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Design and Development of a Web-Monitored Integrated Electricity KWh Meter Using an IoT-Based Microcontroller

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Abstract

This study aims to develop an Internet of Things (IoT)-based electrical energy (kWh) monitoring system using an ESP32 microcontroller integrated with a web monitoring platform. The system employs ACS712 current and ZMPT101B voltage sensors to measure voltage, current, power, and electrical energy in real time. The research method used is Research and Development (R&D) with the 4D model, consisting of define, design, development, and dissemination stages. The test results indicate that the ZMPT101B sensor has an error rate of 0.49%–0.81%, while the ACS712 sensor has an error rate of 4.0%–14.2%. Measurement data were successfully transmitted and displayed on the monitoring website through an internet connection. The developed system is capable of providing real-time electrical energy monitoring with adequate accuracy and easy accessibility for users.

Keywords: *Internet of Things (IoT), ESP32, Electrical Energy Monitoring, kWh Meter, Web Monitoring.*

Abstrak

Penelitian ini bertujuan mengembangkan alat monitoring energi listrik (kWh) berbasis Internet of Things (IoT) menggunakan mikrokontroler ESP32 yang terintegrasi dengan website monitoring. Sistem menggunakan sensor arus ACS712 dan sensor tegangan ZMPT101B untuk mengukur tegangan, arus, daya, dan energi listrik secara real-time. Metode penelitian yang digunakan adalah Research and Development (R&D) dengan model 4D yang meliputi define, design, development, dan dissemination. Hasil pengujian menunjukkan bahwa sensor ZMPT101B memiliki tingkat error sebesar 0,49%–0,81%, sedangkan sensor ACS712 sebesar 4,0%–14,2%. Data pengukuran berhasil dikirim dan ditampilkan pada website secara stabil melalui jaringan internet. Hasil penelitian menunjukkan bahwa sistem mampu melakukan monitoring penggunaan energi listrik secara real-time dengan tingkat akurasi yang cukup baik dan mudah diakses oleh pengguna.

Kata-kata kunci: *Internet of Things (Iot), Esp32, Monitoring Energi Listrik, Kwh Meter, Website Monitoring.*

1. Introduction

Electricity is a primary necessity in various sectors of life, ranging from households, education, and offices to industry **[1]**. Along with the increasing use of electrical appliances, electricity consumption has also risen significantly. This situation calls for an electricity monitoring system capable of providing information on energy usage that is accurate, fast, and easily accessible to users. Effective monitoring can help users control their energy consumption, thereby minimizing waste of electrical energy.

Generally, monitoring of electrical energy usage is still conducted through manual readings of kWh meters. This method has various limitations, particularly in providing real-time energy usage information and enabling remote access. Users can only determine the amount of energy used at a specific time, making it difficult to conduct continuous monitoring. In addition, delays in energy usage information can lead to an increase in uncontrolled electricity consumption

Advances in Internet of Things (IoT) technology have opened up new opportunities in the development of electrical energy monitoring systems **[2]**. IoT technology enables electronic devices to connect to one another via the internet, allowing for the automatic measurement, processing, and transmission of data. Various studies have developed IoT-based electrical energy monitoring systems that utilize microcontrollers and electrical sensors to obtain real-time energy usage data. These systems have proven capable of improving monitoring efficiency and making it easier for users to access energy usage information from various locations.

However, some previous studies have focused solely on monitoring specific electrical parameters, such as current and voltage, without providing integrated energy consumption information through a web-based monitoring system **[3]**. Additionally, some systems still rely on additional communication modules, thereby increasing device complexity and implementation costs. The use of the ESP32 microcontroller, which is equipped with an internal Wi-Fi module, offers the opportunity to develop a monitoring system that is simpler, more economical, and easier to implement **[4]**.

Based on these issues, this study proposes the design of an Internet of Things (IoT)-based electricity kWh meter using an ACS712 current sensor, a ZMPT101B voltage sensor, and an ESP32 microcontroller integrated with a web-based monitoring system. The developed system is capable of measuring electrical parameters—including voltage, current, power, and electrical energy—in real time and presenting the measurement results via a website accessible from various devices. The objective of this study is to design, build, and test the performance of an IoT-based electricity kWh meter integrated with a web monitoring system so that it can be used as an effective, practical, and real-time solution for monitoring electrical energy **[5]**.

2. Method

This study employs the Research and Development (R&D) method using the 4D development model (Define, Design, Development, Dissemination) [6]. This model was chosen because it is suitable for the development of technological products that require systematic design, testing, and validation processes.

a. Define

The Define phase aims to identify the requirements for an electrical energy monitoring system. During this phase, a literature review was conducted, hardware and software requirements were analyzed, and issues with conventional electrical energy monitoring systems were identified.

b. Design

The design phase involves system design, which includes: the system design phase begins with hardware design, encompassing the selection of key components used in the device. Next, sensor circuit design and program development are carried out as part of the data acquisition system to detect and measure the required parameters. The measured data is then processed and stored through a database design that serves as a medium for storing and managing information. After that, to simplify the process, a website interface is designed to serve as a tool for real-time monitoring and data presentation to users, ensuring that the entire process runs systematically and in a structured manner.

c. Development

The development phase includes the fabrication of hardware, ESP32 programming, sensor integration, website development, and testing

d. Dissemination

The dissemination phase involves the implementation and evaluation of the system's development results, as well as the preparation of a research report.

Diagram of method research can be seen in **Figure 1.**

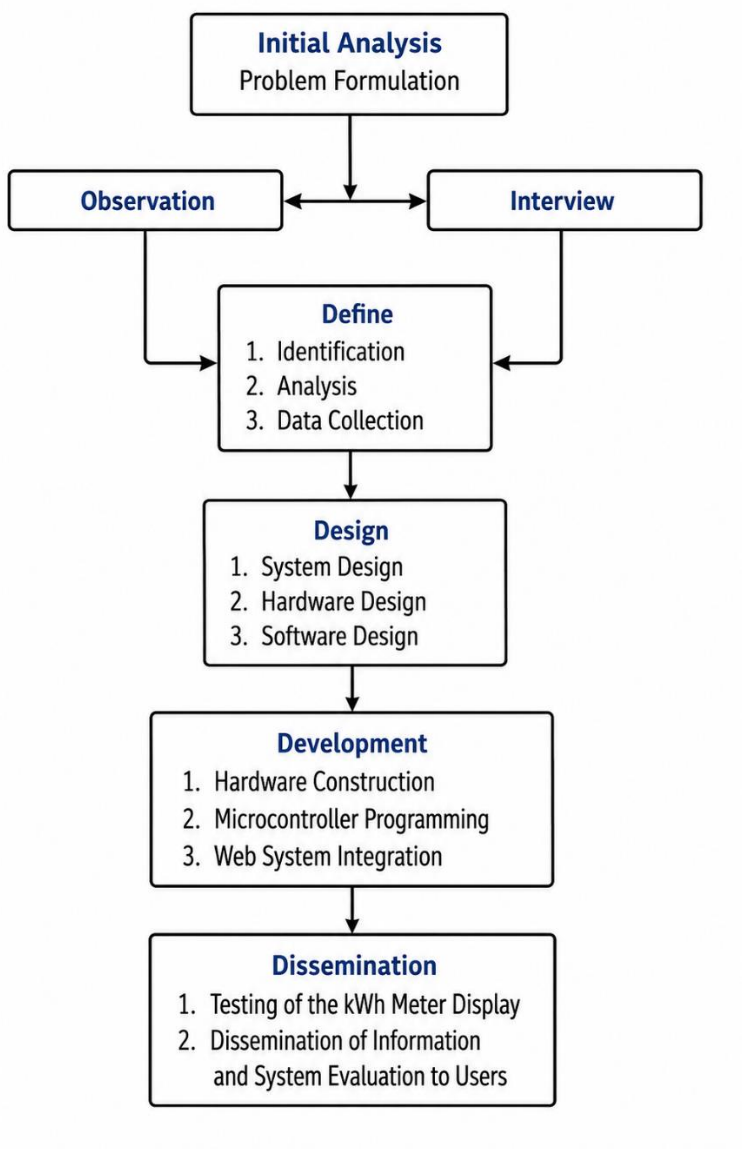

Figure 1. Method Research

The research phase began with the identification of a problem: electricity usage monitoring is still conducted manually, making it difficult for users to monitor power consumption in real time and remotely. To address this issue, an Internet of Things (IoT)-based electricity kWh meter was developed and integrated with a web-based monitoring system so that electricity usage information can be accessed quickly, accurately, and at any time via the internet.

Next, data collection was conducted through observation, interviews, and a literature review. Observation was used to examine the existing system, interviews to identify user needs, and the literature review to study the technologies used, such as the ESP32, ACS sensors, ZMPT101B sensors, and IoT. The data obtained was then used as the basis for designing a web-based electricity monitoring system capable of functioning optimally in the process of real-time electricity monitoring. The system consists of several main components, namely: a ZMPT101B voltage sensor, an ACS712 current sensor, an ESP32 microcontroller, a 16×2 LCD, a web server and database module, and a monitoring website. **Figure 2** is electronic circuit for this product.

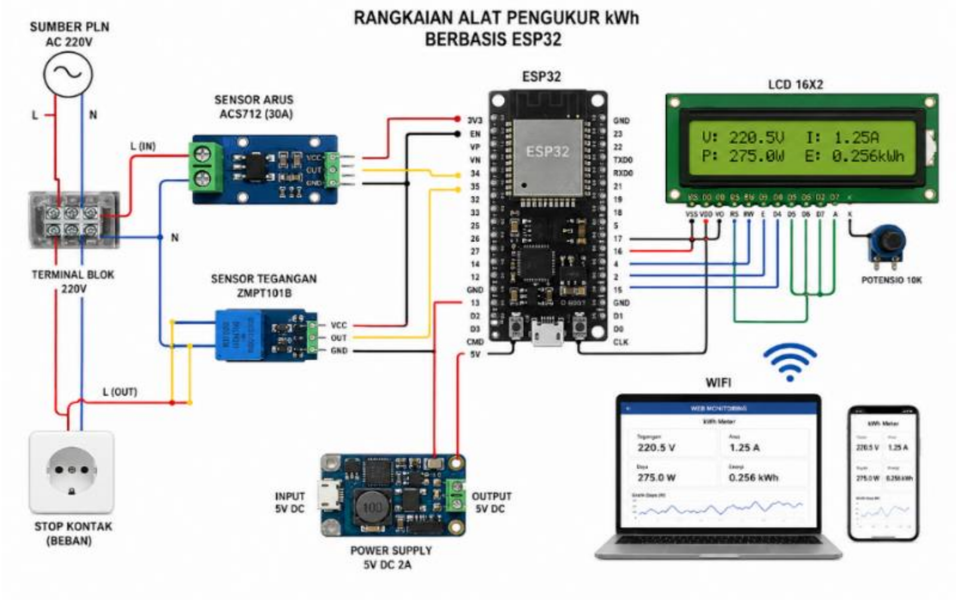

Figure 2. Electronic Circuit

3. Results and Discussion

3.1. Result

This research successfully developed an Internet of Things (IoT)-based electricity kWh meter integrated with a web-based monitoring system. The system consists of a ZMPT101B voltage sensor, an ACS712 current sensor, an ESP32 microcontroller, a 16×2 LCD, and a monitoring website accessible via computer or smartphone. These components are housed in a protective enclosure, giving the device a neater, safer, and more user-friendly appearance. The 16×2 LCD is used to display voltage, current, power, and electrical energy information in real time, while the website serves as a platform for real-time monitoring.

Software implementation was carried out using the Arduino IDE with support from the WiFi.h, HTTPClient.h, ACS712.h, ZMPT101B.h, and LiquidCrystal_I2C.h libraries. Measurement data obtained from the sensors is processed by the ESP32 to calculate power and electrical energy, then sent to the server via a Wi-Fi network and stored in a database before being displayed on the monitoring website.

Internet connection testing showed that the ESP32 was able to connect to the Wi-Fi network and transmit data to the website reliably. Voltage, current, and power parameters could be displayed in real time, and the data was successfully stored in the database without any loss of information. The results are presented in the **Table 1.**

Table 1. Internet Connection Test Results

No.	Parameter	Monitoring Result	Status
1	Voltage	Displayed in Real Time	Successful
2	Current	Displayed in Real Time	Successful
3	Power	Displayed in Real Time	Successful
4	ESP32 Connection to the Web System	Connected	Successful
5	Data Storage	Data Successfully Stored in the Database	Successful

Tests conducted on several electrical loads showed that the system is capable of effectively managing electrical energy consumption. The energy consumption of several electrical appliances is presented **Table 2.**

Table 2. Electrical Load Test Results

No.	Appliance	Power (W)	Operating Time	Energy Consumption (kWh)
1	LED Lamp	15 W	8 Hours	0.12 kWh
2	Television	80 W	6 Hours	0.48 kWh
3	Refrigerator	150 W	20 Hours	3.00 kWh
4	Rice Cooker	300 W	4 Hours	1.20 kWh
5	Welding Machine	900 W	1.5 Hours	1.35 kWh

Testing of the ZMPT101B voltage sensor was conducted by comparing the sensor’s readings with those of a digital multimeter. The test results showed that the sensor’s error rate fell within the range of 0.49%–0.81%, indicating that the sensor has a good level of accuracy for use in electrical energy monitoring systems.

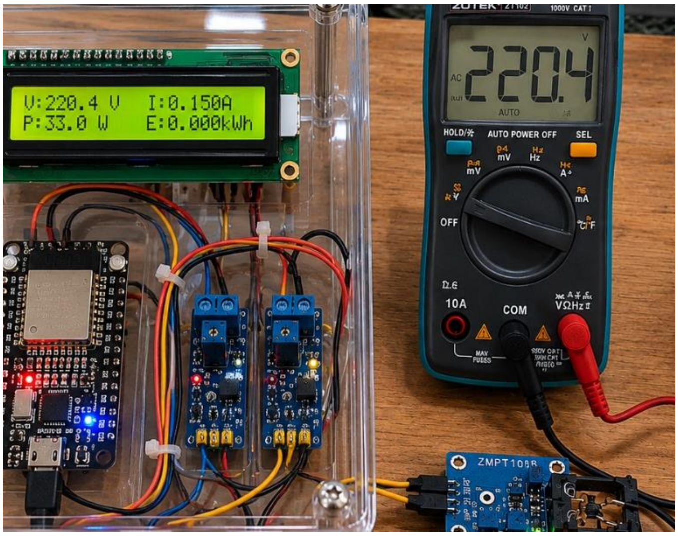

Figure 3. Voltage Sensor Testing

The amount of electrical power is calculated using the equation:

$$P = V \times I$$

Where P is electrical power (watts), V is voltage (volts), and I is current (amperes). The power data obtained is then used to automatically calculate electrical energy (kWh) and displayed on the LCD and the monitoring website. The results are presented in Table 3.

Table 3. Voltage Sensor Testing

Load	Sensor (V)	Multimeter (V)	Error (%)
LED Lamp	221,5	220	0,68
Fan	222,8	221	0,81
Charger Laptop	223,1	222	0,49
Welding	224,8	223	0,80

Testing of the ACS712 current sensor was conducted by comparing the sensor's measurement results with those of a digital clamp meter. The test results showed an error range of 4.0% to 14.2%. This variation was influenced by the sensor's sensitivity to signal interference and the characteristics of the load used during testing.

Figure 4. Current Sensor Testing

The results of the current sensor testing are presented in **Table 4.**

Table 4. Current Sensor Test Results

Load	Sensor (A)	Tang Ampere (A)	Error (%)
Lampu LED	0,08	0,07	14,2
Kipas Angin	0,32	0,30	6,6
Charger Laptop	0,15	0,14	7,1
Mesin Las	3,85	3,70	4,0

In addition, testing of the web monitoring system showed that the measurement data was successfully transmitted from the ESP32 to the server and properly stored in the database. The website is capable of displaying real-time information on voltage, current, power, and electrical energy and can be accessed via a computer or smartphone, making it easier for users to monitor their electricity usage remotely. The test results are presented in **Table 5.**

Table 5. Web Monitoring Test Results

Parameter	Result	Keterangan
Tegangan	Tampil Real-Time	Berhasil
Arus	Tampil Real-Time	Berhasil
Daya	Tampil Real-Time	Berhasil
Koneksi ESP32 ke Web	Terhubung	Berhasil
Penyimpanan Database	Tersimpan	Berhasil

3.2. Discussion

The research results show that the Internet of Things (IoT)-based electricity kWh meter developed in this study is capable of performing real-time electricity monitoring functions in accordance with the research objectives **[11]**. The integration of the ZMPT101B sensor, the ACS712 sensor, the ESP32 microcontroller, and the monitoring website enables the measurement, data processing, and transmission of information to occur automatically via the internet **[13]**.

Based on the test results, the ZMPT101B voltage sensor exhibits excellent accuracy with an error rate below 1%. This indicates that the sensor is suitable for voltage measurement in electricity monitoring systems **[7]**. Meanwhile, the ACS712 current sensor has a higher error rate, particularly when measuring small currents. Nevertheless, the error rate obtained is still within acceptable limits for household-scale electrical energy monitoring applications.

Internet connection testing and web monitoring showed that the ESP32 was capable of transmitting data stably to the server without any data loss [9]. Information on voltage, current, power, and electrical energy can be displayed in real time via a website accessible from both computers and smartphones **[12]**. This capability makes it easy for users to monitor their electricity usage without having to be physically present at the device's location.

Overall, the developed system has successfully met the research objectives, namely measuring electrical parameters, calculating electrical power and energy, transmitting data via the internet, and presenting real-time electrical energy usage information through a monitoring website **[10]**. With these capabilities, this device has the potential to become a more modern, practical, and efficient solution for monitoring electrical energy compared to conventional methods that are still performed manually.

4. Conclusion

Based on the results of the research conducted, it can be concluded that: an Internet of Things-based electricity kWh meter using an ESP32 microcontroller was successfully designed and built in accordance with the planned specifications. The ZMPT101B voltage sensor has an error rate ranging from 0.49% to 0.81%, while the ACS712 current sensor has an error rate ranging from 4.0% to 14.2% [8]. The web monitoring system successfully displays voltage, current, power, and electrical energy data in real time and stores the data in a server database. The developed system can be used as a practical, easily accessible tool for monitoring electricity usage and supports the application of Internet of Things technology in the field of electricity monitoring.

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