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Power Usage Monitoring Simulator for Estimating Usage Tariffs and Carbon Emission Levels at STO Bogor Based on IoT

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ABSTRACT

In this modern era, the efficiency of electricity usage has become one of the main concerns in the efforts toward sustainable energy management. The limitations in monitoring electricity usage have become a challenge for technicians, resulting in inefficiencies in data collection and discrepancies between the actual power usage and manual recordings. This research aims to design and develop a prototype of an Internet of Things (IoT)-based electricity usage monitoring tool to monitor electricity consumption in real-time, provide usage cost estimates, and measure the emission levels generated by the devices being used. It also facilitates data recording, accelerates decision-making, and improves electricity management with high accuracy, with a margin of error of 0.8% for power calculations and 0.5% for total power calculations. This allows for accurate measurement of voltage, load, power, and total power. The data obtained is used to calculate electricity tariffs based on actual consumption, such as a subscription fee of IDR 127,134, a rate per kWh of IDR 528.76, and a tax of 4%, resulting in a total cost of IDR 132,768 for 0.366 kWh usage over 60 minutes. The use of electronic devices also increases carbon emissions, with a 69% increase in the first 10 minutes and 28% in 60 minutes, highlighting the importance of environmental awareness and wise electricity usage.

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1. INTRODUCTION

Technology and knowledge are increasingly developed. One of the technologies that is currently Electricity is energy that is used every day and is a necessity for many activities, such as studying, working, and entertainment; without electricity, life feels like it has stopped. Although important, electricity needs to be conserved to prevent excessive usage. Energy conservation also plays a crucial role in reducing the impacts of climate change and supporting the transition to renewable energy sources [1]. Moreover, energy conservation is often more economical and environmentally friendly than increasing energy production.

Energy conservation is a key component in energy policy that can reduce per capita energy consumption and demand, thereby helping to offset the increased energy needs resulting from population growth. It not only lowers energy costs but also reduces the need for new energy generation plants or energy imports, providing more flexibility in choosing energy production methods [2]. Meanwhile, electricity generation, while essential for technological and economic progress, is one of the main sources of carbon dioxide (CO_2) emissions and other greenhouse gases [3], which negatively impact the environment, human health, and ecosystem stability [4].

There are various national and international missions aimed at creating environmentally friendly strategies in the energy sector, including electricity, as outlined in the Kyoto Protocol. This diplomatic agreement aims to reduce greenhouse gas emissions, particularly carbon dioxide (CO_2) [5], which can exacerbate global warming and climate change [1]. These carbon emissions are primarily produced from the burning of fossil fuels, prompting major industrialized countries to reduce their usage [6].

6 Telkom Indonesia, as one of the state-owned enteIDRrises (BUMN) operating in the telecommunications sector, derives most of its revenue from services such as mobile voice, SMS, mobile broadband, and digital services for cellular customers. To enhance customer satisfaction, Telkom Indonesia provides uninterrupted network services, which can lead to an increase in electricity costs from PLN. To monitor power consumption in real-time, the NA team must record the electricity usage of each STO every month and report it to Witel Bogor. Given the limited personnel, an effective power monitoring tool is needed to track usage over a month with IoT applications [7], [8], [9].

By having data on electricity consumption at each STO, Telkom Indonesia can estimate the costs to be incurred for paying for the electricity supplied by PLN. This enables comprehensive monitoring of electricity usage and expenditure estimates for electricity costs, thereby assisting in budget planning and more effective cost management [10], [11].

2. RESEARCH METHOD

In this research method, there are several factors that will be tested and subsequently presented in the form of graphs. The following are the aspects that will be tested:

2.1. Carbon Emission Factor

This carbon emission is calculated based on the usage of electronic devices at the Yogyakarta Institute of Technology. Before calculating the carbon emissions from electricity usage at the Bogor STO, an emission factor calculation is performed for the power plants operated by PLN that supply electricity to the Bogor area.

Tabel 1. Average Emission Factor Calculation

Power Plant Name	Type of Power Plant	Fuel	Emission Factor	Capacity	(tCO2)
UP Semarang	PLTGU	Gas	0,4	1409	563,6
UP Paiton Swasta 1	PLTU	Coal	0,99	1230	1217,7
UP Paiton Swasta 2	PLTU	Coal	0,99	1300	1287
UP Muara Karang	PLTU	Coal	0,99	1000	990
	PLTGU	Gas	0,4	200	80
UP Cilacap	PLTU	Coal	0,99	660	653,4
UP Pacitan	PLTU	Coal	0,99	630	623,7
Total				6429	5415,4
Emission Factor				0,84	

In calculating the CO_2 emission level, the following equation is used:
Emission CO_2 = *Emission Factor x Electricity Consumption*
Description:
Emission Factor : 0,84 kg CO_2/kWh
Electricity Consumption : Electricity consumed (kWh)

2.2. Electricity Tariff

Monthly electricity usage is measured in kilowatt-hours (kWh) and is subject to a progressive tariff, where higher usage results in a higher rate per kWh [11], [12]. This electricity tariff is determined and periodically adjusted by the government through the State Electricity Company (PLN), taking into account national energy policies and current economic conditions [12]. The calculation of electricity tariffs in Indonesia is as follows.

Electricity Demand Charge : 40 (Operating Hours) x Power Connected (kVA) x Usage Charge
kWh Cost : Power Usage x Usage Charge
Electricity Usage Cost : Electricity Deman Charge + kWh Cost
Public Tax Cost (PPJ) :Electricity Usage Cost x Tax
Bill :Electricity Usage Cost + Public Tax Cost

2.3. Device Flowchart

Figure 1 shows a flowchart for the automated process of:

1. Reading voltage, current, and power sensor data.
2. Data processing to calculate electricity rates and carbon emissions.
3. Displaying results on LCD and Blynk for user monitoring.

This flow allows the system to run efficiently with transparent condition checking, displaying results, and calculations.

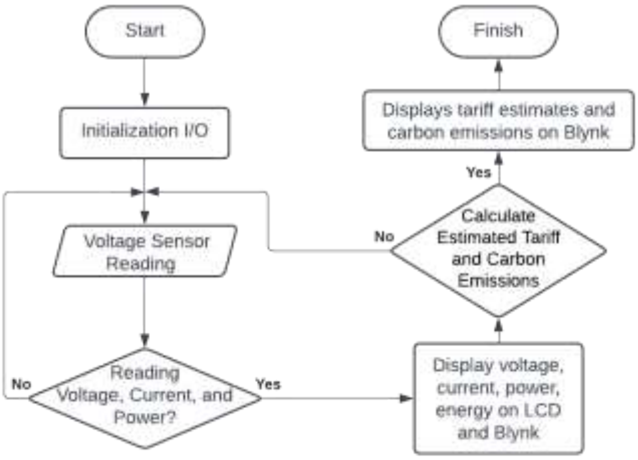

Figure 1. Flowchart of the Device's Working System

3. RESULTS AND DISCUSSION

3.1. Testing Using Sensor PZEM-004T

There are 3 PZEM-004T sensors in this device, each equipped with 1 power socket to connect to electronic devices. The electronic devices will be detected at each power socket and will later be displayed on the LCD. This data will be input into a calculation to estimate the electricity tariff and the carbon emissions produced. The readings from this device in Table 2.

Table 2. Testing Data Using PZEM-004T Sensor

Time	Catuan	Voltage (V)	Current (A)	Power (W)	Power Total (Wh)
10 Minutes	1	220	0,60	90,5	15
	2	221	0,55	108,7	19
	3	214	1,72	369,9	32
20 Minutes	1	220	0,57	88,9	30
	2	222	0,56	120,8	27
	3	214	1,72	368,8	54
30 Minutes	1	219	0,60	92,3	46
	2	216	0,55	116,7	46
	3	216	1,71	374,5	75
40 Minutes	1	220	0,88	131,0	63
	2	219	0,55	108,0	60
	3	218	1,72	362,9	98
50 Minutes	1	218	1,07	233,3	98
	2	219	0,56	119,2	71
	3	216	1,71	373,2	117
60 Minutes	1	220	1,08	237,0	136
	2	220	0,56	119,9	90

3	216	1,72	376,0	140

The results of the measurements will be displayed on the LCD, as shown in Figure 2.

Figure 2. Testing Using Sensor PZEM-004T

This testing produces data presented in Table 2. However, to ensure that this device provides accurate results, another measuring instrument is needed as a reference. The reference measuring instrument used here is a Watt Meter sold in online shops. The results from the reference measuring instrument are as follows:

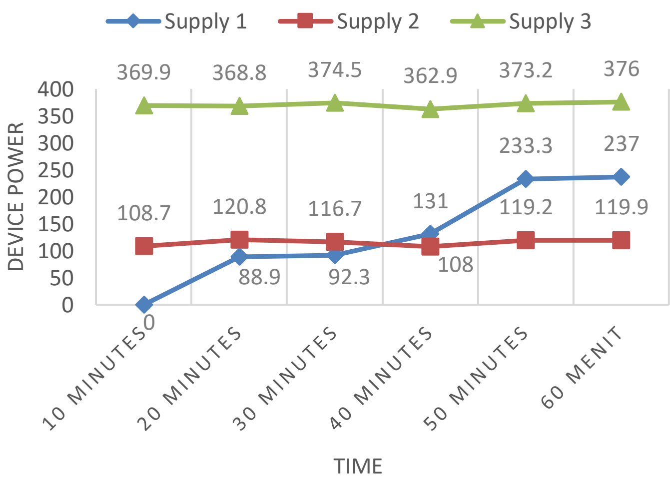

Figure 3. Power Graph in Testing Using PZEM-004T Sensor

Next, measurements were taken using a digital watt meter to determine the power level.

Figure 4. Testing Using a Digital Watt Meter

The results of the testing were obtained for 6 trials at different times to determine the voltage, current, and power levels (Table 3 is shown).

Table 3. Testing Data Using a Digital Watt Meter

Time	Supply	Voltage (V)	Current (A)	Power (W)	Total Power (Wh)
10 Minutes	1	220	0,58	90,5	0,015
	2	221	0,55	111,0	0,019
	3	215	1,72	368,1	0,032
20 Minutes	1	220	0,57	87,5	0,03
	2	222	0,55	119,2	0,027
	3	214	1,70	361,9	0,054
30 Minutes	1	218	0,61	90,9	0,045
	2	217	0,54	115,7	0,046
	3	216	1,69	365,3	0,074
40 Minutes	1	220	0,88	129,1	0,062
	2	219	0,55	110,9	0,06
	3	218	1,70	371,0	0,097
50 Minutes	1	218	1,07	230,9	0,097
	2	219	0,55	117,9	0,07
	3	215	1,70	365,4	0,116
60 Minutes	1	220	1,08	234,8	0,135
	2	220	0,55	118,2	0,09
	3	215	1,71	367,6	0,14

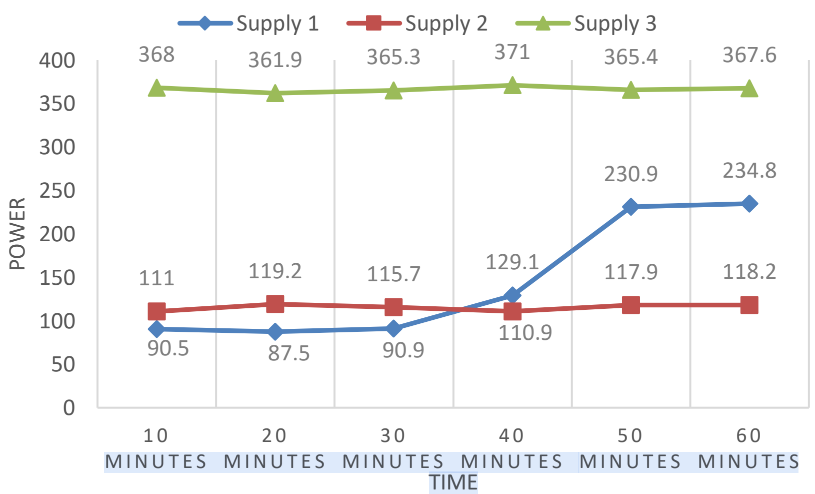

Figure 5. Data Testing Graph Using Digital Watt Meter

From the data in Table 3 and Figure 5, it is presented in the form of a graph as shown in the image below. Testing of the voltage and current sensors is conducted to ensure that the sensors are functioning properly and that their readings are accurate and meet the expected measurements. After that, monitoring tests are carried out on the LCD and the Blynk application to ensure that both are working well and displaying the correct information [11]. Finally, a test is performed to determine the system's error rate while operating in measurement mode. This error rate can be calculated using the following Formula (1) and Formula (2).

$$\%\ Error = \left(\frac{Vout\ Testing - Vout\ Measurement}{Vout\ Measurement}\right) x\ 100\% \quad (1)$$

$$\%\ Mean\ Error = \frac{\Sigma\%\ Error}{n} \quad (2)$$

3.2. Results of Power and Total Power Calculation

Testing of the voltage and current sensors is conducted to ensure that the sensors are functioning properly and that their readings are accurate and meet the expected measurements. After confirming that they can measure voltage and current, calculations can be performed to obtain the readings for power and total power [13], [14].

The error data obtained from the observations are recorded in Table 1 and Table 2 and analyzed using Formula (1). This equation is used to calculate the individual error for each measurement. Subsequently, the mean error value of all these measurements is calculated using Formula (2). By performing this calculation, a clearer picture of the overall accuracy of the system can be obtained. The results of the Power and Total Power calculations are presented in Table 4 and Table 5, which are visualized through the graphs in Figure 6 and Figure 7.

Table 4. Comparison of Power Measurement of the Device with Reference

Time	Device Power	Reference Power	Error
10 Minutes	569,1	569,6	0,09%
20 Minutes	578,5	568,6	1,71%
30 Minutes	583,5	571,9	1,99%
40 Minutes	602,0	611,0	1,49%
50 Minutes	725,7	714,2	1,58%
60 Minutes	732,9	720,6	1,67%
	Error		0,89%

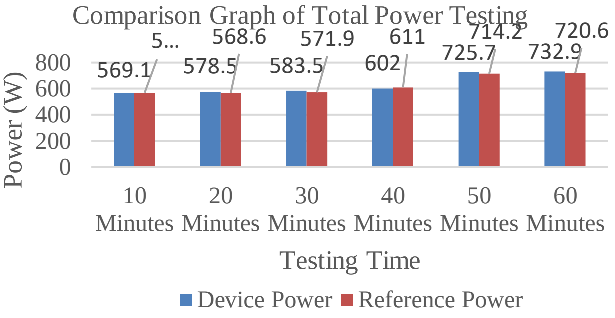

Figure 6. Comparison Graph of Power Testing

Table 5. Comparison of Total Power Measurement of the Device with Reference

Time	Total Device Power	Total Reference Power	Error
10 Minutes	0,066	0,066	0,22%
20 Minutes	0,111	0,111	0,00%
30 Minutes	0,167	0,165	1,20%
40 Minutes	0,221	0,219	0,90%
50 Minutes	0,286	0,283	1,05%
60 Minutes	0,366	0,365	0,27%
Error		0,53%	

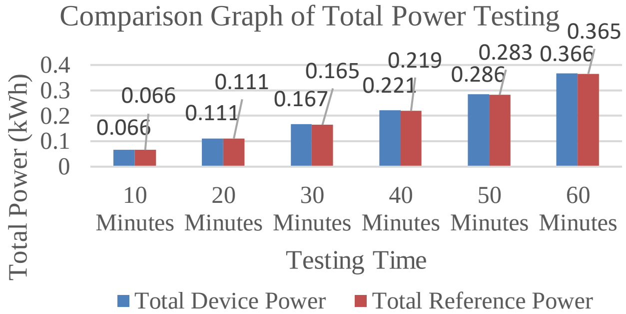

Figure 7. Comparison Graph of Total Power Testing

3.3. Results of Estimated Tariff Calculation

In data collection, the loads used are electrical appliances commonly found in boarding houses, such as rice cookers, irons, refrigerators, televisions, soldering irons, and fans [15]. This data collection aims to determine how much energy in kWh is consumed and how much must be paid for each electrical load over a specific period [16]. The price per kWh uses the R-1 tariff for 2,200 VA, which is IDR 1,444.7 per kWh. This price is the rate set by the government, referring to the Electricity Tariff (TTL). Table 3 shows the current usage, kWh, and electricity bill costs that must be paid for each electrical load over a specified time

Table 6. Estimation of Usage Tariff Calculation

Time	IDR Load	IDR KWH	IDR PTL	IDR PPJ	IDR Billing
10 Minutes	IDR 127.134	IDR 95,142	IDR 127.228,742	IDR 5.089,150	IDR 132.317,89
20 Minutes	IDR 127.134	IDR 160,362	IDR 127.293,962	IDR 5.091,758	IDR 132.385,72
30 Minutes	IDR 127.134	IDR 241,265	IDR 127.374,865	IDR 5.094,995	IDR 132.469,86
40 Minutes	IDR 127.134	IDR 319,279	IDR 127.452,879	IDR 5.098,115	IDR 132.550,99
50 Minutes	IDR 127.134	IDR 413,184	IDR 127.546,784	IDR 5.101,871	IDR 132.648,66
60 Minutes	IDR 127.134	IDR 528,760	IDR 127.662,360	IDR 5.106,494	IDR 132.768,85

3.4. Results of Emission Level Calculation

Basically, the emissions produced have a constant increase over time. Based on the data in Table 4.5, the increase in emissions in the first 10 minutes is 69%, while in 60 minutes, the increase is only 28%.

Table 7. Emission Level Generated from the Use of Electronic Devices

Time	Emission Level	Increase
10 Minutes	0,05532	-
20 Minutes	0,09324	69%
30 Minutes	0,14028	50%
40 Minutes	0,18564	32%
50 Minutes	0,24024	29%
60 Minutes	0,30744	28%
Mean		42%

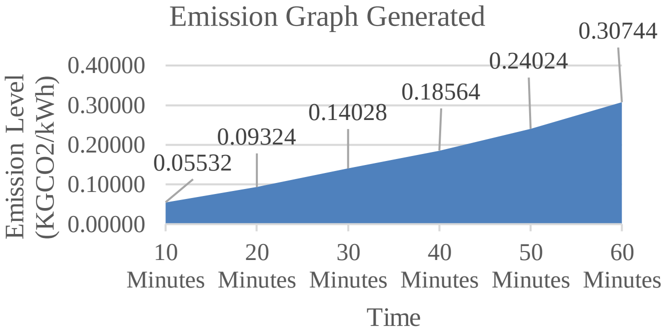

Figure 8. Emission Graph Generated

4. CONCLUSION

This device is designed using the NodeMCU ESP8266 as the microcontroller and the PZEM-004T sensor to read Voltage, Load, Power, and Total Power. The readings are displayed directly on the LCD screen at the front of the device, making it easy for users to view the information. Additionally, this device can be monitored remotely through the Blynk application connected to the system, providing real-time and efficient access without the need to be near the device. This feature facilitates data recording, speeds up decision-making, and enhances convenience in electricity management. The device has an average error of 0.8% for power calculations and 0.5% for total power calculations compared to the reference Digital Watt Meter. Thus, this device can be used to measure Voltage, Load, Power, and Total Power. With a margin of error below 1%, this device demonstrates high accuracy, ensuring that the generated data is reliable. The data obtained can be used to calculate the electricity usage tariff in the building, based on actual consumption details. The usage tariffs vary by region, following the policies in effect in those areas. By performing the calculations, it is found that in the Bogor area, the subscription fee is IDR 127,134 and the cost per kWh is IDR 528.76 for a power usage of 0.366 kWh, with an additional 4% tax. Therefore, the total tariff to be paid over a period of 60 minutes is IDR 132,768. Based on the available data, the carbon emissions generated from electronic usage show a constant increase. From the off state to the first 10 minutes, there is an increase of 69%, and in 60 minutes, the increase is 28%. This data also allows for the monitoring of carbon emissions from the daily use of electronic devices to raise awareness about environmental impacts and encourage more responsible electricity usage.

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