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Modeling and implementing a load management system for a solar home system based on Fuzzy Logic

Makmur Saini*, Muhammad Ruswandi Djalal, Muhammad Azhar, Golda Evangelista Patrix
Energy Powerplant Study Program, Department of Mechanical Engineering, Politeknik Negeri Ujung Pandang, Indonesia

Abstract
Solar Home System is one of the technologies for utilizing solar power at home. To optimize the performance of PLTS, it is necessary to regulate the use of electrical energy. In this research, an effort is made to control the load using fuzzy logic to regulate the power consumption used by the load so that energy can be utilized effectively. The fuzzy logic method works based on the input given so that the desired results can be as expected. To test the effectiveness of the fuzzy logic method, this study was tested with two types of loads: lighting and fan loads. For lighting loads, it uses two light sensor inputs, and for air conditioning, it uses two temperature sensor inputs and a PIR sensor. The test results show that in the experiment of setting the light load using fuzzy logic, the average power usage at the load is 11.31 watts. In contrast, without fuzzy logic, the average power usage value for the load is 14.29 watts. In the fan load control experiment using fuzzy logic, the energy consumption setting was obtained according to the room temperature input and the number of people in the room. The test results received power usage without using fuzzy logic, where the average fan power usage value is 4.32 Watts, while without fuzzy logic, the average power usage value is 2.97 Watts. For one sensor input, the average power usage value of the average fan is 3.02 Watts; without fuzzy logic, the average power usage value is 2.93 Watts for two sensor inputs.

Keywords:
Fuzzy Logic;
Load;
Management;
Modeling;
Solar Home System;

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Corresponding Author:
Makmur Saini
Mechanical Engineering Department, State Polytechnic of Ujung Pandang, Indonesia
Email:
makmur.saini@poliupg.ac.id

INTRODUCTION

Energy use in the world is still dominated by non-renewable energy sourced from fossils. Total energy use in 2019 reached 418 EJ, and oil was ranked first with a value of 169 EJ [1]. The results of burning fossil fuels cause an increase in the temperature of the earth and sea levels, climate change, and damage to ecosystems due to greenhouse gas emissions [2]. In addition to the problems related to the depletion of fossil fuel energy sources and the negative impacts they cause, the government has made important decisions by encouraging the use of new and renewable energy [3]. Indonesia has a fairly large renewable energy potential with a total equivalent of 442 GW for power generation. The potential comes from hydropower 94.3 GW, geothermal 28.5 GW, bioenergy 32.6 GW, wind 60.6 GW, ocean currents 17.9 GW, and the largest from solar energy 207.8 GWP [1].

Solar panels use environmentally friendly generation technology because they do not release pollutants like fossil fuel plants [4]. The Indonesian government has targeted the construction of solar panels with an installed capacity of 6.5 GW by 2025, but the installed capacity has only reached 100 MW [5]. In its structure, there are obstacles, namely the large initial investment and the relatively high price per kWh of electricity generated (USD 3-5/Wp). This is because the components of solar system, such as panels, batteries, inverters, and control units, are still imported from abroad [6].

Solar energy produces electrical energy whose amount depends on the intensity of sunlight received so that solar panels can only work to charge batteries during the day [7, 8]. For this reason, the efficiency of battery use must be considered in its distribution to the load. There are still many consumers who are wasteful in the use of energy. It is often found that the lighting conditions in the room are not to the needs of the room and the contribution of light from outside [9]. Consumers also often forget to turn off the air conditioner every time they leave the room so that the air conditioner stays on even though there is no activity. User negligence in using the load when it is not used results in battery life not lasting long, and electrical energy use becomes inefficient [10].

Several previous studies used intelligent optimization based on Fuzzy Logic. The fuzzy logic method is a logic that has a value of ambiguity or ambiguity between right and wrong [11]. In fuzzy logic theory, a value can be true or false simultaneously. But how much truth and error depends on its membership weight [12]. Another study conducted research using the fuzzy logic method as a temperature controller for the grain dryer. It showed that the fuzzy control system worked well because of the LPG gas with a stable temperature [13]. Other research has been conducted on the automatic control of lights and air conditioners in lecture rooms based on Arduino nano microcontrollers and managed to save electricity expenditure for a month with PIR sensors detecting the presence of people and LDR sensors which detect light intensity in the room [14, 15]. Another study conducted research where the effectiveness of controlling using fuzzy logic on air conditioning can reduce energy consumption by 25% per year [16] The dimming response of the bulb automatically corresponds to the ambient light, and good effects of energy saving have been obtained from research [17].

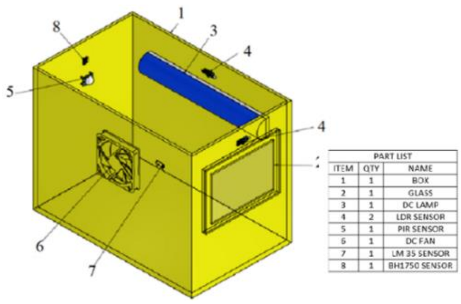
From this thought, the author makes a fuzzy logic-based load arrangement to obtain optimal utilization of solar panel energy use [18, 19]. The regulation system in the lighting system is designed so that the lights can adjust their lighting according to the desired light intensity of the room. In contrast, the cooling system is an efficient air conditioning setting that can read human activities in a room. In several studies on the application of solar panels, such as [20-22], load regulation has not been carried out optimally. It is still in direct use without regulating the energy consumption used.

Based on these problems, it is necessary to have a controller that can optimally regulate the loading to supply electricity to the load according to its needs without having to worry about waste batteries. This research developed a power generation technology sourced from solar energy to supply electrical energy to the load. It is hoped that the results of this study can provide an overview and input on the development of PV mini-grid technology and support national programs in overcoming the energy crisis in Indonesia. Therefore, the authors propose this research which is expected to overcome energy management problems, especially in solar home systems.

METHOD

Design Stage

The design stage is the first step before applying the solar home system's load regulation system. The DC 12 V lamp load and DC 12 V fan load are used. This stage aims to provide an overview of the system that will run and consider several designs for the control system. It can operate optimally. In this research, MATLAB-Simulink software is used for fuzzy logic modeling. This software can communicate with external devices [23, 24]. Designing the solar panel frame construction is needed to obtain optimal sunlight for solar panels at the research site. Figure 1 is the simulation box. Figure 2 is a PLTS electrical design scheme to regulate the 12 V DC lamp load and 12 V DC fan.



PART LIST		
ITEM	QTY	NAME
1	1	BOX
2	1	GLASS
3	1	DC LAMP
4	2	LDR SENSOR
5	1	PIR SENSOR
6	1	DC FAN
7	1	LM 35 SENSOR
8	1	BH1750 SENSOR

Figure 1. Simulation Box

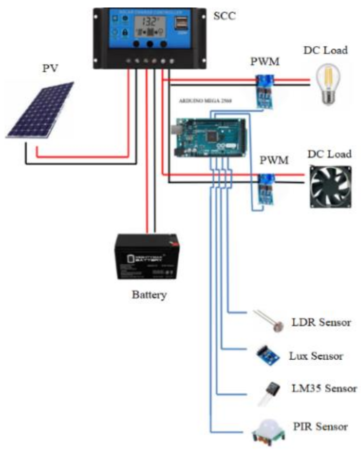


Figure 2. Overall Solar System Electric Circuit Schematic

Programming Design

Based on the system block diagram in Figure 3, the function of each component is as follows: The power supply functions as a voltage supplier to the circuit / as a power supply, Arduino Mega functions as an input and output processor in the circuit to regulate or control the instrument ordered in the program so that the tool can function as intended for the design of the tool. Arduino mega was chosen because it has a large input-output [25], so the system is flexible if further development exists, The lamp dimmer functions to adjust the LED light from off to maximum brightness. Batteries function as energy storage generated by solar panels.

RESULTS AND DISCUSSION

Modeling Software

The system begins with testing without settings from Fuzzy Logic. After that, the system is optimized with Fuzzy Logic as a load controller. A fuzzy Logic System Design is used based on the load. In this study, there is a fan load and a lamp load. This study used the type of Fuzzy Mamdani method. This method was chosen because the Mamdani method is a fuzzy set, while the Sugeno method is in the form of constants or linear equations. In addition, the Mamdani method has a simple structure. Mamdani fuzzy logic uses min-max or max-product operations with a set of rules defined in the rules shown in Figure 5.

Data Collection

After the load testing process on the SHS is carried out, several parameters are recorded, which are shown in Table 1.

Table 1. Parameters measured

Parameters	Unit	Symbol	Measuring Tools/ Formula
Voltage Power Current	V P A	V P A	PZEM-017 DC
Number of solar panels	Pcs	n_{pv}	Total Energy: (Maximum peak per day*panel capacity)
Battery Usage Capacity	Ah	Ah	Total Daily Load Usage: (DoD * Vdc)
Number of Batteries Used	Pcs	n_{batt}	Battery Capacity (Ah): Strong Current per Hour used (Ah)
Sunlight Intensity	G	W/m^2	Solar Power Meter

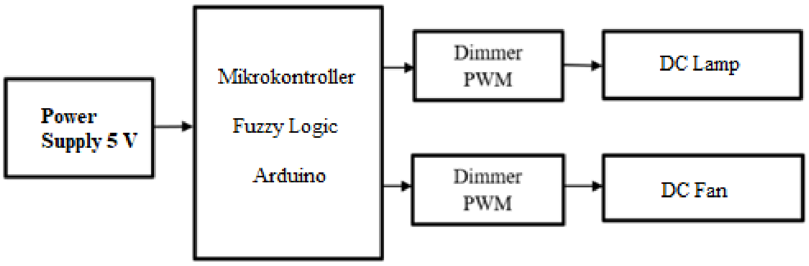


Figure 3. Programming Block Diagram

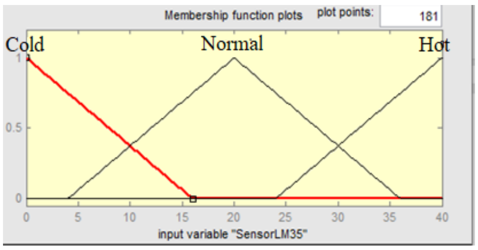


Figure 4. System Design One Input Fuzzy Logic fan load

1. If (SensorLM35 is Cold) then (PWM is Slow)
2. If (SensorLM35 is Normal) then (PWM is Normal)
3. If (SensorLM35 is Hot) then (PWM is Fast)

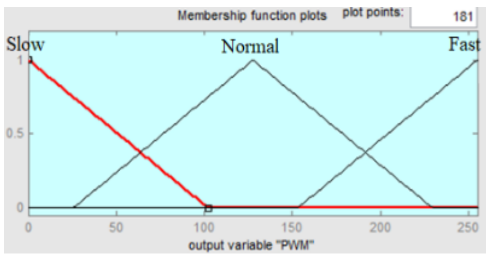


Figure 5. Fuzzy Logic Rule and Output Design for Fan Load (1 Input)

Fuzzy Logic Modeling for Fan Load

One Input Fuzzy Logic Design

The Fuzzy Logic modeling design for the fan load uses two input mechanisms: one input and two inputs. This is to see the effectiveness of the fuzzy logic method in adjusting the fan load. Figure 4 shows the system design for one input, with fuzzy input sourced from the LM35 temperature sensor.

The system begins with the LM35 sensor reading the temperature value received. The value read by the sensor is then processed to become a set called the temperature set, which has three variables, namely “Cold”, “Normal”, and “Hot”. The value read by the sensor will enter the set, which will then be carried out by the inference process, namely the decision-making process. The decision from the inference will be entered into the defuzzification process, where the input value will be converted into a crisp value. The defuzzification process works based on the rules shown in Figure 5. To obtain the membership function in this study, the light variable with the combined form of a triangular curve, a descending linear curve, and an ascending linear curve is used, as shown in Figure 5, and to be able to determine the degree of membership of the set, with use the formulas (1), (2) and (3).

$$\mu[Cold] = \begin{cases} \frac{16-x}{16-0}; 0 \le x \le 16 \\ 0; x \ge 2 \end{cases} \quad (1)$$

$$\mu[Normal] = \begin{cases} 0; x \le 4 \; or \; x \ge 36 \\ \frac{x-4}{20-4}; \quad 4 \le x \le 20 \\ \frac{36-x}{36-20}; \quad 20 \le x \le 36 \end{cases} \quad (2)$$

$$\mu[Hot] = \begin{cases} 0; x \le a \\ \frac{x-24}{40-24}; \quad 24 \le x \le 40 \\ 1; \; x \le 40 \end{cases} \quad (3)$$

The defuzzification process uses the centroid method, where the value obtained is multiplied by the weight of each set to get the crisp value. The defuzzification process uses the following equation,

$$z = \frac{\sum \pi i \, zi}{\sum \pi i} \quad (4)$$

The results of the defuzzification equation with the values obtained are presented as an output in the form of a singleton, namely a membership function with membership degrees of one and zero. Figure 5 is a form of output from the system used. The system works based on room temperature. If the temperature is hot, the fan output will be faster, and so on. The system will adjust based on predetermined rules. Figure 6 is the overall system modeling using Simulink MATLAB.

Two-Input Fuzzy Logic Design

The second system test for the fan load has two inputs for fuzzy logic, namely the LM35 Sensor and the PIR Sensor. Figure 7 shows the system design for two inputs, with fuzzy input sourced from the LM35 temperature sensor and the PIR sensor. The fuzzy design for the temperature system is the same as the previous model, while the PIR sensor for the second fuzzy input design will be described next.

The PIR sensor is tasked with reading the movement in the room. If there is no motion, then the sensor output = 0. Otherwise, if there is movement, then the sensor output = 1. The value read by the sensor is then processed to become a set called the motion set, which has two variables, namely "Empty" and "Contains". The value read by the sensor will enter the set, which will then be carried out by the inference process, namely the decision-making process. The decision from the inference will be entered into the defuzzification process, where the input value will be converted into a crisp value. The defuzzification process works based on the rules shown in Figure 8.

To obtain the membership function in this study, the light variable with a combined shape of a triangular curve, a descending linear curve, and an ascending linear curve was used, as shown in Figure 7. The rules in this study are shown in Figure 8. The defuzzification process uses the centroid method, where the value obtained is multiplied by the weight of each set to get the crisp value. The defuzzification process uses (4).

The results of the defuzzification equation with the values obtained are presented as an output in the form of a singleton, namely a membership function with membership degrees of one and zero. Figure 8 is a form of output from the system used. The system works based on room temperature. If the temperature is hot, the fan output will be faster, and so on. The system will adjust based on predetermined rules, as shown in Figure 9.

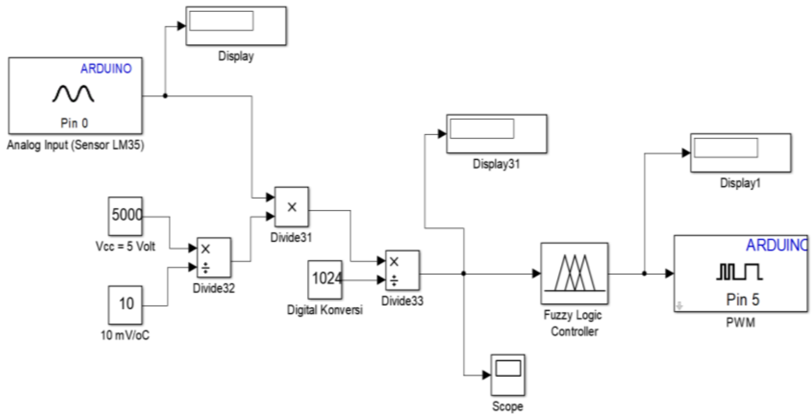


Figure 6. Fuzzy Logic Modeling for Fan Load (1 Input)

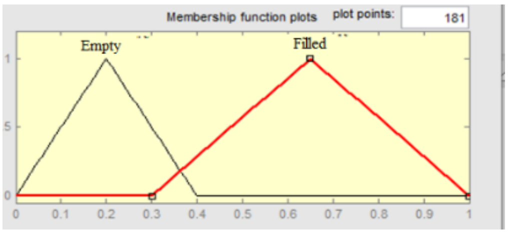


Figure 7. System Design 2 Input Fuzzy Logic Fan Load

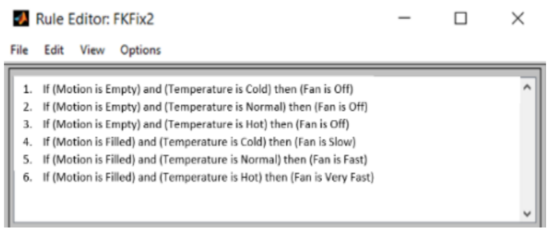


Figure 8. Fuzzy Logic Rule Design for Fan Load (2 Inputs)

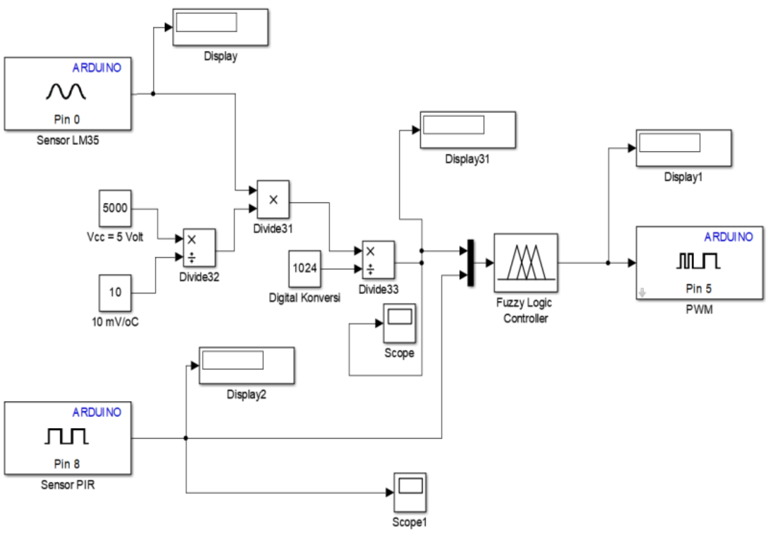


Figure 9. Fuzzy Logic Modeling for Fan Load (2 Inputs)

Fuzzy Logic Modeling for Lamp Load

Two-Input Fuzzy Logic Design

The light load system testing has two inputs for fuzzy logic: LDR 1 and LDR 2 sensors. Figure 10 shows the system design for two inputs, with fuzzy input sourced from the internal and external LDR sensors. The fuzzy design for the temperature system is the same as the previous model, while the LDR sensor for the second fuzzy input design will be described as follows.

For the LDR sensor serving as a light sensor in the room, the LDR value depends on the intensity of the light it receives (light from outside and inside the room). The value read by the sensor is then processed to become a set called the LDR 1 and LDR 2 sets, which have three variables, namely Dark, Medium, and Light. The value read by the sensor will enter the set, which will then be carried out by the inference process, namely the decision-making process. The decision from the inference will be entered into the defuzzification process, where the input value will be converted into a crisp value. The defuzzification process works based on the rules shown in Figure 11.

To obtain the membership function in this study, the light variable with a combined shape of a triangular curve, a descending linear curve, and an ascending linear curve was used, as shown in Figure 11. The rules in this study are shown in Figure 12.

The defuzzification process uses the centroid method, where the value obtained is multiplied by the weight of each set to get the crisp value. The defuzzification process uses (4).
The results of the defuzzification equation with the values obtained are presented as an output in the form of a singleton, namely a membership function with membership degrees of one and zero. Figure 11 is a form of output from the system used. The system works based on the intensity of light received inside and outside the room.

The brightness level of the lamp will adjust to the two sensor inputs. Figure 12 is the overall system modeling using Simulink MATLAB.

Hardware Testing

After performing the stages of determining the capacity of the components used and modeling the software, the next step is to install components consisting of Solar Cells, Solar Charge Controllers, Batteries, Light Dependent Resistor (LDR) Sensors, Passive Infra Red (PIR) Sensors, Pulse Width Modulation (PWM) Modules.

Table 2 shows the characteristics of the solar home system without fuzzy logic on the lamp load. These results show the use of electrical energy for lamps without regulation.

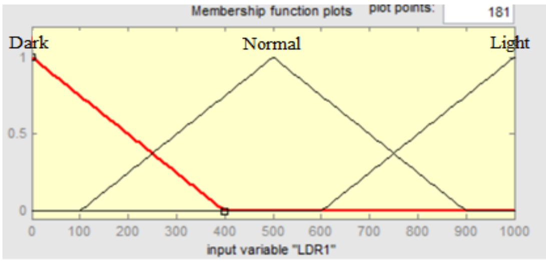


Figure 10. Light Load Fuzzy Logic Input System Design

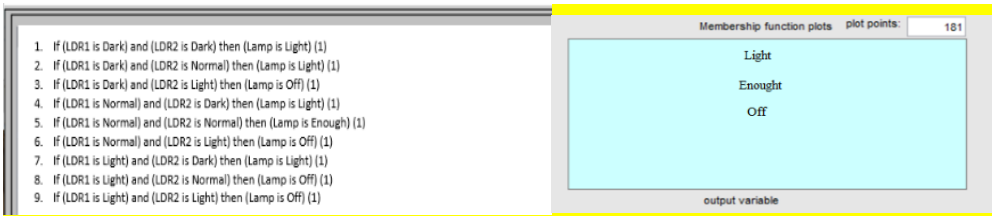


Figure 11. Fuzzy Logic Rule Design and Output for Lamp Loads

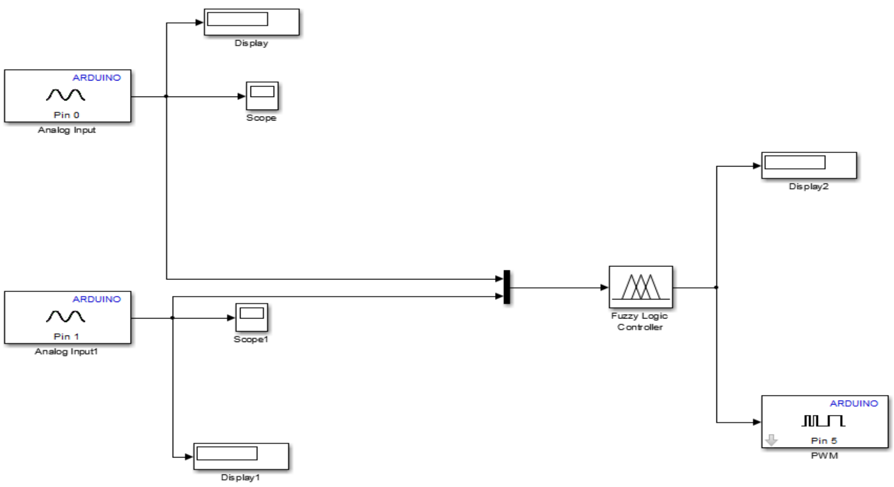


Figure 12. Fuzzy Logic Modeling for Lamp Load

Table 2. Characteristics of Solar Home System Without Fuzzy Logic Lamp Load

Time	V_{load}	I_{load}	P_{load}	G (W/m^2)	BH1750
9:00	13.37	1.32	17.6	767	1104.07
9:15	14.08	1.56	21.9	878	1107.50
9:30	14.09	1.56	21.9	642	1121.67
9:45	13.15	1.29	16.9	486	1127.50
10:00	14.48	1.68	24.3	574	1083.33
10:15	12.49	1.05	13.1	536	1071.67
10:30	13.87	1.47	20.3	403	1106.67
10:45	14.05	1.53	21.4	432	1097.50
11:00	13.86	1.47	20.3	663	1090.83
11:15	13.92	1.50	20.8	389	1086.67
11:30	12.39	1.05	13.0	906	1038.33
11:45	12.38	1.02	12.6	913	1037.50
12:00	12.29	1.02	12.5	814	1042.50
12:15	12.32	1.02	12.5	907	1046.67
12:30	12.70	1.14	14.4	417	1075.00
12:45	12.23	0.96	11.7	842	1015.00
13:00	12.30	0.99	12.1	437	1034.17
13:15	12.25	0.99	12.1	596	1023.33
13:30	12.58	1.05	13.2	422	1051.67
13:45	13.37	1.29	17.2	490	1123.33
14:00	13.44	1.32	17.7	373	1089.17
14:15	14.35	1.62	23.2	395	1087.50
14:30	13.62	1.38	18.7	423	1108.33
14:45	12.30	0.96	11.8	323	1021.67
15:00	12.22	0.96	11.7	302	1020.83

Table 3. Characteristics of Solar Home System with Fuzzy Logic Lamp Load

Time	V_{load}	I_{load}	P_{load}	LDR_1	LDR_2	Fuzzy
11:00	12.58	0.99	12.4	265	227	238.3
11:15	12.63	1.02	12.8	304	249	233.1
11:30	12.63	1.02	12.8	252	236	238.5
11:45	12.46	0.96	11.9	294	250	233.8
12:00	13	1.11	14.4	289	257	233.5
12:15	13.72	1.32	18.1	337	315	221.7
12:30	12.6	1.02	12.8	220	198	243.5
12:45	13.4	1.2	16	313	246	232.7
13:00	13.09	1.14	14.9	327	245	231.7
13:15	12.59	1.02	12.8	374	298	219.9
13:30	12.48	0.99	12.3	360	297	221.5
13:45	12.7	0.54	6.8	229	215	241.8
14:00	12.93	0.6	7.7	227	213	242.0
14:15	12.87	0.57	7.3	216	202	243.4
14:30	12.7	0.54	6.8	213	192	244.2
14:45	12.58	0.51	6.4	206	179	245.3
15:00	12.58	0.48	6	201	179	245.6

Table 4. Characteristics of Solar Home System Without Fuzzy Logic Fan Load

Time	V_{load}	I_{load}	P_{load}	G (W/m^2)
9:00	14.48	0.21	3.0	145.5
9:15	14.31	0.21	3.0	133.1
9:30	14.61	0.21	3.0	161.5
9:45	14.65	0.21	3.0	256
10:00	14.84	0.21	3.1	610
10:15	14.39	0.21	3.0	1064
10:30	14.70	0.21	3.0	713
10:45	14.66	0.21	3.0	373
11:00	14.63	0.21	3.0	535
11:15	14.65	0.21	3.0	498
11:30	14.61	0.21	3.0	350
11:45	14.43	0.21	3.0	585
12:00	14.17	0.21	2.9	286
12:15	14.61	0.21	3.0	469
12:30	14.50	0.21	3.0	580
12:45	13.99	0.21	2.9	248
13:00	14.16	0.21	2.9	275
13:15	14.30	0.21	3.0	394
13:30	14.18	0.21	2.9	310
13:45	14.08	0.21	2.9	410
14:00	13.67	0.21	2.8	580
14:15	14.60	0.21	3.0	505
14:30	14.56	0.21	3.0	269
14:45	14.54	0.21	3.0	420
15:00	14.19	0.21	2.9	342

Table 5. Characteristics of Solar Home System with Fuzzy Logic Fan Load (1 Input)

Time	Load			Fuzzy	T°C
	V_{load}	I_{load}	P_{load}		
9:15	14.61	0.27	3.9	127.5	27.83
9:30	14.61	0.30	4.3	130.8	31.74
9:45	14.51	0.24	3.4	127.5	28.81
10:00	14.40	0.21	3.0	135.7	33.69
10:15	14.38	0.24	3.4	127.5	28.32
10:30	14.25	0.27	3.8	137.2	34.18
10:45	14.49	0.33	4.7	127.5	29.3
11:00	14.61	0.42	6.1	138.8	34.67
11:15	14.49	0.36	5.2	127.5	29.3
11:30	14.47	0.21	3.0	133.1	32.71
11:45	14.32	0.46	6.5	128	30.27
12:45	14.25	0.30	4.2	127.5	29.79
13:00	14.46	0.36	5.2	133.1	32.71
13:15	14.48	0.33	4.7	127.5	29.79
13:30	14.61	0.30	4.3	140.4	35.16
13:45	14.33	0.33	4.7	128	30.27
14:00	14.56	0.39	5.6	148.3	37.11
14:15	14.60	0.33	4.8	128	30.27
14:30	13.90	0.21	2.9	144.1	36.13
14:45	13.99	0.27	3.7	128	30.27
15:00	13.85	0.24	3.3	140.4	35.16

Table 6. Characteristics of Solar Home System with Fuzzy Logic Fan Load (2 Inputs)

Time	V_load	I_{load}	P_{load}	Fuzzy	T°C
12:45	14.86	0.21	3.1	0	30.76
13:00	15.01	0.21	3.1	229	31.74
13:15	14.82	0.21	3.1	0	30.76
13:30	14.70	0.21	3.0	231	32.33
13:45	14.96	0.21	3.1	0	31.25
14:00	13.75	0.21	2.8	234	33.69
14:15	19.47	0.27	5.2	0	30.76
14:30	14.13	0.21	2.9	239	35.64
14:45	13.94	0.21	2.9	0	31.25
15:00	14.01	0.21	2.9	234	33.69
15:15	13.00	0.21	2.7	0	30.76
15:30	13.33	0.21	2.7	235	34.18
15:45	12.64	0.18	2.2	0	30.27
16:00	12.49	0.18	2.2	234	33.69
16:15	12.46	0.18	2.2	0	29.79
16:30	12.43	0.18	2.2	239	35.64
16:45	12.40	0.18	2.2	0	29.3
17:00	12.37	0.18	2.2	238	35.16

Table 3 shows the system's characteristics with fuzzy logic on the lamp load from the test results received the optimal arrangement of electrical energy consumption. In Table 3 the testing of lighting settings using fuzzy logic starts at 11.00 WITA.

Fan Load Test

Table 4 shows the system's performance without fuzzy logic at fan load, where electrical energy consumption is used optimally without any settings. Table 5 and Table 6 show the system performance with fuzzy logic on fan load with one input and two inputs. From the test results obtained, the optimal load regulation mechanism for fan speed regulation is based on the two inputs given.

Graphics and Discussion

Based on Figure 13, which is a graph of the comparison of the output power of the lamp load without and with fuzzy logic, it can be seen that the lamp power without using fuzzy obtained an average power of 14.29 Watt while the lamp power using fuzzy logic the average power of the lamp received was 11.31 Watt.

Based on Figure 14, which is a graph of the comparison of fan power without and with fuzzy logic with one input, it can be seen that the fan power without using fuzzy looks constant with an average power of 2.97 Watts, while the fan power using fuzzy logic with one input is larger and tends to fluctuate. Where the average fan power obtained is 4.32 watts. This is due to the simulation of a hot room temperature so that the fan performance is maximized.

Based on Figure 15, which is a comparison graph of fan power without and with fuzzy logic with two inputs, it can be seen that the fan power without using fuzzy looks smaller than the fan power using fuzzy logic with two inputs, where the average power of the fan without fuzzy is 2.93 Watt while the fan power using fuzzy logic with two inputs is 3.02 Watt. Based on the graph, it can also be seen that the fan power without fuzzy and with fuzzy logic two inputs tends to be constant.

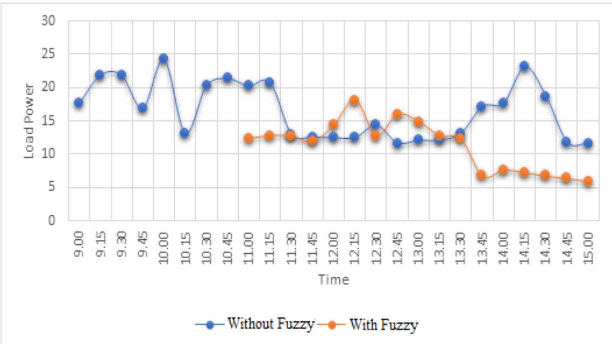


Figure 13. Comparison of Lamp Load Output Power Without and With Fuzzy Logic

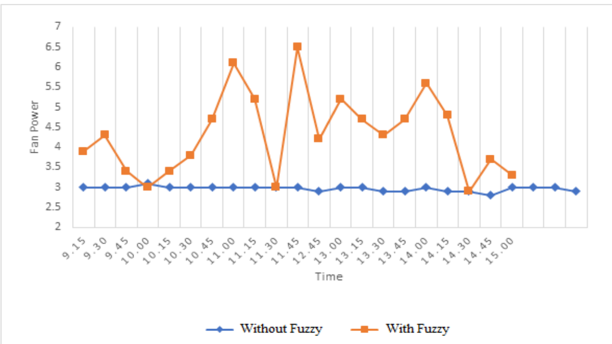


Figure 14. Comparison of Output Power of Fan Load Without and With Fuzzy Logic (1 Input)

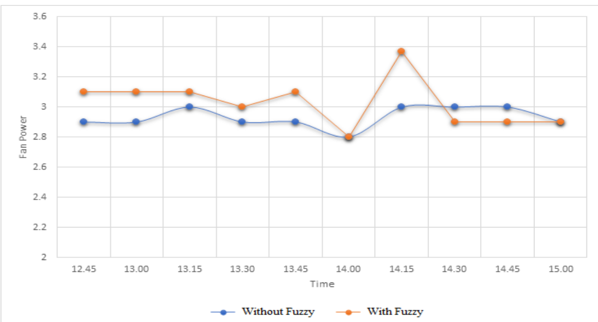


Figure 15. Comparison of Fan Load Output Power Without and With Fuzzy Logic (2 Inputs)

This is due to the simulation of a hot room temperature so that the fan performance is maximized.

In this study, the regulation of electricity consumption in the SHS system was tested with two types of loads: light and fan loads. Setting the use of this load can optimize battery performance on SHS. For example, on lighting loads, the lights will work based on the light intensity in the room. Whereas in the fan load test, the use of electrical energy is carried out based on the temperature in the room and the number of people in the room.

CONCLUSION

A system for controlling the load on a solar panel based on fuzzy logic has been made using light and fan load control. At the fan load, it uses a variation of 1 sensor input, namely the LM35 temperature sensor, and a variation of 2 sensor inputs, namely the LM35 sensor and PIR Motion Sensor, to regulate the fan's speed. In contrast, it uses 2 LDR sensors at the light load that detects indoor and outdoor temperatures and adjusts the level. Lighting from lamps. Based on the research we did, the use of solar panel energy that uses fuzzy logic can minimize the power used in the lamp load and optimal control of the fan load that works based on the input of the number of people and room temperature. The average power load of the lamp without fuzzy is 16.52 watts, and with fuzzy 11.36 watts. This study is only devoted to DC loads, so it is proposed to test it on a 220 Volt AC load using a setting based on the Fuzzy Logic method.

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