in Tables 2 and 3 respectively. In the experimental results of voltage measurements, a difference ($\Delta(\%)$) of 1.35% was obtained for voltage measurements, while for current measurements a difference ($\Delta(\%)$) of 0.85% was obtained. This difference value can be considered small, namely under 1.5% so that the developed system can potentially be used for monitoring.



(a) (b) (c)

Figure 4. The calibration testing: (a) sample of calibration testing by using a rice cooker as a load obtained system, (b) display of voltage, current, frequency, power factor, time and date in the Blynk platform, and (c) display of power and energy consumption in the Blynk platform

Table 2. Experimentation results for voltage measurement

No.	Loads	x_m (V)	x_s (V)	Δ (V)	$\Delta(\%)$
1	No loads	225	224.3	0.7	0.31
2	Smartphone charging	225	230.8	5.8	2.58
3	Laptop charging and smartphone charging	225	230.8	5.8	2.58
4	Solder and smartphone charging	220	226.1	6.1	0.027
5	Rice cooker and smartphone charging	220	226.1	6.1	0.027
6	Laptop charging, smartphone charging and rice cooker	220	225.7	5.7	2.59
	Mean			5.03	1.35

Table 3. Experimentation results for current measurement

No.	Loads	x_m (A)	x_s (A)	Δ (A)	Δ(%)
1	No loads	0.001	0.000	0.001	0.1
2	Smartphone charging	0.121	0.121	0	0
3	Laptop charging and smartphone charging	0.395	0.393	0.002	0.51
4	Solder and smartphone charging	0.175	0.175	0	0
5	Rice cooker and smartphone charging	1.011	1.035	0.024	2.37
6	Laptop charging, smartphone charging and rice cooker	1.260	1.287	0.027	2.14
	Mean			0.009	0.85

3.3. Experimentation for continuous monitoring in 10 minutes

The next test was a continuous monitoring measurement of electrical power consumption and quality which is carried out for 10 minutes. The data was recorded every minute. In this test, the developed system was given a load, namely for charging the Acer N136 N20755 laptop. Table 4 presents the result of monitoring measurements for 10 minutes using the developed system.

Table 4. Measurement results for continuous monitoring experimentation in 10 minutes

i^{-th} Minute	Time	Current (A)	Voltage (V)	Power (W)	Energy (kWh)	Frequency (Hz)	Power Factor	Load
1	23:00:00	0.294	231.1	36.4	0.01	50	0.54	Charging Acer N136 N20755 laptop
2	23:01:00	0.295	230.4	36.5	0.011	50	0.54	
3	23:02:00	0.294	230.5	36.3	0.011	50	0.54	
4	23:03:00	0.298	230.7	36.9	0.012	50	0.54	
5	23:04:00	0.407	231.1	52	0.013	49.9	0.56	
6	23:05:00	0.314	231.3	38.9	0.014	50	0.54	
7	23:06:00	0.294	232.1	36.7	0.014	50	0.54	
8	23:07:00	0.293	232.6	36.5	0.015	50	0.54	
9	23:08:00	0.305	232.7	38.1	0.015	50	0.54	
10	23:09:00	0.318	232.5	39.9	0.016	49.9	0.54	

3.4. Experimentation for continuous monitoring in 90 minutes

After testing with a duration of 10 minutes, the next test was carried out with a longer duration, namely 90 minutes. Data was recorded every 10 minutes. The test was carried out using the same load as the previous test, namely for charging the Acer N136 N20755 Laptop. The measurement results shown in Table 5 show that the developed system has stable measurements without any drastic changes in measurement results. The record of energy consumption in real-time would be useful for energy management as also reported in [32]. The use of Blynk platform was considered more user-friendly if compared to presenting monitoring data using short message services (SMS) by using global system for mobile (GSM) networks proposed in [33].

Table 5. Measurement results for continuous monitoring experimentation in 90 minutes

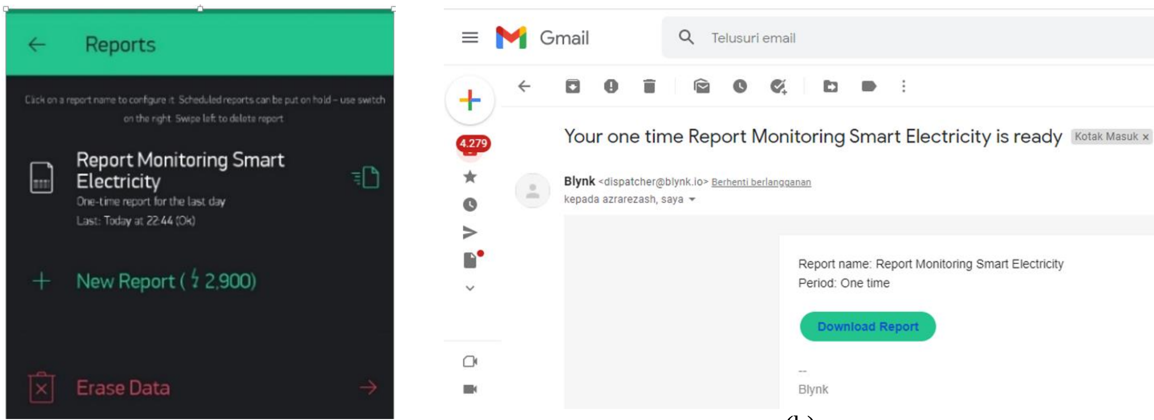
i^{-th} data	Time	Current (A)	Voltage (V)	Power (W)	Energy (kWh)	Frequency (Hz)	Power Factor	Load
1	23:00:00	0.293	231.1	36.4	0.01	50	0.53	Charging Acer N136 N20755 laptop
2	23:10:00	0.318	232.2	39.9	0.02	49.9	0.54	
3	23:20:00	0.311	232.7	39.03	0.02	49.9	0.54	
4	23:30:00	0.264	231.3	32.5	0.03	50	0.53	
5	23:40:00	0.245	232.9	30.8	0.03	50	0.54	
6	23:50:00	0.239	233	29.5	0.04	49.9	0.53	
7	00:00:00	0.242	233.6	30.1	0.04	50	0.53	
8	00:10:00	0.247	231.9	30.2	0.05	49.9	0.52	
9	00:20:00	0.239	232.9	29.7	0.05	49.9	0.48	

3.5. Discussion

The developed system has uniqueness compared to other works published previously, which is summarized in Table 6. It can be noted that the uniqueness of the developed system falls in the technical side including the use of the main processor, and distance monitoring features. In the developed system, data from measurements by using the PZEM 004t sensor can be sent to a Gmail email address via the Blynk application on a smartphone. The data is sent in the form of an MS Excel file so that it can be used for further analysis using spreadsheet software. Figure 5(a) shows data logger display of system measurement results developed in the Blynk application. The registered email address can be changed according to the user. Figure 5(b) is a display of receiving data sent from the Blynk application on a smartphone. The use of wireless internet would be able to represent all monitored variables in more informative and attractive ways than when data were represented using SMS data communication in [6], [33]. The recording data on the MS Excel file in the email of the developed system has the advantage of the providing data for further data analysis when compared to data representation in other works such as in [2], [7], [24], [31], [32].

Table 6. The developed system compared to other published works

Year, Reference	Main processor and sensors	Variables monitored	Distance monitoring features	Data communication
The developed system	Wemos D1 Mini, PZEM 004t sensor	Current, voltage, power, energy, frequency, power factor	Blynk platform, MS Excel file from email	Wireless internet (Wi-Fi),
2023 [1]	Raspbery Pi, SmartPlug, SmartMeter	Total energy consumption	CSV file	MQTT
2022 [32]	ESP32, CST-1020 current sensor, attenuator voltage sensor, ADE7758 energy measurement IC	Voltage, current, power, energy	Web application	MQTT
2017 [33]	ATMega2560,	Voltage, current, power, energy, power factor	SMS	GSM networks
2021 [24]	ESP8266, CT sensor	Power, energy consumption	Web application	Wi-Fi
2023 [31]	ESP8266, PZEM 004T sensor	Power consumption	Web application	Wi-Fi
2019 [2]	Raspberry Pi 3, 2MCT103C current sensor	Voltage, current, power	Web application	Wi-Fi
2020 [6]	Arduino, SCT-013-030 current sensor	Energy consumption	SMS	GSM networks
2019 [7]	ESP8266, PZEM 004T sensor	Power consumption	Android application	Wi-Fi



(a) (b)

Figure 5. Distance monitoring feature of the developed system: (a) display of data logger in the Blynk application of the smartphone and (b) display of received monitoring data in the email

4. CONCLUSION

A sub-meter system for monitoring electrical energy quality variables, power and energy consumption based on a microcontroller system and Blynk platform on a smartphone has been successfully developed. The developed system has a continuous recording feature. The voltage, current, power, frequency, power factor and energy can be measured using the PZEM 004t sensor and then the measurement data can be monitored in real time using a smartphone via the Blynk application. This data can be sent to an email address in the form of a spreadsheet file. The email address can be changed according to the user. In calibration testing, the measurement results by using the developed system were compared to those by using a commercial multimeter available in the market. The comparison showed that the voltage measurement has a difference of 1.35% and the current measurement has a difference of 0.85%. The continuous measurement testing results showed that the developed system was able to measure all variables stably without any sudden change. In the future, research could be enhanced involving the use of automatic breakers to protect the power line to households if the power quality is not in its standard values.

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