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Telemetry System Design for Monitoring Electrical Energy in Residential Homes

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ABSTRACT

This project aims to (1) create and design a telemetry system for monitoring electrical energy in residential homes, (2) determine the functional tests of each component used, and (3) determine the performance tests of the tools being made. The manufacturing and testing process for this tool was carried out at the Electrical Installation Laboratory, Vocational Faculty, Yogyakarta State University. The data analysis technique used is calculating the percentage error between the tool data created and standard measuring tool data. The results obtained are (1) an electrical energy monitoring system was produced with components in the form of an ACS712 current sensor, ZMPT101B voltage sensor, Arduino Uno, NodeMCU ESP8266, LCD 20×4, buzzer, and Blynk application. (2) The functional test results show that each component has a good accuracy value. The error percentage level from sensor testing shows a value below 5%, so the sensor accuracy is good. (3) The results of system performance testing also show quite high accuracy. The highest percentage error rate was 4.4%, namely in refrigerator current and energy-saving lamp power factor data.

Proyek ini bertujuan untuk (1) membuat dan merancang sistem telemetri untuk monitoring energi listrik pada rumah tinggal, (2) mengetahui uji fungsi setiap komponen yang digunakan, dan (3) mengetahui uji kinerja alat yang dibuat. Proses pembuatan dan pengujian alat ini dilakukan di Laboratorium Instalasi Listrik Fakultas Vokasi Universitas Negeri Yogyakarta. Teknik analisis data yang digunakan adalah menghitung persentase kesalahan antara data alat yang dibuat dengan data alat ukur standar. Hasil yang diperoleh adalah (1) dihasilkan sistem monitoring energi listrik dengan komponen berupa sensor arus ACS712, sensor tegangan ZMPT101B, Arduino Uno, NodeMCU ESP8266, LCD 20×4, buzzer, dan aplikasi Blynk. (2) Hasil uji fungsional menunjukkan bahwa setiap komponen mempunyai nilai akurasi yang baik. Tingkat persentase error dari pengujian sensor menunjukkan nilai dibawah 5% sehingga akurasi sensor baik. (3) Hasil pengujian kinerja sistem juga menunjukkan akurasi yang cukup tinggi. Persentase tingkat kesalahan tertinggi sebesar 4,4% yaitu pada arus lemari es dan data faktor daya lampu hemat energi.

1. Introduction

The rapid development of technology causes changes in several things in life. The development of this technology certainly has benefits, namely that it can make human work easier to make it more effective (Kidi, 2018). An example of these changes is the development of electrical equipment to make household work easier, such as washing machines, water pumps, electric irons, refrigerators, and so on.

The use of electrical equipment requires a supply of electrical energy. In Indonesia, the electrical energy supply is managed by PT. PLN, so that policies on electricity user groups and electricity rates per group are also regulated by PT. PLN. Where is the electricity payment to PT. PLN is divided into two types, namely prepaid and postpaid.

For residential scale consumers, there are no devices used to monitor electrical energy completely, where in the monitoring system there are quantities of current, voltage, power, energy and electricity usage costs during a certain period. So that residential electricity consumers who subscribe to electricity using a prepaid or postpaid system cannot know the amount of electricity used. In fact, monitoring electrical energy in residential homes needs to be carried out so that the use of electrical energy in residential homes can be monitored in real time, as well as being able to find out various things that occur in residential electricity usage, such as excessive increases in loading voltage (Setiawan, 2022).

Based on the things described in the paragraph above, the author plans to design a telemetry system for monitoring electrical energy in residential homes. The design of this monitoring system aims to properly monitor the use of electrical energy in each electrical equipment in the home, so that electrical energy consumption can be regulated. Furthermore, the aim of using a telemetry system is so that the monitoring process can be carried out remotely in real time.

2. Problem Solving Approach

2.1 Electrical Energy

Electrical energy is a source of energy that is produced due to the movement of electrons from one place to another. The transfer of electron flow occurs due to the potential difference between one place and another. Electrical energy is produced when electrons move through a conductor. So if there is an electric voltage at the ends of the conductor, electrons start to move from one end to the other. These conditions will create the flow of electric current (Aliyah, 2024).

In general, electrical energy comes from various sources, namely hydroelectric power plants, wind power, solar power and fossil fuels. Where these materials do not produce greenhouse gas emissions. In this way, electricity becomes an alternative choice to reduce negative impacts on the environment and overcome climate change.

Electrical energy can be determined by multiplying the voltage value, current value, power factor and load usage time. The following is the formula for calculating electrical energy:

$$\boldsymbol{W = V \times I \times cos\varphi \times t} \quad (1)$$

Where :
W = Power
V = Voltage
I = Current
Cos φ = Power Factor
t = Time

2.2 Electricity Tariffs

Electricity tariffs are the amount of fees paid by electricity consumers to holders of Business Permits for Providing Electricity for Public Use (IUPTLU) who have Business Areas as producers. Electricity tariffs are determined by the Minister of Energy and Mineral Resources (ESDM) after

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obtaining approval from the DPR (Director General of Electricity, 2024). Electricity consumers are divided into three categories, namely residential, commercial and industrial electricity consumers. The types of loads and use of electrical energy for the three categories of electricity consumers are of course different, so the electricity rates are also different. Based on adjustment tariff data on the PLN website, the electricity tariff for residential consumers in the R1/T-R category with a power limit of 900VA is IDR 1,532,- during off-peak load times and during peak load times.

2.3 Telemetry System

Telemetry is the process of measuring the parameters of an object, which can be an object, space or natural conditions, the results of the measurement are sent to another device through a data transmission process either using cables or without cables (wireless), then the data is utilized directly or used for analysis purposes. . In general, a telemetry system consists of six supporting parts, namely measuring objects, sensors, transmitters, transmission channels, receivers, and displays. Long distance data transmission allows measurement data to be accessed from locations far from the measurement process taking place. (Rovianto, et al., 2008)

Alternative communication media for telemetry systems are not limited to cable, wireless, satellite or GSM. However, because telemetry systems are usually used as long-distance monitoring tools, the most widely used communication media is wireless.

2.4 Blynk

Various platforms for monitoring purposes are Thingspeak, Firebase, Arduino IoT Cloud Remote, Domoticz, Adafruit IO, and Blynk. The author chose the Blynk application as a data viewer on a cellphone. Blynk has three main components, namely Blynk app, Blynk server, and Blynk libraries. Blynk app is a mobile application available on iOS and Android which is a user interface where users can create dashboards to monitor and control IoT devices. Then there is the Blynk server which is an intermediary between applications and hardware. Meanwhile, finally there are Blynk libraries, which are libraries that are integrated with various hardware platforms such as Arduino, Raspberry Pi, ESP8266, and others. This library allows the hardware to communicate with the Blynk server and control it through the application. There are several advantages of Blynk compared to other monitoring applications, including:

- **Easy use**
  The intuitive, drag-and-drop user interface makes it very easy for users to create dashboards and applications without needing much programming experience.
- **Wide compatibility**
  It supports a wide variety of hardware platforms and provides libraries for various programming languages.
- **Monitoring and Control**
  Ability to monitor and control devices in real-time via mobile application with a very easy to understand dashboard display.
- **Complete libraries**
  Blynk has libraries that support up to 400 microcontroller boards, such as Arduino, ESP8266, ESP32, Raspberry Pi, and many more.
- **Connectivity**
  Blynk can be used not only via a WiFi connection but can also be connected to Ethernet, Cellular (GSM, 2G, 3G, 4G, LTE), and LoRaWAN connectivity (Anonymous, 2024).

Several advantages that have been stated above were the main considerations for the author in choosing Blynk as the monitoring media for this final project.

3. Device Design

Research methods are the steps taken so that research can be successful. The steps that will be carried out for this research are explained in the following research flowchart:

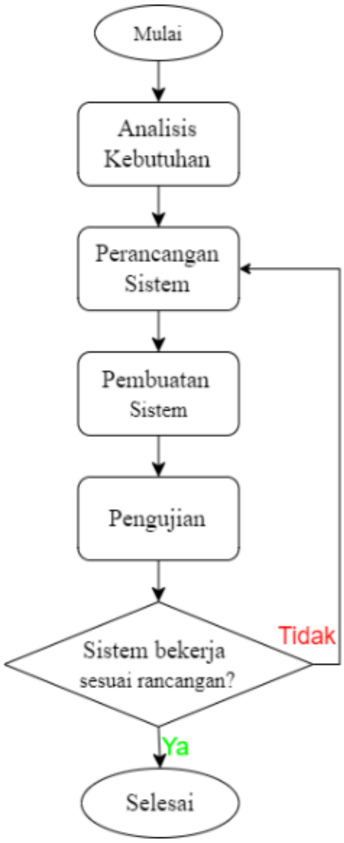

Fig. 1. Research Flowchart

Needs analysis is the first step in carrying out this research, which aims to find out what is needed to create a telemetry-based electrical energy monitoring system in residential homes. This needs analysis was carried out by means of field observations and literature studies.

Field observations are carried out by observing what things can be developed into the title of the Final Project for a residential house. This observation was carried out for about one week and the results obtained were that there was no telemetry system for monitoring electrical energy in residential homes which could monitor current, voltage, power, energy and cost values in one monitor. So far, monitoring of electrical energy can only be done by monitoring kWh meters, so monitoring cannot be done remotely.

After making observations, the next step is to conduct a literature study. This literature study was carried out with the aim of knowing what things are needed to overcome the problems found during field observations. This literature study was carried out by reading online journals, online theses and websites. After conducting a literature study, it can be seen that monitoring electrical energy in residential homes needs to be carried out so that the use of electrical energy in residential homes can be monitored in real time, as well as being able to find out various things that occur in residential electricity use, such as an increase in excessive loading voltage (Setiawan, 2022).

3.1 Design Flowchart

The first stage in the system design process is making a flowchart for the design of the device to be made, namely a telemetry system for monitoring electrical energy in residential homes. Figure 2 below is a flowchart for the design of the tool to be made:

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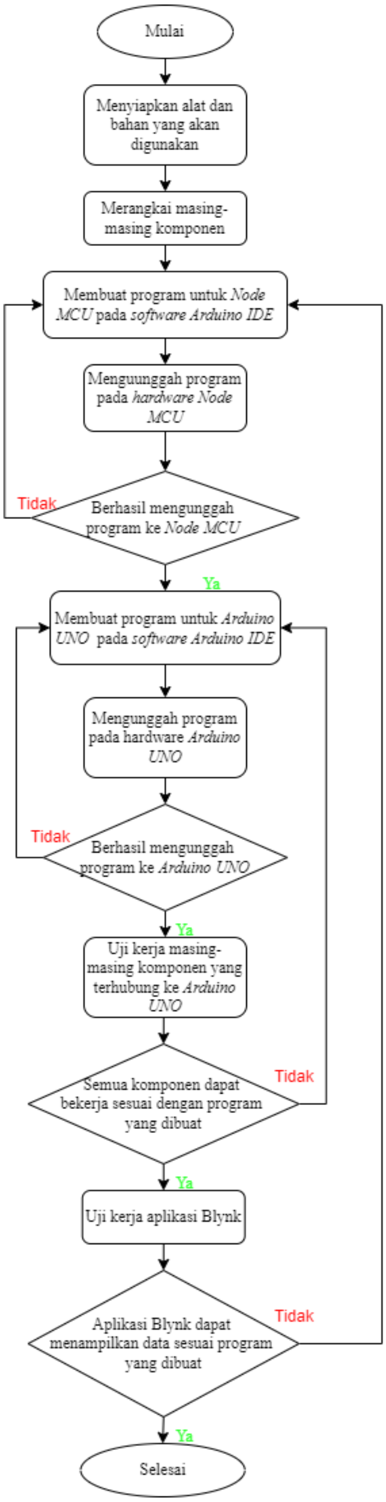

Fig. 2. Design Flowchart

3.2 Block Diagram

This block diagram is made so that the system work process can be more easily understood. Figure 3 shows the block diagram of this final project.

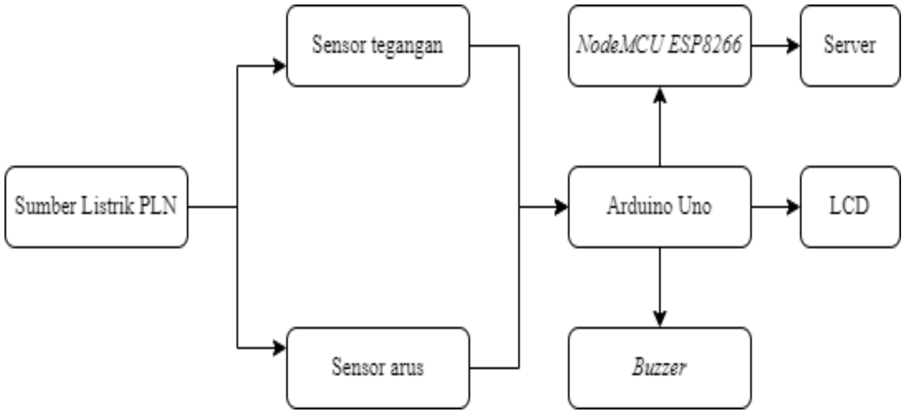

Fig. 3. Block Diagram

The way this system works starts from a voltage sensor and a current sensor which take data from the installed load. Next, the data from the sensor readings will be processed using the Arduino Uno microcontroller. The results of data processing on the Arduino Uno will be displayed on the 20×4 LCD. Furthermore, the results of data processing by Arduino Uno are also displayed in the Blynk application with the help of NodeMCU. The Arduino is also connected to a buzzer where if the time shows less than 2 (two) minutes before the initial reset, the buzzer will sound and electricity usage costs can be monitored.

3.3 Wiring Diagram

The wiring diagram is designed so that the connections between the components used can be identified. The purpose of making this wiring diagram is to make it easier to assemble each component used. Furthermore, this wiring diagram can also function as a reference in carrying out repairs if there are errors or deficiencies when testing the system. This wiring diagram design was created using Fritzing software. Figure 18 shows the wiring diagram design that has been created.

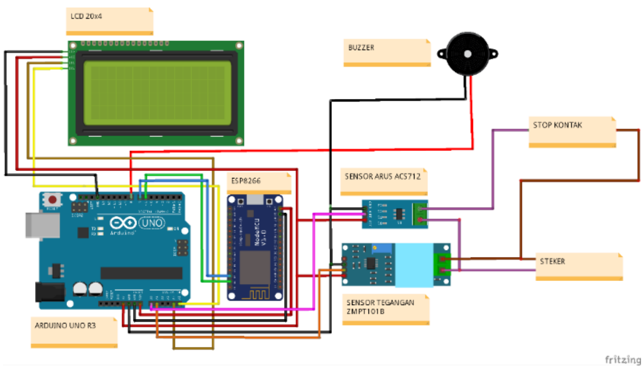

Fig. 4. Wiring Diagram

3.4 Software Design

The next step in the device design process is software design. The aim of designing this software is to understand the coding process for a telemetry system for monitoring electrical energy in residential homes. The software design process is divided into two stages. The first stage is making the main coding in the Arduino IDE, where two codes will be made to be uploaded to the Arduino Uno R3 and NodeMCU ESP8266 hardware respectively. Next, the second stage is creating a dashboard on the Blynk website which is used as a remote monitoring device. Figure 5 below is the default display of the Arduino IDE software:

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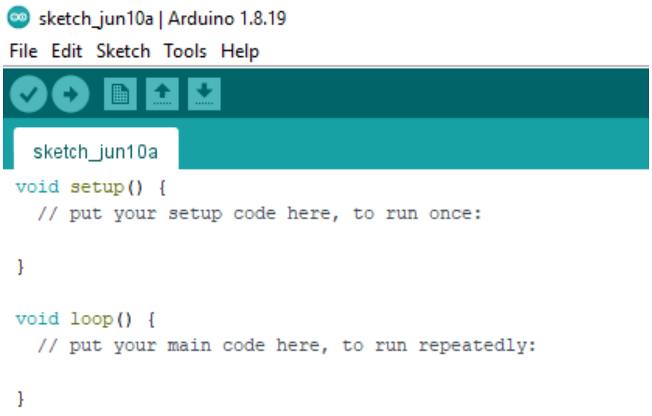

Fig. 5. Arduino IDE Default Display

Furthermore, the platform used to carry out remote monitoring of the telemetry system design for monitoring electrical energy in residential homes is Blynk. Figure 6 is a display of the Blynk Website.

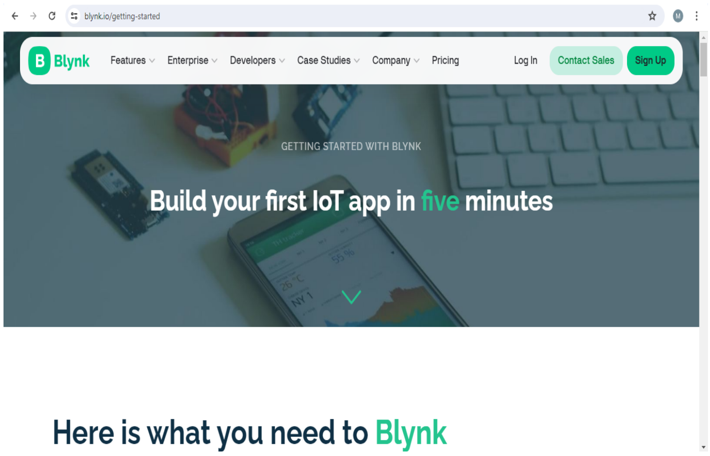

Fig. 6. Blynk Default Display

The image above is the initial appearance of the Blynk website. The first step to take if you want to create a project is to create an account first. Once the account has been created, the next step is to create a template and fill in the name of the template, the hardware used and the type of connection used. The next step is to create a datastream for the project to be created. Creating the datastream begins with selecting the type of pin that will be used, then filling in the data according to the project parameters. The data that must be entered is the parameter name, pin number, data type, units, as well as the minimum and maximum values of the data displayed. The next stage is to add widgets to the dashboard. Widgets function to display data and control devices.

4. Results and Discussion

4.1 The Results of Creating System Hardware

The stages of making hardware are divided into two, namely making mechanical systems and electrical systems. Making an electrical system is the process of assembling each component according to the wiring diagram design that has been made. while making a mechanical system is making a box design that is used to place the electrical circuit. Figure 7 below is the result of making an electrical and mechanical system.

Fig. 7. Hardware Manufacturing Results

4.2 The Results of Creating System Software

Making software for the telemetry system for monitoring electrical energy in residential homes is divided into two, namely making coding for the Arduino Uno as the main microcontroller and coding for the NodeMCU ESP8266 as a WiFi module. The program for the Arduino Uno will function as a command to control components such as the current sensor, voltage sensor, LCD and buzzer. Arduino Uno will also send data to the NodeMCU ESP8266 to be displayed in the Blynk application. Meanwhile, the program for the NodeMCU ESP8266 contains commands to receive data from sensors sent by the Arduino Uno, then the data is displayed on the Blynk application. Figure 8 below is the result of creating system software

Fig. 8. The Result of Creating System Software

4.3 System Performance Test Results

4.3.1 System Voltage Test Results

Table 1 is data from voltage readings by the ZMPT101B sensor which has been assembled in the system and compared with voltage measurement data from a multimeter. Based on Table 24, it can be seen that the sensor accuracy level shows good results because the error percentage is still below 5%. The highest error percentage was found in the cell phone charger load, namely 1%, while the lowest error percentage was found in the large fan load, namely 0.047%.

Table 1. System Performance Accuracy Testing Results

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Load	Measurement Results		Difference	%*Error*	Hasil
	Measuring Instrument (V)	Voltmeter (V)			
Small Fan	214,2	215	0,0037	0,37%	Normal
Cell phone charger	209,2	211,3	0,001	1%	Normal
Night light (filament)	212,1	212,6	0,0024	0,24%	Normal
Refrigerator	213,7	214,08	0,0018	0,18%	Normal
Magic jar	209,6	210,9	0,0061	0,61%	Normal
Dispenser	207,6	208	0,002	0,2%	Normal
Hair dryer	210,1	211	0,0043	0,43%	Normal
Big Fan	213,1	213	0,00047	0,047%	Normal
Iron	207,1	208	0,0043	0,43%	Normal
Laptop Charger	213,6	214,3	0,0032	0,32%	Normal
Energy Saving Lamps	214,7	215	0,0013	0,13%	Normal

4.3.2 System Current Test Results

Table 2 is data from current readings by the ACS712 sensor which has been assembled in the system and compared with current measurement data from ampere pliers. Based on Table 2, it can be seen that the sensor accuracy level is good because the error percentage is still below 5%. The highest error percentage was found in the refrigerator load, namely 4.4%, while the lowest error percentage was found in the hair dryer load, namely 1.3%.

Table 2. System Current Performance Accuracy Testing Results

Load	Measurement Results		Difference	%*Error*	Results
	Measuring Instrument (A)	Amperemeter (A)			
Small Fan	0,15	0,145	0,034	3,45%	Normal
Cell phone charger	0,2	0,204	0,019	1,96%	Normal
Night light (filament)	0,11	0,112	0,018	1,8%	Normal
Refrigerator	0,59	0,617	0,044	4,4%	Normal
Magic jar	0,25	0,264	0,014	1,4%	Normal
Dispenser	1,17	1,2	0,025	2,5%	Normal
Hair dryer	1,48	1,5	0,013	1,3%	Normal
Big Fan	0,24	0,246	0,024	2,4%	Normal
Iron	1,13	1,1	0,027	2,7%	Normal
Laptop Charger	0,31	0,325	0,015	1,5%	Normal
Energy Saving Lamps	0,14	0,145	0,034	3,4%	Normal

4.3.3 System Power FactorTest Results

Table 3 below is data from a comparison of the power factor value on the measuring instrument made and the power factor measurement value on the cosphimeter. The comparison results show that the error percentage is not too high. The highest error percentage was found in the Energy Saving Lamp load, namely 4.4%, while the lowest error percentage was found in the night light (filament) load, namely 1.8%.

Table 3. System Power Factor Performance Accuracy Testing Results

Load	Measurement Results		Difference	%*Error*	Results
	Measuring Instrument	Cosphimeter			
Small Fan	0,4	0,41	0,024	2,4%	Normal
Cell phone charger	0,34	0,35	0,029	2,9%	Normal
Night light (filament)	0,55	0,56	0,018	1,8%	Normal
Refrigerator	0,45	0,46	0,021	2,1%	Normal
Magic jar	0,32	0,33	0,03	3%	Normal
Dispenser	0,83	0,85	0,023	2,3%	Normal
Hair dryer	0,97	0,99	0,02	2%	Normal
Big Fan	0,44	0,46	0,043	4,3%	Normal
Iron	0,8	0,82	0,024	2,4%	Normal
Laptop Charger	0,49	0,5	0,02	2%	Normal
Energy Saving Lamps	0,47	0,45	0,044	4,4%	Normal

4.3.4 System PowerTest Results

Table 4 below is data from a comparison of the power values on the tool being made and the power values on the wattmeter. The comparison results show that the error percentage is not too high. The highest error percentage was found in the cell phone charger load, namely 4.3%, while the lowest error percentage was found in the hair dryer, namely 0.16%.

Table 4. System Power Performance Accuracy Testing Results

Load	Measurement Results		Difference	%*Error*	Results
	Measuring Instrument (W)	Wattmeter (W)			
Small Fan	13,04	13,2	0,012	1,2%	Normal
Cell phone charger	14,09	14,72	0,043	4,3%	Normal
Night light (filament)	12,83	13,26	0,032	3,2%	Normal
Refrigerator	56,27	57,13	0,015	1,5%	Normal
Magic jar	16,55	17	0,026	2,6%	Normal
Dispenser	200,5	201	0,0025	0,25%	Normal
Hair dryer	303,5	304	0,0016	0,16%	Normal
Big Fan	22,68	23	0,014	1,4%	Normal
Iron	187,9	188,67	0,004	0,4%	Normal
Laptop Charger	32,99	33.6	0,018	1,8%	Normal
Energy Saving Lamps	14,03	14,2	0,012	1,2%	Normal

4.3.5 System Energy Test Results

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Table 5 below is data from a comparison of the energy values on the measuring instrument made and the energy values measured on the kWhmeter. The comparison results show that the error percentage is not too high. The highest error percentage was found in the small fan load, namely 3.5%, while the lowest error percentage was found in the refrigerator load, namely 1.1%.

Table 5. System Energy Performance Accuracy Testing Results

Load	Measurement Results		Difference	%*Error*	Results
	Measuring Instrument (Wh)	kWhmeter (Wh)			
Small Fan	0,55	0,57	0,035	3,5%	Normal
Cell phone charger	0,43	0,44	0,023	2,3%	Normal
Night light (filament)	0,38	0,37	0,027	2,7%	Normal
Refrigerator	0,81	0,821	0,011	1,1%	Normal
Magic jar	0,62	0,64	0,031	3,1%	Normal
Dispenser	1,23	1,26	0,024	2,4%	Normal
Hair dryer	9,5	9,72	0,023	2,3%	Normal
Big Fan	0,58	0,6	0,033	3,3%	Normal
Iron	4,56	4,69	0,028	2,8%	Normal
Laptop Charger	1,09	1,12	0,03	3%	Normal
Energy Saving Lamps	0,5	0,516	0,031	3,1%	Normal

4.3.6 Cost Data for Each Electricity Load

The cost data that has been obtained from each electricity load can be used to estimate the estimated electricity load usage for one month (30 days). Data sampling for each electrical load was carried out over a period of 15 minutes. The cost calculation is done by multiplying the energy by the electricity tariff for residential consumers with non-subsidized 900VA power, which is IDR 1,352.-. Table 6 below is an estimate of costs for 30 days.

Table 6. Cost Calculation for Each Electricity Load

Load	Cost for 15 minutes (Rp)	Cost for 1 hours9 (Rp)	Estimated time for 1 day (hour)	Estimated time for 30 day (hour)	Estimated cost for 30 days (Rp)
Small Fan	0,74	2,96	8	240	710,4
Cell phone charger	0,58	2,32	4	120	278,4
Night light (filament)	0,51	2,04	7	210	428,4
Refrigerator	1,1	4,4	24	7200	31.680
Magic jar	0,84	3,36	12	360	1.209,6
Dispenser	1,66	6,64	24	7.200	47.808
Hair dryer	12,84	51,36	0,25	1,75	89,88
Big Fan	0,78	3,12	12	360	1.123,2
Iron	6,17	24,68	3	90	2.221,2
Laptop Charger	2,16	8,64	6	180	1.555,2
Energy Saving Lamps	0,67	2,68	3	90	241,2
Cumulative Costs					**87.345,48**

5. Conclusion

The results obtained are (1) an electrical energy monitoring system was produced with components in the form of an ACS712 current sensor, ZMPT101B voltage sensor, Arduino Uno microcontroller, NodeMCU ESP8266 wifi module, 20×4 LCD, buzzer, and Blynk application. (2) The results of functional testing show that each component has good accuracy values so that the components used can work well. The percentage error rate from sensor testing shows a value below 5%, so the sensor accuracy is good. (3) The results of system performance testing also show quite high accuracy. The highest percentage error rate of the entire data was 4.4%, namely in refrigerator current data and energy-saving lamp power factor data. The telemetry system that has been created can also work well by being able to monitor in real time via the Blynk application.

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