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Design of Electrical Energy Monitoring System Using NodeMCU ESP8266 and PZEM-004T for Power Usage Control

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ABSTRACT

Electricity is one of the essential needs for society today, serving as a primary economic resource. The use of electricity in household sectors reached 50.80% in 2020, contributing to the total electricity consumption in Indonesia each month. To raise awareness about excessive electricity usage leading to inflated electricity bills, there is a need for a remote monitoring and control device, based on the Internet of Things (IoT), specifically targeting electronic appliances that consume electricity.

Addressing this issue, a research study titled "Design of Electricity Monitoring System Using NodeMCU ESP8266 and PZEM-004T for Controlling Electricity Usage" was conducted. The energy usage monitoring system is implemented in a terminal socket device capable of displaying power consumption through a module. Additionally, this terminal socket can be connected to the internet, allowing users to view electricity usage data on the ThingSpeak website. The necessary tools and materials for designing the monitoring and controlling system include a laptop, NodeMCU ESP8266 module, PZEM-004T sensor, relay (Rlay), OLED display, power terminal, plug (Stekker), and jumper cables.

Based on testing using the blackbox method, the system has demonstrated effective monitoring and control of energy usage. It was observed that the power consumption stated for an electronic device may differ from the actual power consumed. This difference could be attributed to variations in the stated power consumption information compared to the actual power consumption

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1. INTRODUCTION

Electricity is a fundamental necessity for today's society, serving as a primary economic resource. With the ongoing advancements in the digital era and the increasing demand for electronic devices, the need for electrical energy in society is growing. Household electricity consumption reached 50.80% in 2020 [1]. Implementing energy-saving measures in household electricity usage is an initial step to anticipate potential energy crises.

Traditionally, electricity usage is monitored only through kWh meters, which function to monitor and limit overall electricity usage in a household. To enhance public awareness of excessive electricity usage leading to inflated electricity bills, there is a need for a remote monitoring and control device based on the Internet of Things (IoT). This device would specifically target electronic appliances such as TVs, air conditioners, refrigerators, fans, washing machines, rice cookers, and more.

The Internet of Things (IoT) is a concept that enables data transfer and extends the benefits of continuous internet connectivity without requiring human-computer interaction. IoT operates wirelessly and allows for automatic control regardless of distance. The IoT works by utilizing programming that generates interactions and communications between connected machines automatically. The internet serves as the medium connecting these devices.

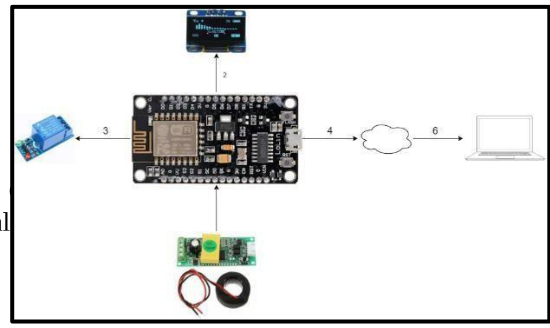
ThingSpeak is an IoT application and API service that provides open-source functionality for storing and retrieving data from various devices using HTTP over the internet or LAN. Utilizing ThingSpeak allows for creating applications for sensor logging, location tracking, and social networks for anything connected to the internet with status updates [15].

Several sensors, such as ACS712, ZMP101B, and PZEM-004T, can be employed to monitor energy usage. The ACS712 is a current sensor based on the Hall Effect for measuring current. The ZMP101B sensor is designed to measure a maximum voltage of 250 Vac, using a differential attenuator of 230 VACrms with a tolerance of 5VACpp. The PZEM-004T sensor module is chosen for its ability to simultaneously measure voltage, current, and active power with a 99% accuracy rate [2].

In light of the aforementioned challenges, a research study titled "Design of Electricity Monitoring System Using NodeMCU ESP8266 and PZEM-004T for Controlling Electricity Usage" has been conducted. The energy usage monitoring system is implemented in a terminal socket device capable of displaying power consumption through a module. Additionally, this terminal socket can be connected to the internet, allowing users to view electricity usage data on the ThingSpeak website. Monitoring can be accessed through the ThingSpeak web channel, and for visualization, the ThingView application is installed on smartphones. The website also features a function to turn the terminal socket on or off remotely. This allows users to remotely disconnect power to electronic devices connected to the terminal socket in case they forget to unplug or turn off the devices.

2. RESEARCH METHOD (10 PT)

3.1. System Architecture Design



ure for
electrical PZEM-
004T.

Figure 5. System Architecture Design

The following is an explanation of the design and processes in Figure 3.2:

In the first process, the PZEM-004T module will detect the consumption of electric current used at the built-in power outlet terminal.

In the second process, the relay will act as a breaker for the electric current according to user instructions.

In the third process, the OLED will display the energy usage of the electric current taken from the PZEM-004T module.

In the final process, the NodeMCU will send electric current usage data via the sensor to the IoT Broker, and Thingspeak serves as an intermediary for receiving data and displaying it in the form of a graph.

3.2. Hardware Design

In the hardware design, a rough design of the electrical current monitoring system will be created with necessary modules such as NodeMCU ESP8266, OLED, Relay, and PZEM-004T.

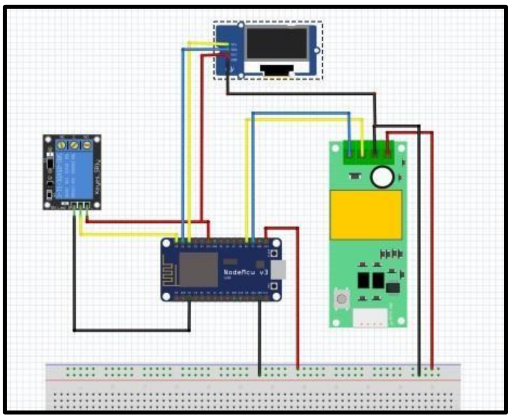


Figure 6. Hardware Design

The above figure represents the hardware system design that will be implemented. In this hardware design, the NodeMCU ESP8266 microcontroller receives data on electric current usage from the current sensor (PZEM- 004T), and this data will be displayed on the OLED. The relay functions as a breaker for the electric current.

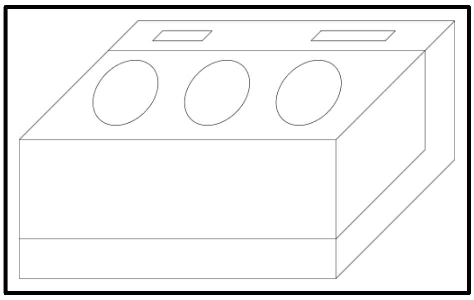


Figure 7. Terminal

3.3. Software Design

The software design phase is utilized for the design of the software used.

3.3.2 ThingSpeak Communication Design

Figure 10. ThingSpeak Communication

The above diagram illustrates the ThingSpeak communication design. The microcontroller (NodeMCU publisher) reads the electric current using a sensor, and then the data is sent to ThingSpeak (server) via the internet. ThingSpeak stores the data and displays it in graph form.

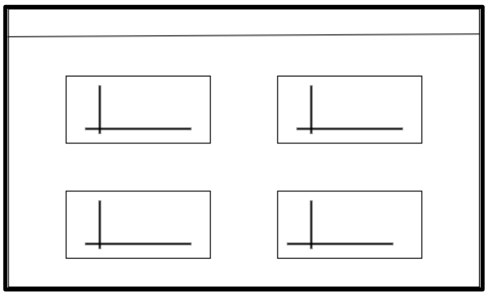
To design the website used for monitoring and controlling electric current.

3.3.1 System Website Design

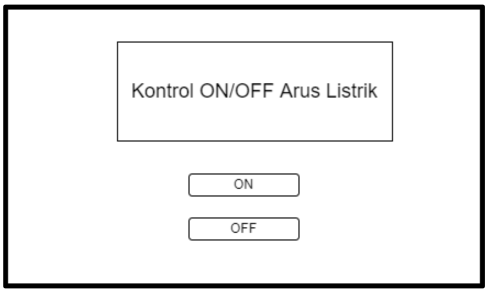
Below is the design of the system that will be created:

1. **User Interface System**

a. **Electric Current Monitoring Page**



b. **Electric Current Controlling Page**



3.4. System Implementation

The system implementation phase involves organizing the components of the Electrical Energy Monitoring System Using NodeMCU ESP8266 and PZEM-004T for Controlling Electric Usage. The implementation is

1. **Hardware Configuration Assembly:**
   - The NodeMCU, PZEM-004T, Relay, OLED, Plug, and Electric Terminal configurations will be assembled into a single circuit used to control the electric current monitoring system.
2. **Software Development:**
   - The software development phase is used to create a website for controlling the ON/OFF state of the electric current.

divided into two parts:

3.5. Testing

The testing and evaluation phase of the system is conducted to assess the built system and evaluate the results of the system testing process. There are two stages of testing performed as follows:

Table 1. Hardware Testing Scenarios

Component	Testing Scenario	Result	Desired Outcome
PZEM-004T	Detecting the presence of electric current flow	Can detect the electric current used at the power outlet terminal	Detection of electric current at the power outlet terminal
Oled 16x2	Displaying the value of the electric current used	Can display the value of the electric current used at the power outlet terminal	Display of the electric current value at the power outlet terminal
Relay	Interrupting the electric current flow	Can interrupt the electric current flow to the power outlet terminal	Interruption of electric current to the power outlet terminal

Table 2. Software Testing Scenarios

Test Case	Testing Scenario	Result	Desired Outcome
Login	Logging into the ThingSpeak web with registered credentials	User can log into the ThingSpeak web with the registered username and password	Successful login with registered credentials
Home Page	Viewing the data of the electric current usage	Can display the data of the electric current usage	Display of electric current usage data
Controlling Page	Turning off the electric current outlet device	Can turn off the electric current outlet device	Successful turning off of the electric current

Test Case	Testing Scenario	Result	Desired Outcome
			device

3. RESULTS AND ANALYSIS

4.1. System Implementation

In this implementation phase, several aspects will be discussed, including the implementation of hardware assembly, software system development, and the implementation of the system design as outlined in the previous chapter.

4.1.1 Hardware Assembly Implementation

In this stage, the realization of the hardware design from the research "Design of Electrical Energy Monitoring System Using NodeMCU ESP8266 and PZEM-004T for Controlling Electric Usage" will be discussed. The visual representation of the hardware design can be seen in the image below.

Figure 11. Overall Hardware Design

At this stage, there are five main components: NodeMCU ESP8266, PZEM-004T sensor, relay, Oled 16x2, and electric terminal. These components will be integrated into a unified system with their respective functions. NodeMCU ESP8266 serves as the controller for other components, where these components will operate according to the commands from NodeMCU ESP8266. The PZEM-004T sensor reads the electric current power at the built-in power outlet, Oled 16x2 displays the used electric current power, and the relay functions to interrupt the electric current flow to the power terminal. The result of the hardware design is shown below.

4.1.2 Software Development Implementation

Figure 12. Software Development Implementation

The diagram above illustrates the workflow of the electric current monitoring system. It begins with the PZEM-004T sensor detecting the usage of electric current, and the results are displayed on the Oled module. Subsequently, the data, representing the detected electric current usage, is sent to the ThingSpeak web server and displayed accordingly.

4.2. System Testing and Analysis

In this phase, comprehensive testing is conducted on the entire system to verify whether the system functions according to the requirements. Hardware and software testing are performed using the black-box testing method to analyze and check the functionality of the system features.

4.2.1 Hardware Testing

H rdware testing aims to determine if all the hardware c mponents function as expected.

1. **PZEM-004T Sensor Testing**
    - **Test Case:** Detecting electric current power at the power outlet terminal.
    - **Result:** Valid

Table 3. PZEM-004T Sensor Test Results

Test Case	Testing Scenario	Result
PZEM-004T Current Sensor	Detecting electric current power at the power outlet terminal	Valid

2. **Oled Module Testing**
    - **Test Case:** Displaying the value of electric current power used at the power outlet terminal.
    - **Result:** Valid

Table 4.2 Oled Module Test Results

Test Case	Testing Scenario	Result
Oled 16x2	Displaying the value of electric current power used at the power outlet terminal	Valid

3. **Relay Testing**
    - **Test Case:** Checking if the relay functions correctly.
    - **Result:** Valid

Table 4.3 Relay Module Test Results

Test Case	Input	Current Condition	Result
Relay	HIGH	Off	Valid
Relay	LOW	On	Valid

4. **System Testing**
    - **Test Case:** Verifying the overall functionality of the system, including the relay as an electric current flow interrupter, Oled display, and website for monitoring electric energy usage.

Figure 13. System Testing With Mobile Charging.

Testing and System Analysis (continued)

Testing was conducted by connecting electronic devices (laptop charger, mobile phone charger, and iron) to the power terminal. The system was evaluated to determine if it could read and display the electric current power used by the connected electronic devices. The power source used for testing was the household electrical source (AC

220V power outlet) connected to the terminal, and an adapter (DC 5V 1A) with a USB 2.0 head for the NodeMCU 8266 microcontroller.

Table 4.4 System Testing Results

Test Case	**Testing Scenario**	**Desired Outcome**	**Result**
System Testing	Connecting various electronic devices to the power terminal and checking if the system can accurately read and display the electric current power usage.	Accurate reading and display of electric current power usage.	Valid (Accuracy level: 99.9%)

From the above test, it can be seen that the accuracy level of the built electrical energy monitoring system is very high, with only a 0.1% difference between the displayed and actual power consumption. The slight discrepancy in the iron consumption may be due to differences in the stated power consumption and the actual power consumption.

4.2.2 Software Testing

Software testing was conducted using the black-box method. The results of the testing are presented below.

Table 4.5 Software Testing Results

Test Case	**Testing Scenario**	**Desired Outcome**	**Result**
Login	Entering the correct username and password as registered.	User can access the system by entering the correct username and password.	Valid
Monitoring Page	Viewing electric current usage data, electric current usage graph, and downloading monitoring data.	Displaying electric current usage data, electric current usage graph, and allowing users to download monitoring data.	Valid
Controlling Page	Turning on or off the power terminal device by pressing the On/Off button on the website.	User can turn on or off the power terminal device by pressing the On/Off button on the website.	Valid

4. CONCLUSION

Based on the conducted research, the following conclusions can be drawn:

The electrical current monitoring system using the PZEM-004T sensor demonstrates a high level of accuracy.

The actual power consumption by an electronic device may differ from the stated power consumption. This difference could be attributed to variations between the stated and actual power consumption information.

The web-based monitoring and control system using ThingSpeak enables effective monitoring of electrical current energy usage. It allows users to download energy usage data and remotely control devices.

This research proves that integrating the PZEM-004T sensor with the ThingSpeak platform and controlling through a website can be an effective solution for monitoring and controlling electrical energy usage. The high accuracy in measurements and the ability to control devices remotely make this system valuable for optimizing energy usage and improving efficiency.

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