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| RESEARCH ARTICLE

IoT-based Electrical Power Recording using ESP32 and PZEM-004T Microcontrollers

Kadek Amerta Yasa[1] ✉ I Made Purbhawa[2], I Made Sumerta Yasa[3], I Wayan Teresna[4], Aryo Nugroho[5] and Slamet Winardi[6]

[1234]*Departement of Electrical Engineering, Politeknik Negeri Bali, Bali, Indonesia*
[5]*Departement of Information System, Narotama University, Surabaya, Indonesia*
[6]*Departement of Computer System, Narotama University, Surabaya, Indonesia*

Corresponding Author: Kadek Amerta Yasa, **E-mail**: amerta.yasa@pnb.ac.id

| ABSTRACT

The electricity usage recording system in Indonesia still uses conventional kWh meters. Electricity usage is recorded by officers who visit customers' homes every month. This results in the electricity company having to provide employees who become a burden on the company's costs. Technological advances enable convergence between communication channels and various things. A technology known as the Internet of Things (IoT) allows customer kWh meters to be recorded in real-time. This research aims to create an Internet of Things (IoT)-based kWh meter that can make it easier for electricity companies to monitor each customer's electricity usage. The IoT kWh meter created can be monitored and controlled from a remote location in real-time. If there is a change in load usage, it will be monitored directly via a mobile device because the kWh meter is directly connected to the internet network and cloud server. To determine the functionality of the tool being made, several tests were carried out, such as a) sensor testing, b) LED indicator, buzzer, and relay testing, c) OLED display testing, d) Firebase database testing, and e) load testing. The test results obtained are used to calculate the error of the tool made with a comparator, and the results show that the percentage of voltage error with different loads is very small, namely 0.35% and 1.45%. This research produced a prototype using ESP32 and PZEM-004T, which is so accurate that it is recommended for recording electrical power, which can reduce the burden on operational costs for electricity companies.

| KEYWORDS

Recording, electrical power, ESP32 microcontroller, PZEM-004T

| ARTICLE INFORMATION

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1. Introduction

Electricity in Indonesia is managed by PT. PLN (Persero), which is a State-Owned Enterprise ((Persero), 2023). This electricity company implements decisions and policies taken jointly by the government for the benefit of the people. Through this electricity company, the Indonesian Government is committed to providing sufficient electricity continuously and at affordable prices to communities throughout Indonesia (Hidayah, Alfita, & Aji, 2020). In protecting underprivileged people, the government guarantees the community by assisting in the form of electricity subsidies so that people can pay electricity tariffs at more affordable prices than the normal tariffs set by the government.

Electricity customers who receive assistance from the government are subsidized customers, while people outside of this are all non-subsidized customers. If the amount of electricity used is the same as other consumers who receive subsidized rates, they will pay cheaper electricity bills compared to non-subsidized consumers (Albatayneh, Juaidi, Abdallah, Peña-Fernández, & Manzano-Agugliaro, 2022). The difference between subsidized rates and non-subsidized rates. The number of people receiving subsidies in 2021 will be 24.3 million household consumers with 450 VA electricity and 8.2 million household consumers with 900 VA power.

The subsidy funds provided to household consumers reached IDR 39.65 trillion or 79.6% of the total electricity subsidy provided at IDR 49.76 trillion in the 2021 budget year. The problem that often arises in the management and distribution of electricity is monitoring power usage by consumers (Fiaschetti et al., 2018). Electricity companies have made maximum efforts to monitor customer electricity usage, such as replacing kWh meters periodically and paying employees who record electricity usage to customers' homes every month. Of course, this requires a lot of time and money. The solution we offer is to automatically record electricity usage consumed by customers.

Based on these problems, this research can make a real contribution by creating a prototype kWh meter device based on the Internet of Things (IoT), which will later make it easier for electricity companies to monitor electricity usage for each customer to reduce the burden on operational costs for electricity companies.

2. Literature Review

Researchers (Adkhar & Afianti, 2023) created a tool for monitoring electrical energy consumption to prevent excessive electricity consumption, and this tool can also function as security for the electronic devices used. This research uses the PZEM-004T sensor. The tool created as a result of monitoring is connected to the internet network with the Telegram application. The result of the error value obtained in the test is that the PZEM-004T is suitable for measuring current and voltage with very satisfactory results.

Research (Andriana, Zuklarnain, & Baehaqi, 2019) creates a tool that can make it easier to use electricity in homes as a smart switch so that it can save electricity usage. Smart switches include automation systems that are easy to implement and develop (Oluwafemi, Bello, & Obasanya, 2023). An activity that is often neglected by some people is leaving their equipment charged for a long time so that the electric current in the equipment becomes overcharged, which can damage the equipment. To connect the timer socket, use a relay that functions to break the contact so that the electricity supply to the device can be cut off after a set time (Kolo & Dauda, 2008).

Researchers (Chairunnisa & Wildian, 2022) created digital kWh meter system equipment to help customers find out how much electricity consumption costs at home so that customers can anticipate electricity savings. The sensor used is PZEM-004T, which reads current, voltage, power, and energy values. WeMos D1 Mini Pro is used as the main controller, which will process current, voltage, power, and energy values so that the costs used can be determined by calculating the conversion of kWh values to predetermined rupiah values (Suryono, Prabowo, Suhanto, & Sazali, 2020). The tool built can display the amount of electrical energy used and its costs in real time on an LCD and the Blynk application. Tests were carried out using loads in the form of televisions, laptops, fans, dispensers, rice cookers, irons, power banks, and mobile devices.

Researchers (Jokanan, Widodo, Kholis, & Rakhmawati, 2022) created an Android operation-based electrical energy usage monitoring tool using the PZEM-004T module, a system designed and used to read the amount of electrical energy usage which includes voltage, current, active power, and accumulated energy. The monitoring tool is connected to an Android smartphone, which is used as a user interface media that displays electrical energy consumption (Ida Bagus Gede, I Nyoman, & Made, 2020). The test results show that the electrical energy usage monitoring tool using the PZEM-004T module can measure and display the values of current, voltage, active power, and accumulated energy. Besides that, the electrical energy usage monitoring tool using the PZEM-004T module can monitor in real time and be stored in the database. Apart from that, research based on the Internet of Things (IoT) is currently being carried out a lot, such as research (Herpendi, Noor, & Sayyidati, 2020) examining the efficiency of using electrical energy which was developed for an IoT-based TV assistant (Taştan, 2019).

3. Methodology

3.1 Research procedure

The research was conducted using a commonly used method, namely the waterfall method. This method uses a systematic approach and is very popular with researchers because it is very simple. The stages of the waterfall method are the first analysis stage, second the design stage, third the coding stage, and fourth the testing stage (Kramer, 2018). The first stage carried out in this research was collecting kWh meter data and how to implement the Internet of Things (IoT) on the kWh meter. Of course, at this initial stage, a model is created that will be developed. The second stage is to create a model of the system being developed by creating a block diagram and creating a prototype of the IoT-based kWh system. The next step is to create a program code that is entered into the ESP32 microcontroller. This microcontroller is connected to the PZEM-004T sensor and other components such as relays, sensors, and LEDs. After the circuit is made according to the design and plan, the next step is the testing stage. The testing stage carried out is testing the system created. The testing of this IoT-based kWh meter prototype is sensor testing, LED indicator, buzzer and relay testing, OLED display testing, Firebase database testing, SSID and password change testing, and finally, testing when the load is interrupted.

3.2 Research flow

The research flow is depicted with a block diagram consisting of the electrical load whose power will be measured. The electrical load is turned on by a relay from the mobile device, and then the data is read by the PZEM-004T sensor. The reading data is displayed by a 0.96" OLED display and sent to the Firebase database by the ESP32 microcontroller. Then, the mobile device accesses the database in the cloud in real time to retrieve sensor data and display it on the mobile device screen. The block diagram design can be seen in the research block diagram in Figure 1.

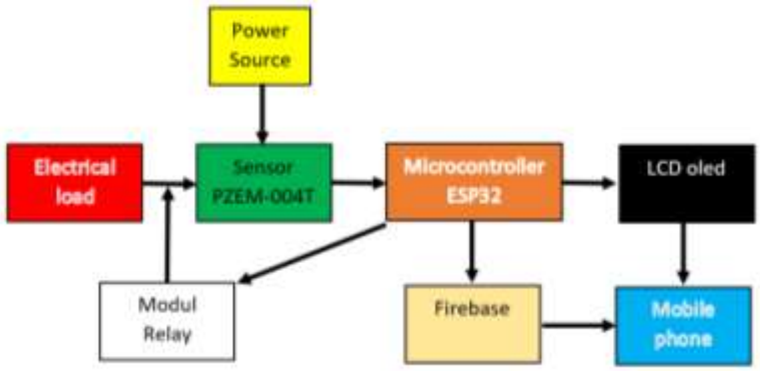

Figure 1. Research Block Diagram

Figure 1 shows the research Block diagram. The loads used in this research are several household electrical appliances, which are assumed to be electrical loads (Rajkumarsingh & Purrahoo, 2021). The following step is to measure electrical power using the PZEM-004T sensor module to the ESP32 microcontroller using pins 16 and 17 and connect the Current Transformer to the terminal of the sensor module, which will measure the current from the installed load. The power used is connected to the sensor module, and the load with one of the cables inserted into the Current Transformer hole so that every time the load is turned on, the flowing current will be read. The cable that enters the Current Transformer is then inserted into the relay module, which will disconnect and connect the electricity to the load. This relay module is controlled by an ESP32 microcontroller, which gets commands from the mobile device.

In the ESP32 microcontroller program, the first thing to do is initialize serial communication, namely communication between the ESP32 microcontroller and the computer used for the program checking process (Setiawan & Purnamasari, 2019), whether the algorithm is appropriate or not by looking at the results sent via the serial monitor. Then, initialize the time using the EzTime library, which is a library used to read internet clocks, so that wherever the tool is moved, this tool will automatically adjust the time when connected to the internet. To be able to work online, this microcontroller must be connected to the nearest access point by adjusting the SSID and password of the accesspoint. The next initialization is the database, which is used to accommodate data variables produced by the PZEM-004T sensor, and the last is the initialization of the 0.96" OLED Display, which is used to display the parameters produced by the sensor so that the kWh meter can also display the data displayed on the system.

The PZEM-004T sensor will read the kWh electricity parameters installed on the input terminal; the parameters read are voltage, current, power, energy, frequency, and power factor (Nuryawan & Jannah, 2022). All parameters read will be placed in a variable for each parameter. Then, the system will display on the OLED display all parameters of the PZEM-004T plus Day, Date, City, and Customer ID. After displaying, all the parameters are stored in a database. The database used is Google's Firebase Realtime, so the database is stored in a cloud that can be accessed anywhere as long as it is connected to the internet. Here, we also simulate a button that is used to disconnect and connect the flow of electrical power to the customer's load. If the database contains a status equal to "DISCONNECTED", then the relay on the system will be disconnected from the contactor, whereas if the status is "CONNECTED", then the relay will be connected, and electrical power will flow to the customer burden.

3.2 Initialize Android Application

Initializing the Android screen is setting the display layout of the system being designed. The display is arranged in such a way as to get the desired display. Then, initialize the database by inserting the Firebase component and preparing the URL and database token so that it can be accessed by Kodular as an IDE for Android programming. After the initialization is complete, the next step is to check the status of the button. It is "DISCONNECTED"; the kWh meter hardware will be disconnected by the relay so that at the start of the installation, the power has not yet flowed to the customer's load. After the kWh meter hardware installation is complete, the button is pressed, and the button status will change to "CONNECT", which will be stored in the database and accessed by the ESP32 microcontroller, which will connect the relay contacts so that electrical power flows to the customer's load.

The process continues with the database access subprogram and displays electrical parameter data on the Android smartphone screen. The day, city, date, and time are generated from ESP32, which is then stored in a database.

3.3 Initialize Firebase

The database uses Google's Firebase Realtime Database, which is accessed at the website address firebase.google.com then follows the instructions shown by the system (Ohyver, Moniaga, Sungkawa, Subagyo, & Chandra, 2019). To be able to access the database, the URL address and database token are used, which are placed in the software for the ESP32 and Kodular microcontrollers (for Android smartphones). Before using the database, a TAG (database variable) is first designed from all the parameters produced by the PZEM-004T sensor. To store the voltage, a TAG variable is created, which is "voltage", and if accessed, it will output the contents of the voltage data plus the text "Volt." To store electric current, the TAG variable is created, namely "current", and if it is accessed to retrieve the data, it will output current data added with the text "amperes." All processes are the same for electrical power with the TAG variable "power" and output power data and the text "Watts", energy with kWh, the frequency with the TAG variable "frequency" and its unit Hz, and finally, power factor with the TAG variable "pf" and inserting the customer ID variable which comes from the kWh meter hardware.

4. Results and Discussion

4.1 PZEM-004T Sensor Testing

To read sensor data, initial testing is carried out, ensuring that the sensor is working properly. The sensor output pin consists of 4 pins, namely VCC, GND, TX, and RX, which are connected to the ESP32 microcontroller on pins 16 and 17 in the form of the second hardware serial from the microcontroller. The sensor input consists of 4 pins, which are connected to an induction coil to measure the current passing through the coil (2 pins) and are connected to the PLN network as a power source for the PZEM-004T sensor module. Testing the PZEM004t sensor by connecting the output pin to the ESP32 microcontroller, then the input pin is inserted into the PLN network and the load, but one of the load cables is inserted into the toroid coil to measure the magnitude of the load current being measured (Setiawan & Purnamasari, 2019). The results of the sensor testing produced parameters in the form of AC input voltage, current, load power, frequency, work factor, and usage energy (kWh). Sensor data is read via the second serial hardware ESP32 using pins 16 and 17, and the library for using the PZEM-004T sensor on Arduino is #include <PZEM004Tv30.h>.

4.2 Testing LED Indicators, Buzzers and Relays

There are 3 indicator LEDs used; namely, the red LED is used as an impulse indicator installed in series with the TX LED on the PZEM-004T sensor output or pin 16 of the ESP32 microcontroller, then the yellow LED is used as an indicator if there is an overvoltage (> 260 Volts).) or under voltage (< 80 Volts), then another green color is used as a power LED, which indicates that the load is ready to be measured by the PZEM-004T sensor, which is connected by a relay (load circuit breaker).

4.3 OLED Display Testing

The IoT-based kWh meter parameters are also displayed on the display in the equipment system using a 128 X 64 OLED display; the display displays the parameters in five lines. The first line displays the voltage, current and electrical power currently being used. The second line displays the system day and date obtained from the internet. The third line is the energy used by the load installed in the kWh system. The fourth row displays the city where the kWh meter is installed, and the last row displays the frequency, power factor and customer ID of the IoT-based kWh meter. The display in the first line shows a voltage of 236.7 volts, a current of 0, and an electrical power of 0. This value of 0 is because the kWh meter system has not been loaded. The second row displays Sunday and June 18 2023. This time, data was obtained from the internet. The third line is the energy used by the installed load of 0.081 KWh. The fourth row displays Denpasar City. The fifth line displays a frequency of 50Hz a power factor of zero, and the last is customer ID 1234567.

4.4 Firebase Database Testing

IoT kWh meter parameter data is stored in a cloud database so that it can be accessed anywhere. Data is stored in Json form, which is formed using the #include <FirebaseESP32.h> library using the FirebaseJson json data object. To access the database requires some initialization and program code and requires the database URL and token, as shown below. This program code has been tested and successfully saved the database in the cloud that has been prepared.

4.5 Load testing

The initial test results for each module created have shown that each module has run as expected. This research is to create an IoT-based kWh meter, so to test this IoT kWh meter, you need a measuring instrument that is the same as the tools on the market. The aim is to compare the measurement results to find out how much error the kWh meter made in this research has. As a comparison, the tool used is a Digital Energy Meter from GF STORE with the following technical specifications: Power Supply: 230 V, Frequency: 50 Hz, Maximum Load: 18A, 3680W, Minimum Power Display: 2W, Power Measurement Accuracy: ±2%, Power Quantity Accuracy: ±2%, Min. Power Quantity Accuracy: 0.01kWh, Range Power Measurement: 0.00 – 9999.9 kWh.

Meanwhile, the specifications for an IoT-based kWh meter made using the PZEM-004t 100A electrical power sensor are as follows:

Voltage: Measuring range 80 ~ 260 V; Measuring accuracy 0.5%; Resolution 0.1 V.
Current: start measuring current 0.02; Measuring range 0 ~ 100A; Measuring accuracy 0.5%; Resolution 0.001A.
Power: Starting power measuring 0.4 W; Measuring range 0 ~ 23 kW; Measuring accuracy 0.5%; Resolution 0.1 W;
Power Factor: Measuring range 0.00 ~ 1.00; Measuring accuracy 1%; Resolution 0.01
Frequency: Measuring range 45 Hz ~ 65 Hz; Measuring accuracy 0.5%; Resolution 0.1 Hz
Energy: Measuring range 0 ~ 9999.99 kWh; Measuring accuracy 0.5%; Resolution 1 W

Figure 7. IoT-based kWh circuit with display on a mobile device

To determine the success of the system created in this research, testing was carried out using household equipment electrical loads. The electrical loads used for household equipment are lights, fans, soldering irons, and irons. Tests carried out on each load of household electrical equipment are used to determine the value of the system's measuring instrument accuracy. The measurement results are shown in Table 1.

The LED lamp tested is capable of working in a voltage range of 110 to 268 Volt AC at a frequency of 50Hz, has an electrical power of 18W with a lifetime of up to 10,000 hours, a light strength of 1620 lumens, and is capable of turning on and off for more than 12,500 times. This LED light was measured using a Digital Energy Meter measuring instrument as a comparison to the measuring instrument created in this research.

The test was carried out by taking 9 data samples so that the average value of each parameter measured between the IoT Kwh Meter and the Comparative Kwh Meter could be calculated. The test results for LED lights are shown in the following table:

Table 1 Measurement Results for 18W LED Light Load

No	O'clock	kWh meter IoT				kWh meter Comparison			
		voltage (V)	current (A)	power (W)	PF	voltage (V)	current (A)	power (W)	PF
1	16:00:01	234.4	0,12	16.9	0.65	233	0.072	16.7	0.98
2	17:09:11	234.4	0,12	16.9	0.65	233	0.072	16.7	0.98
3	18:04:21	234.4	0,12	16,9	0.65	233	0.072	16.7	0.98
4	19:07:04	233.9	0.11	17.0	0.67	233.3	0.071	16.7	0.97
5	20:10:14	233.9	0.11	17.0	0.67	233.3	0.071	16.7	0.97
6	21:05:05	233.9	0.11	17.0	0.67	233.3	0.071	16.7	0.97
7	22:07:01	233.9	0.11	17.0	0.67	233.3	0.071	16.7	0.97
8	23:06:09	233.5	0.114	16.8	0.66	233.1	0.072	16.6	0.98
9	00:10:10	233.5	0.114	16.8	0.66	233.1	0.072	16.6	0.98

By using equation one above, the average value of the IoT kWh Meter can be calculated: voltage = 233.98 Volts, current = 0.1142 amperes, power = 16.92 watts, and the average value of the comparison kWh meter: voltage = 233, 16 Volts, current = 0.072 amperes, power = 16.68 watts.

Meanwhile, the percentage error value can be calculated using equation two; the results are as follows:

%Error (voltage) = $\frac{(233.98-233.16)}{233.16} X\ 100\%$ = 0,351689827 %

%Error (power) = $\frac{(16{,}92-16{,}68)}{16{,}68} X\ 100\%$ = 1,438848921%

Table 1 shows the results of standard measuring instruments and measurements on the kWh meter system. Firstly, for voltage measurements, the average voltage accuracy percentage is 100%. Second, for current measurements, the average percentage of current accuracy is 63.05%. Third, for power measurements, the average percentage of power accuracy is 98.58%. Fourth, for power factor measurements, the average percentage of power factor accuracy is 67.77%. The percentage of error in the measurement test of the average voltage read on the measuring instrument is 0.35%. The percentage error value can be caused by the lack of accuracy of standard measuring instruments. Apart from that, it can also be caused by voltage instability during voltage measurements so that there is a difference in measurements that is still at a reasonable stage of less than 5% (Salama & Vokony, 2022; Sapile, 2005).

Measuring electrical power with a larger power load, in this study, was using a 350W electric iron with a voltage of 220V. The goal is to observe how a device with higher power affects the electrical system and take advantage of it. Measuring electrical power on larger loads, such as electric irons, provides more detailed insight into how these devices interact with the electrical system and how their energy efficiency can be improved to reduce environmental impact and energy costs. The results of testing electric irons with 10 recordings are shown in the following table:

Table 2 Experiment Results Using Electric Iron Loads

No	O'clock	kWh meter IoT				kWh meter Comparison			
		voltage (V)	current (A)	power (W)	PF	voltage (V)	current (A)	power (W)	PF
1	07:00:00	229.7	1.65	378.2	1	233	1.67	388.2	1
2	08:08:10	229.6	1.655	378.3	0.99	233.1	1.66	388.5	1
3	09:12:03	229.8	1.66	378.1	0.98	233.3	1.66	388.2	0.99
4	10:07:05	229.7	1.64	378.4	1	233	1.65	388.3	1
5	11:10:09	229.6	1.64	377.9	1	233.1	1.65	388.0	1
6	12:22:04	229.6	1.65	377.9	0.98	233	1.67	389	0.98
7	13:08:07	229.9	1.66	378.0	099	233	1.66	388.8	1
8	14:10:20	229.8	1.657	378.2	1	233.3	1.66	388.5	1
9	15:09:13	229.6	1.66	378.1	1	233	1.67	388.2	0.99
10	16:18:12	229.6	1.65	378.2	1	233	1.67	388.1	1

By using equation one above, the average value of the IoT kWh meter can be calculated with a voltage value = 229.69 volts, current = 1.6522 amperes, power = 378.13 Watts, and the average value of a comparison kWh meter with a voltage value = 233.08 volts, current = 1.662 amperes, power = 388.38 Watts.

Meanwhile, the percentage error value can be calculated using equation two; the results are as follows:

%Error (tegangan) = ((229.69-233.03))/233.08 X 100% = 1,454436245%
%Error (daya) = ((378,13 - 388,38))/388,38 X 100% = 2,639167825%

Table 2 shows the results of standard measuring instruments and measurements on the kWh meter system. Firstly, for voltage measurements, the average voltage accuracy percentage is 98.55%. Second, for current measurements, the average percentage of current accuracy is 99.41%. Third, for power measurements, the average percentage of power accuracy is 97.36%. Fourth, for power factor measurements, the average power factor accuracy percentage is 99.8%. The percentage of error in the measurement test of the average voltage read on the measuring instrument is 1.45%. The percentage error value can be caused by the lack of accuracy of standard measuring instruments. Apart from that, it can also be caused by voltage instability during voltage measurements so that there is a difference in measurements that is still at a reasonable stage of less than 5% (Salama & Vokony, 2022; Sapile, 2005).

5. Conclusion

This research aims to create an Internet of Things (IoT) based kWh meter, which has been successfully carried out by assembling the PZEM004T sensor module, ESP32 microcontroller, OLED screen, and Relay module. This IoT-based kWh meter can be monitored and controlled remotely in real-time, and if there is a change in usage (addition or reduction), the load will be monitored directly via a mobile device because the kWh meter is connected directly to the internet. The test results based on the tool planning that was made were very good. The testing carried out on this prototype was the first; sensor testing; the second; testing of LED Indicators, Buzzers, and Relays, third; OLED screen testing, fourth; firebase database testing, fifth; load testing. The PZEM-004t sensor can measure several electrical parameters at a certain time, including voltage, current, active power, energy used, frequency, and power factor of the load being measured. The measurement results compared with tools already sold on the market are almost the same. Judging from the comparison of tool error calculations, the percentage of voltage error with different loads is quite small, namely 0.35% and 1.45%.

The test results are very satisfactory, so it can be concluded that the prototype for electrical energy consumption with an Internet of Things (IoT) based kWh meter is running according to plan. This research produces a prototype using ESP32 and PZEM-004T, which can be used to reduce the burden of operational costs for electricity companies in recording electrical power. The IoT-based kWh meter prototype in this research was made for single-phase electricity, so it needs to be developed for three-phase networks.

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