Peer Review Article

Electricity Monitoring System based on Fuzzy Logic and Internet of things

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Abstract: a smart home concept that has a remote control system based on the Internet of things, to provide convenience and security for owners to control household electronic equipment such as lights, tv, and fans, not only controlling the house but homeowners can monitor power, voltage, current and electricity bills in real-time as well as the status of the electrical load used in a lit state or not. And users can also limit the use of power to prevent overloads that impact rising bills or electricity usage costs—monitoring lighting automatically on the house's terrace using the fuzzy logic method and monitoring bathroom lights by detecting the presence and absence of movement. The switch system on electrical devices can be replaced using the ESP8266 microcontroller to be connected to android with the Openhabian application installed. This control system can also be done anywhere without area restrictions as long as the user can connect to the Internet.

Keywords: Android; ESP8266; Raspberry Pi; Smarthome; Internet Of Things

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I. INTRODUCTION

Electrical energy has become one of the primary human needs because all environments require electrical power, such as homes, workplaces, factories, etc. State companies provide electricity needs where each consumer has to pay a fee according to how much electricity is used. Electric power consumption calculation is calculated based on the amount of power consumption multiplied by time with units of kilowatts per hour (kWh).

The state electricity company currently uses two manual and digital power meters. Manual measuring instruments use the principle of magnetism with a mechanism in the form of a rotating disc which is converted to the number of revolutions in numbers that can indicate the amount of power consumption. In contrast, digital measuring instruments are applied to power sensors connected to a minimum system or microcontroller to calculate power. With this digital system, customers pay first and enter in the form of pulses called tokens. The power consumption can be used as long as there are tokens in it and will decrease according to the usage size. From the kWh meter used by PLN, all users must look directly at the display inside to find out the electricity consumption that has been used or the remaining credit deposit that is still available. However, in reality, the recording of electricity kWh cannot be controlled in real-time; often, over-budget usage occurs. So customers have to buy more kWh pulses because electricity is a critical need to support all activities.

The Monitoring and decision-making system is a form of Monitoring and decision-making related to the use of power for household electrical loads, all of which can be controlled directly according to the owner's wishes. Smarthome systems currently exist that use both wired and wireless installation [1,2,3,4,5,7]. Therefore, the utilization and implementation for wireless installation are realized. The working frequency, effectiveness, and several other advantages and advantages of this wireless communication are very suitable for Smarthome systems that support modern technology. Electrical monitoring systems and device decision-making in smart homes continue to develop where several studies discuss this technology. Electrical monitoring systems includes giving notifications to android against excessive power consumption, adjusting the intensity of light entering the room, and adjusting the intensity of the porch light against the intensity of sunlight to minimize usage from electricity [19].

Moreover, Fuzzy logic translates a quantity expressed using language (linguistics), makes decisions about electricity consumption, and regulates the intensity of light expressed in dark, dim, and bright ways. And fuzzy logic shows the extent to which a value is true and to which a value is false. Some of the discussions that can be studied on the fuzzy system include fuzzy inference system (Fuzzy inference system). There are several methods used, including the Mamdani method, TSK method, and Tsukamoto method. Fuzzification is changing the input from crisp form to fuzzy (linguistic variable), usually presented in fuzzy sets with a membership function [9].

Internet of things power consumption is strived to save and limit the use of electrical energy must be implemented by sending notifications to android when power consumption is high [8,11]. For this reason, a monitoring system tool and decision-maker for the use of electric power will be made that can provide information on the results of monitoring the overall power usage of the electrical load, with the Internet of things system that is accessed on the OpenHabian application on Android phones so that later it can be observed, by users in real-time. Therefore, electricity consumption can be monitored anytime and anywhere.

This can be done by creating a microcontroller, PZEM-004T sensor, BH1750 sensor, and of course with the OpenHabian application on Android phones. The microcontroller is a Raspberry Pi integrated with ESP8266 [6] and the Wi-Fi module to monitor electricity quantities online through the OpenHabian application as a media interface on Android phones. Many of these OpenHabian applications act as media that can monitor the amount of electricity that will be used. The application was chosen because it is easy to use and only requires an Android phone to apply it. Based on the background that has been explained, the author takes the title "Monitoring and Decision Making System for the Use of Electric Power in Smarthomes Using the Internet Of Things-Based Fuzzy Logic Method [12]." The development of IoT can be seen from the built communication system, and it can use ESP32 or ESP3288, Node MCU, ZigBee Gateway, M5Stack Board, LoRa Gateway, etc. In this case, data transmission analysis is needed to reach the gateway and Blynk [21], Thingspeak application server [18, 22, 23, 26, 28].

II. RESEARCH-RELATED

Hidayat Nur Isnianto, Muhammad Arrofiq, Rijeqi Rahmawati, and Bagus Mulyo Tyoso in 2019 April with the title "kWh Meter Telemonitoring System Using WI-FI Module ESP8266 Based on Arduino Uno", In this study, a Wi-Fi NodeMCU ESP8266 [10] module system BASED ON ARDUINO Uno (online Wi-Fi) is needed to assist the clerk in recording electricity consumption for consumers. This system uses several sensors: ACS712 current sensor [13], ZMPT101B voltage sensor, and phase difference sensor. RTC DS13070 as a timer and date, Arduino as a data processor, micro SD Card to store date, time, and sensor readings data, LCD as a viewer, and transmitted with the ESP8266 Wi-Fi module to a smartphone or P.C. with a simple web display. The test results indicate that all components can function properly. The current sensor ACS712 30A has an average error of 1%, the voltage sensor ZMPT101B is able to read voltage readings under load and without load conditions with an average error of 0.5%, and the phase difference sensor has an average error of 1% for resistive loads and 4.2% for inductive loads. T.L. lamp. The power measurement has an average error of 1.3% for 75 W incandescent lamps and 300 W irons. The ESP8266 Wi-Fi module beam distance is a maximum of 15 meters when unobstructed and 10 meters when blocked. All measurement data can be stored on the SD Card.

Anggher Dea Pangestu, Feby Ardianto, Bengawan Alfaresi in 2019 June with the title "Arduino-Based Electrical Load Monitoring System NODE MCU ESP826", this research make it easier for users to monitor electrical energy consumption by using an electrical load monitoring system [14]. One electrical load monitoring that households must use is the Arduino NodeMCU ESP8266 in real-time. One of the methods used in this research is the tool testing method. The results of testing this tool use an inductive load in the form of 2 15 Watt LED lights and a resistive load in the form of an electric iron that is set at the maximum hot point; the tool works well and is able to read the amount of current and power used when conditioning ON to inductive loads resistive load, the accuracy of the tool in reading ranges from 96% to 98%.

Hartono Budi Santoso, Sapto Prajogo, Sri Paryanto Murshid in 2018 September with the title "Development of a Household Energy Consumption Monitoring System Based on the Internet of Things (IoT) "Vol. 6 No. 3 Pages 357-366 [7]. In this study, an energy monitoring system will be developed, especially for household loads based on IOT technology, to monitor the use of household electrical energy using an android application on cellular telephone communication devices (cell phones). The results of the measurement accuracy-test carried out by comparing the measurement data with other measuring instruments show that the current reading has an average error of 0% while the voltage reading has an average error of 0.06%.

Asep Muhamad Alipudin, Didik Notosudjono, Dimas Bangun Fiddiansyah in 2018 with the title "Design of a Cost Monitoring Tool for Used Electricity Based on Internet of Things (IoT)" Vol 1, No 1. In this study, a design tool is needed that can monitor the use of electrical energy in real-time and display the cost of using electrical energy accurately. This used electricity cost Monitoring tool works when the electricity supply from PLN provides voltage to the power supply to turn on the ATMega2560 microcontroller, Esp8266 Wi-Fi Module, PZEM-004T Sensor, and LCD Display. The reading of the electrical values (voltage, current, active power, energy) carried out by the PZEM-004T Sensor is then sent to the microcontroller; on the microcontroller, the electrical value is converted into rupiah prices and displayed on the LCD Display The Esp8266 Wi-Fi module is used as a liaison between the microcontroller and the internet network so that the use of electrical energy can be monitored via a smartphone. This monitoring tool for used electricity costs can indicate when the use of electrical energy in a certain rupiah price has been reached.

III. MATERIALS AND METHODS

The term fuzzy logic originated from the ideas of a professor named Lotfi Zadeh in 1965, who promoted that conventional computer logic cannot replace subjective or unclear human thoughts in manipulating data. The essence of fuzzy logic is the mapping of the input space to the output space. Fuzzy logic works by imitating how humans can make decisions from vague or incomplete data to the accuracy of completion. This approach is similar to how humans make decisions that allow a choice between yes and no. In contrast to crisp logic, which has a definite value, fuzzy logic has a continuous value, which means that it allows the membership value to be "yes and no," "good and bad," "true and false" simultaneously. Still, the value depends on the weight of Membership. Until now, fuzzy logic has become a standard technique used in controlling more than one variable. In electronics, fuzzy logic is applied in various systems, such as air conditioning (A.C.) systems and washing machine timings, to classification processes, such as analyzing facial characteristics [29].

Watthour Energy Meter is an electrical energy measuring device that directly measures the product of voltage, current, work factor, times a certain time. *Watthour Energy Meter* is commonly used to measure power and electrical energy. The use of electrical energy in industry and households use units of a kilowatt-hour (kWh) [15]. There are two types of kWh Meters, i.e., Analog kWh Meters and Digital kWh Meters. Moreover, an analog kWh meter is a kWh meter whose operating system measures electrical power with a number reading system listed on the kWh. This kWh meter is usually used at regular electricity rates. The electricity bill is based on the numbers listed on the kWh meter each month. The parts of a kWh meter are a voltage coil, a current coil, an aluminum disc, a permanent magnet whose job is to neutralize the aluminum disc from the induction of a magnetic field, and a mechanical gear that records the number of rotations of the aluminum disc. This tool works using the induction method of the magnetic field generated by the magnetic field. The current flowing through the current coil and the magnetic field will move the counter digit to display kWh. Figure 1 is an Induction Type Single Phase Watthour Energy Meter Working Principle [24, 25, 27, 30].

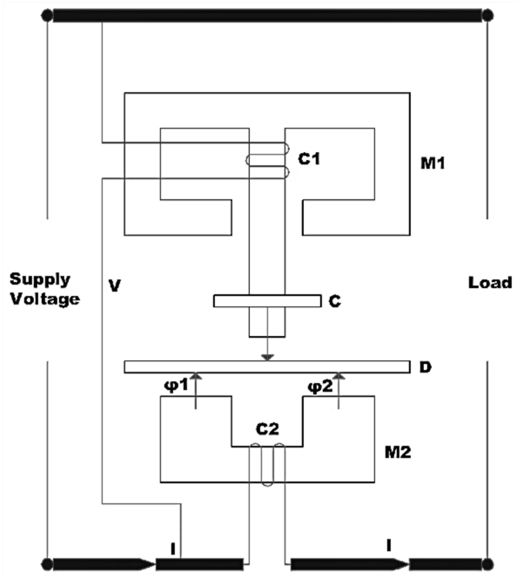

Figure 1. Induction Type Single Phase Watthour Energy Meter Working Principle

Miniature Circuit Breaker (MCB) acts like a guard and short circuit line (short circuit); besides, it also has functions such as guarding too high a load. MCB is a mechanical device that will turn off the flow if the flow through it exceeds the nominal flow capacity limit that has been confirmed in the recorded MCB. The nominal flow also appears in the MCB, including 1A, 2A, 4A, 6A, 10A, 16A, 20A, 25A, 32A, and the nominal flow above it. The nominal MCB can be determined by the number of flows that can be delivered. The unit of electricity used is the ampere.

Relay is an electronic component in the form of an electronic switch that is driven by an electric current. In principle, the relay is a switch lever with a wire wound on a nearby iron rod (solenoid); when the solenoid is energized, the lever will be attracted due to the magnetic force that occurs on the solenoid so that the switch contacts will close. When the current is stopped, the magnetic force will disappear, the lever will return to its original position, and the switch contacts will open again. Relays are usually used to drive large currents/voltages (e.g., 4 A/AC 220V electrical equipment) by using small currents/voltages (e.g., 0.1 A/12 volts D.C.). Relays are electrical components that work on the principle of induction of an electromagnetic field. If an electric current energizes a conductor, a magnetic field will arise around the conductor. The magnetic field generated by the electric current is then inducted into the ferromagnetic metal. The inventor of the first relay was Joseph Henry in 1835. The principle of cooperation with a magnet contractor is that they are both based on the magnetism produced by the coiled-coil if the coiled-coil is given a power source. Based on the incoming power source, the relay is divided into two types, i.e., D.C. relay and A.C. relay, the amount of D.C. voltage that enters the relay coil varies according to the size listed on the relay body, including relays with 6 Volts, 12 Volts, 24 Volts, 48 Volts, while the A.C. voltage is 220 Volts. The relay consists of a coil and a contact; the coil is a coil of wire that gets an electric current, while the contact is a kind of switch whose movement depends on the presence or absence of an electric current in the coil. There are two types of contacts: Normally Open (the initial condition before being activated is open) and Normally Closed (the initial condition before being activated is closed). In simple terms, the working principle of a relay is as follows: when the coil is energized, an electromagnetic force will arise, which will attract the springing armature, and the contact will close.

The IRF520 MOSFET module driver is a breakout board for the IRF520 MOSFET transistor. This module is designed to switch D.C. voltage loads from a single digital microcontroller pin. The main objective of this module is to provide a low-cost way to drive D.C. motors in robotics applications. However, this module can also be used to control most D.C. voltage loads, such as controls on LED lights, small pumps, and solenoid valves. This module has provided screw terminals on the interface for external loads and power sources and LED indicators that provide a visual indication of when the load is being switched. Furthermore, IRF520 MOSFET Module can be seen in Figure 2 [20].

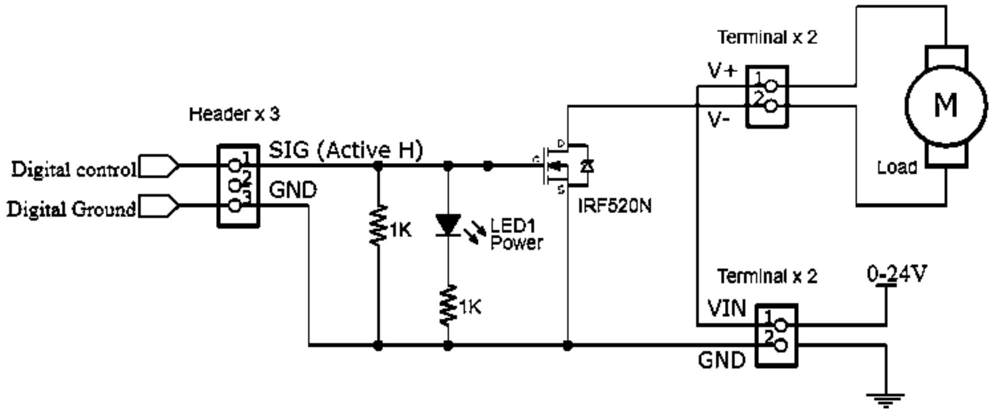

Figure 2. *an IRF520 MOSFET Module*

Furthermore, PIR (Passive Infrared Receiver) is an infrared-based sensor. However, unlike most infrared sensors, which consist of an IR LED and a phototransistor. PIR doesn't emit anything like IR LED. As the name implies, 'Passive,' this sensor only responds to energy from passive infrared rays that are owned by every detected object. The PIR Sensor can be seen in Figure 3.

This research focuses on monitoring power and motion sensors processed by the Arduino Microcontroller and the Raspberry Pi mini Processor. Furthermore, Arduino Uno is an Arduino board that uses the ATmega328 microcontroller. Arduino Uno has 14 digital input/output pins and six analog inputs. Arduino Uno contains everything needed to support a microcontroller [16]. Just connecting it to a computer via USB or supplying D.C. voltage from a battery or A.C. to a D.C. adapter can get it working. The complete RaspBerry Pi pin is shown in Figure 4. One of the essential things in research is the block diagram; Figure 5 shows the blog diagram of this research, consisting of connectivity between components that play a role in running the system, starting from the microprocessor, input, and output devices. Accordingly, ESP8266 is a microcontroller used to communicate with Arduino, raspberry and send sensor data to the Internet. As for the Relay and MOSFET used to control the Output. Furthermore, The following system flowchart aims to control the Raspberry Pi to process data from readings from the PZEM-004T Sensor, PIR Sensor, BH1750 Light Sensor, and control relays via android. For an overview of the program, a flowchart display is made, as shown in Figure 6.

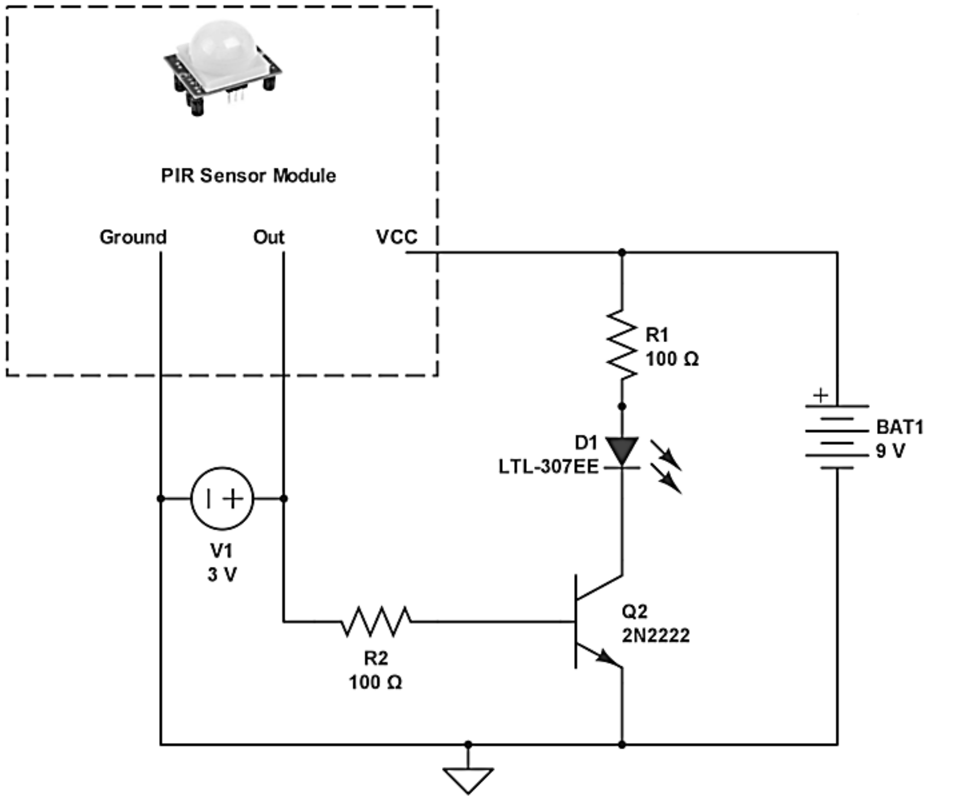

Figure 3. *a PIR Sensor Schematic*

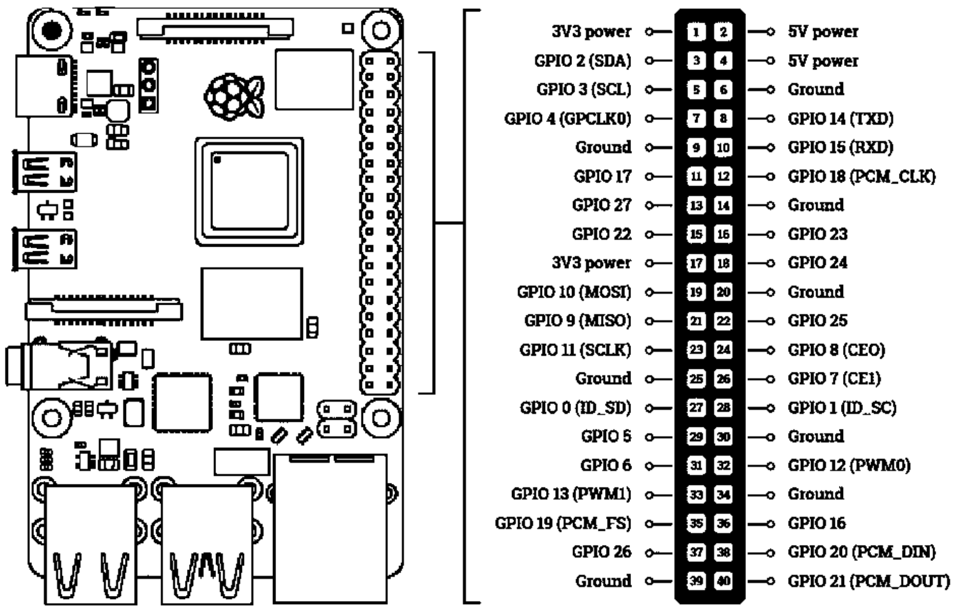

Figure 4. *a RapsBerry Pi Schematic*

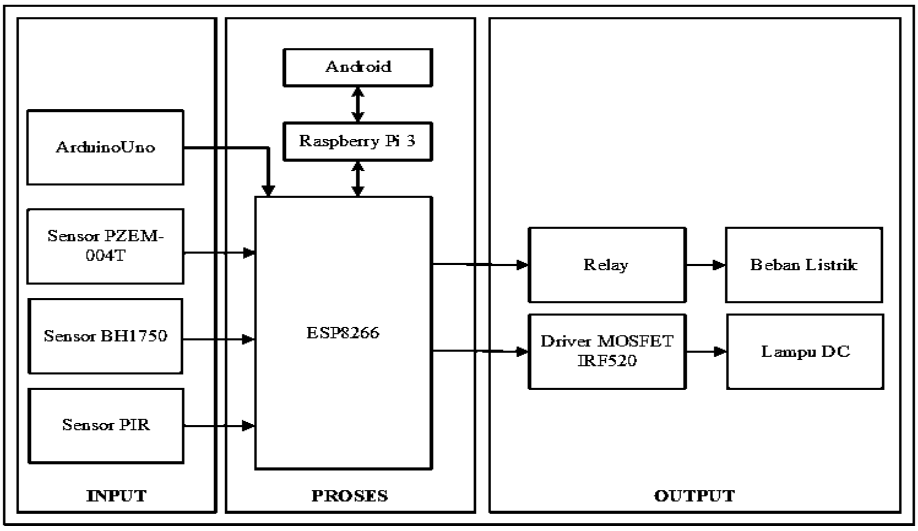

Figure 5. *a Block Diagram of this research*

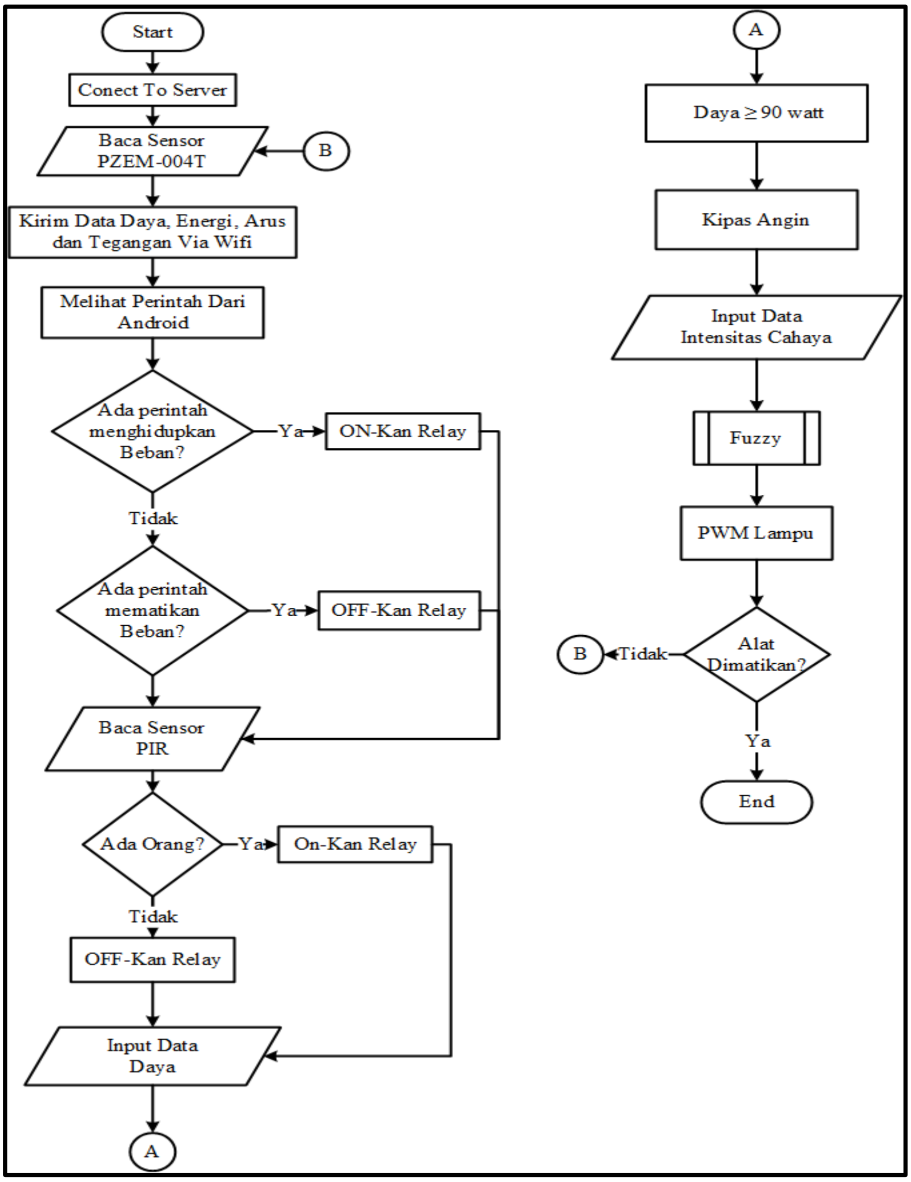

Figure 6. *The Flowchart System*

The mechanical design of the "System Control and Decision Support Electric Power Smarthome Based on the Internet Of Things" will be made in the form of a miniature house consisting of 6 rooms. The mechanical design will be shown in Figure 7.

Figure 7. *a Miniature House*

In Figure 7, 1.Terrace, 2.Living room, 3.Front room, 4.Recreation room, 5.Backroom, 6. Bathroom, and 7.Kitchen. Furthermore, a smart home display will later be controlled according to the device that will be used. The following is the design of the control device in each room of the house. The front porch of the device used is a BH1750 light intensity sensor, an ESP8266 module, a MOSFET driver, and a 12V D.C. lamp. In the living room, the equipment used is an ESP8266 module and a living room lighting lamp. In the front room, the devices used are the ESP8266 module and the front room lighting. Recreation room, the equipment used is the ESP8266 module, tv, refrigerator, fan, and lighting lamp for the recreation room. In the backroom, the devices used are the ESP8266 module and rear bedroom lighting. In the bathroom, the devices used are the PIR sensor, ESP8266 module, and bathroom lighting. In the kitchen, the devices used are Relays and kitchen lights. After everything is installed, it will be channeled to the PZM-004T sensor to read the overall value of power and total energy, voltage, and current of the electric load used [17]. Raspberry will be installed adjacent to the internet network source.

IV. RESULTS AND ANALYZE

After the design and manufacture of the tool are complete, this chapter will contain testing the system on the assembled device according to the design in the previous chapter to find out whether the tool is running as planned. The test was carried out to compare the results of the theoretical design with experimental results. The test results show whether the tool has worked as intended in the tool design in the previous chapter. Moreover, The OpenHAB view and the menu can be seen in Figures 8, 9, 10, 11, 12, and 13.

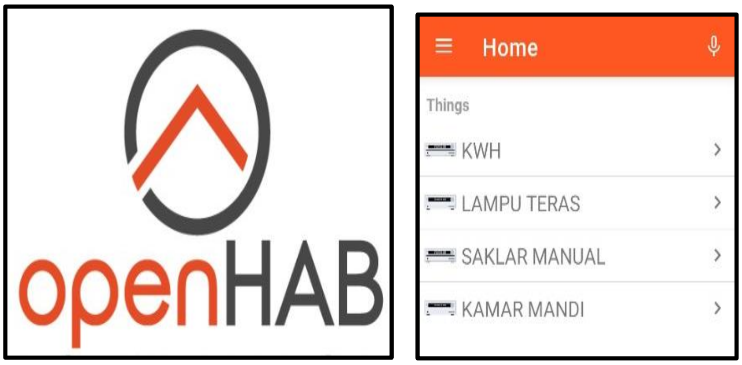

Figure 8. *The openHAB view*

Figure 9. *Channel Display in the Things Menu*

Figure 10. Decision Making Tests on PIR Sensors

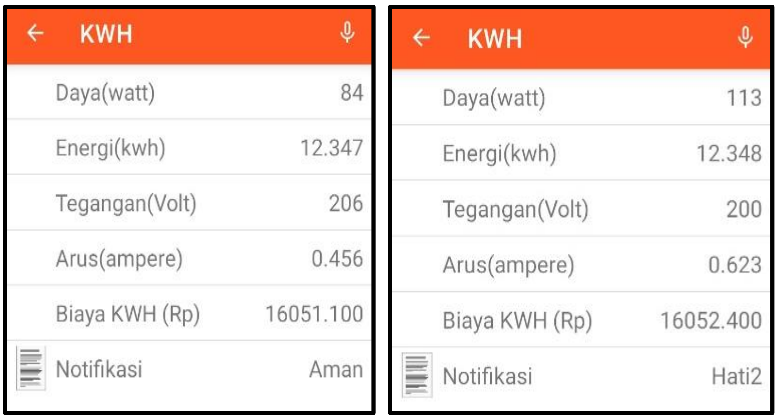

Figure 11. Display of Test Results Notification Power Exceeded the Limit

Figure 12. Testing to Convert KWH into Rupiah (Rp.)

Figure 13. Openhabian Application Light Intensity Reading Results

```
GNU nano 3.2

rule "rupiah"
when
    Item KWH_EnergiKwh received update
then
   var Number Rp = KWH_EnergiKwh.state as Number*1300
   KWH_BiayaKWHRp.postUpdate(Rp)
end
```

Figure 14. Display of KWh Program into Rupiah (Rp.)

```
GNU nano 3.2

rule "Notifikasi"
when
    Item KWH_DayaWatt received update
then

    if (KWH_DayaWatt.state >=90) {
        KWH_Notifikasi.sendCommand("Hati2")
        SAKLARMANUAL_KipasAngin.sendCommand("OFF")
    }
    else
    {
        KWH_Notifikasi.sendCommand("Aman")
    }
end
```

Figure 15. Notification Power Rule Program Exceeded the Limit

Figure 16. *Result of ON and OFF Switch Response on Electrical Load*

Figure 16 shows how to see the direct response of the ON and OFF switches to the electrical load used on the mock-up. The following table 3, the test results of the electrical load on-off switch and detection time. Figure 10 From the test results of decision-makers on the PIR sensor displayed on the Openhabian application with bathroom lamp items. When the PIR sensor detects hand movement, the switch turns ON, and the 60 lamp counter is automatically bright. When the PIR sensor does not detect any movement, the switch becomes OFF, and the counter will count down from 6 to 0; when the counter is 0, the bathroom light is automatically dark.

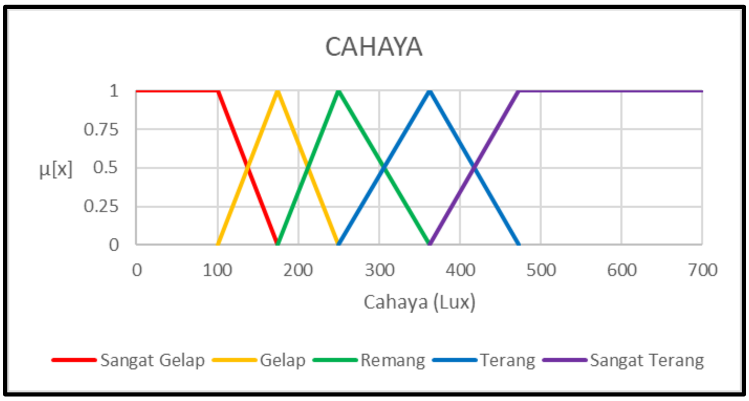

Figure 17. Light Input Membership Function Curve

Table 1. Light Input Range Domain Display

Nu.	Membership Function	*Range (Lux)*
1	Very dark	[0 ≤175]
2	Dark	[75 275]
3	dim	[175 362]
4	Light	[250 473]
5	Very bright	[362 857.5]

Table 2. Light Output Domain Display

Nu.	Membership Function	*Range (PWM)*
1	off	31
2	Very Dim	62
3	Dim	124
4	Light	187
5	Very bright	250

Table 1 and Table 2 are specific membership functions and Range on Lux and Pulse Width Modulation [PWM] of Light input and Output Range Domain Display, membership functions i.e., off or very dark, very dim and dim, light, and very bright. Moreover, Figure 14 and Figure 15 are program codes on OpenHAB to set and display the conversion of prices to rupiah [Result in Table 8] and notifications if the use of KWh is excessive. Moreover, Power Measurement Test Results, Voltage Measurement Results, and Current Measurement Results are shown in Table 5, Table 6, and Table 7.

Table 3.Test Results of Electrical Load ON-OFF Switch and Detection Time

Nu.	***Load Sample***	**ON Switch Test Results**			**OFF Switch Test Results**		
		Time (ms)	**Success**	**Unsuccessful**	***Time (ms)***	**Success**	**Unsuccessful**
1	Main Switch	0,67	✓	-	0,63	✓	-
2	TV	0,64	✓	-	0,66	✓	-
3	Fan	0,64	✓	-	0,65	✓	-
4	Living Room 1 Lights	0,66	✓	-	0,62	✓	-
5	Living Room 2 Lights	0,68	✓	-	0,64	✓	-
6	Front Room Lights	0,64	✓	-	0,66	✓	-
7	Back Room Light	0,62	✓	-	0,62	✓	-
8	Kitchen	0,64	✓	-	0,64	✓	-
	Average	**0,65**			**0,64**		

Source: personal test data

The test will be trained 10 times to find out the PIR sensor detects the presence and absence of movement by looking at the response of the bathroom lights to the programmed timer. Table 4. detection results 10 times on the PIR sensor on the bathroom lights.

Table 4. Detection Results on PIR Sensors Against Bathroom Lights

Nu.	**Bathroom Condition**	**PIR Sensor Response**	***Time (ms)***	**Bathroom light response**
1	There's a Movement	ON	60	Light
2	There is no movement	OFF	0	Dark
3	There's a Movement	ON	60	Light
4	There is no movement	OFF	0	Dark
5	There's a Movement	ON	60	Light
6	There is no movement	OFF	0	Dark

Nu.	Bathroom Condition	PIR Sensor Response	*Time (ms)*	Bathroom light response
7	There's a Movement	ON	60	Light
8	There is no movement	OFF	0	Dark
9	There's a Movement	ON	60	Light
10	There is no movement	OFF	0	Dark

Source: personal test data

Table 5. Power Measurement Test Results

Nu.	Description of Openhabian Application Load	Power Measurement		Error (%)
		PZEM-004T Sensor (Watt)	kWh Module (Watt)	
1	Porch Light	9	9	0%
2	Living Room Lights	9	9	0%
3	Front room light	9	9	0%
4	Recreation Room Lights	9	9	0%
5	Back Room Light	9	9	0%
6	TV	16	15	6.6%
7	Fan	37	37	0%
8	Bathroom Lights	10	10	0%
9	Kitchen Lights	10	9	11,1%
	Average			1,96%

Source: personal test data

Table 6. Voltage Measurement Results

Nu.	Description of Openhabian Application Load	Voltage Measurement		Error (%)
		PZEM-004T Sensor (Volt)	kWh Module (Volt)	
1	Porch Light	213	213	0
2	Living Room Lights	213	213	0
3	Front room light	215	215	0
4	Recreation Room Lights	221	220	0
5	Back Room Light	217	217	0
6	TV	210	208	0,96
7	Fan	219	219	0
8	Bathroom Lights	216	214	0,93
9	Kitchen Lights	214	211	1,42
Average				0,36%

Source: personal test data

Table 7. Current Measurement Results

Nu.	Description of Openhabian Application Load	Current Measurement		Error (%)
		PZEM-004T Sensor (Ampere)	KWh Module (Ampere)	
1	Porch Light	0,26	0,25	4
2	Living Room Lights	0,26	0,25	4
3	Front room light	0,26	0,25	4
4	Recreation Room Lights	0,25	0,25	0
5	TV	1,02	1,02	0
6	Fan	1,21	1,21	0
7	Bathroom Lights	0,26	0,25	4
8	Kitchen Lights	0,26	0,25	4
Average				2,5%

Source: personal test data

Table 8. Testing to Convert KWh into Rupiah 12 Days

Days	Energy(kWh)	Cost (Rupiah)
1	1,532	1.991
2	2,017	2.622,100
3	2,582	3.356,600
4	3,089	4.015,700
5	4,178	5.431,400
6	4,605	5.986,500
7	4,85	6.305
8	5,691	7.398,300
9	6,239	8.110,700
10	7,895	10.263,500
11	8,978	11.671,400
12	9,538	12.399,400
13	10,55	13.715
14	11,01	14.313
15	12,348	16052,400

Source: personal test data

While the results of the comparison of BH1750 Sensor test results on light intensity of 2 parameters, namely BH1750 (Lux) and Lux Light Meter (Lux) App and the comparison of error (%) produces an average of 1.5%. Completely can be seen in Table 9.

Table 9. BH1750 Sensor test results on light intensity

Nu.	BH1750 Sensor (Lux)	Lux Light Meter (Lux) App	*error %*
1	53	50	6.0
2	74	72	2.8
3	88	86	2.3
4	91	89	2.2
5	104	100	4.0
6	130	127	2.4
7	155	152	2.0
8	204	200	2.0
9	230	227	1.3
10	287	284	1.1
11	316	313	1.0
12	349	348	0.3
13	402	401	0.2
14	441	439	0.5
15	470	469	0.2
16	531	531	0.0
17	593	591	0.3
18	659	657	0.3
19	682	679	0.4
20	729	726	0.4
Average			1.5%

Source: personal test data

V. DISCUSSION, CONCLUSION, AND SUGGESTION

From the results of the design and testing of the Monitoring and decision Making Systems for the Use of Electric Power in Smarthomes Using the Internet Of Things-Based Fuzzy Logic Method obtained conclusions and suggestions that are useful for the development of this final project. This final project concludes that smart homes with the Openhabian application can help control home appliances become more practical because all home appliances can be integrated and controlled using one application. Moreover, from the results of this final project, there are suggestions, smart home research still can use the same application, i.e., openhabian, and this application still needs to be explored deeply.

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