Energy Efficiency In Lighting Systems Using Fuzzy Logic Control

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ABSTRACT

Energy consumption is increasing in daily life along with the development of human life. The most widely used energy source in everyday life is light. In tropical areas and islands such as Bangka Belitung, the intensity of light changes rapidly. Sunny weather in the morning turns dark in the afternoon. This change will certainly affect the energy consumption of the lamp. The lights are often turned on in dark weather conditions, but people forget to turn them off when the weather has turned bright. In this study, fuzzy logic control was used to adjust the intensity of the lamp light with input from light in the surrounding environment and processed through lamp dimming according to the fuzzy rule. The highest error reached 2.61% in the "Light" condition. The average error with 5 sample data was 0.64%. The electric power sensor has been tested valid with an error percentage of 3.2%. The test data was taken at Polman Babel (1° 51' 8" S 106° 7' 51" E), which was a campus with geographical conditions close to the coastline. The implementation of this system can achieve power savings of 52.12% during the day.

Keywords: *Energy management, Light Intensity, Fuzzy Logic Control,*

1. INTRODUCTION

The increasing human population affects the world's energy consumption. The population is directly proportional to the consumption of electrical energy. World Energy demand increase by 4.6% in 2021 [1]. Energy consumption in buildings reaches 40% of the total energy from all sectors [2,3]. In the previous study, results have obtained opportunities for energy savings from the outside of working hours in the building in university up to 21.06% [4].

Technology is required to be able to solve this problem. A smart home is also a solution for solving this problem. Electrical device control systems using the Internet of Things (IoT) can help control electricity consumption. Control using the Web called cayenne can be accessed through Android OS, IOS, and windows phones [5]. Research on the use of power, energy, voltage, electric current, and usage costs that can be sent to smartphones has been carried out. There is a buzzer sound if the load used exceeds the user's desired electricity price limit. The percentage of reading errors in this system is still above 30% [6]. The light control system using Fuzzy Logic Control (FLC) can save 57.21% of energy. The test was carried out for 4 hours in the form of a prototype [7]. Control lighting lamp using 15 W T8 LED tube (non-induction light) has been done. In the proposed leader-follower office lighting system (assuming that the office is occupied for 10 hours a day and that the hourly low-light mode is 20 minutes), then the power-saving rate is as high as 28.13% [8].

This research focuses on the implementation of FLC to control the light in the room. Using fuzzy logic controller on electric equipment, we can achieve improved users' performance without paying any extra cost [9]. Variable external light conditions are used for reference to adjust the lamp light. The light setting certainly affects the current, voltage, and power used. However, the light intensity in the room will remain stable. Thus there will be an efficient use of electric power. The android application is made for monitoring the required data.

2. MODELING AND DESIGN SYSTEM

2.1 Modeling Lighting System

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The indoor average illuminance is calculated by the following Equation (1):

$$E_{av} = \frac{\emptyset NUK}{A} \tag{1}$$

where E_{av} is the average illuminance, f is the luminous flux, N is the number of lamps, U is the utilization coefficient, K is the maintenance coefficient of lamps, and A is the illuminated area.

Generally, we need to maintain indoor illuminance above a certain level to ensure working environment comfort, that is, the superposition of natural light and artificial light should meet the indoor demand. As a result, the lighting load can be determined by the following Equation (2):

$$P_{l,t} = \begin{cases} \dfrac{(E_{set} - E_e)A}{\emptyset UK} P_l, & t \in t_{work} \\ 0, & t \notin t_{work} \end{cases} \tag{2}$$

Where $P_{l,t}$ is the power consumption at the end of the tth time slot, E_{set} is the target illuminance, E_e is the natural illuminance, P_l is the power of one lamp [2].

2.2 Design System

This research starts from the control system design and simulation. The benefit of using FLC design is that it could apply the linguistic variables as input or output [10]. The control system block diagram is shown in Figure 1.

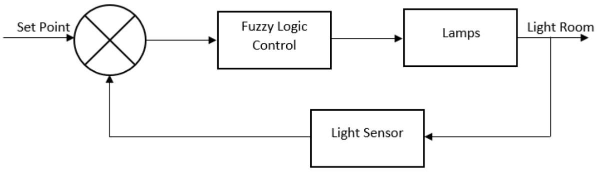


Figure 1 Diagram of Block Control System

The input of the FLC is the light sensor data minus the set point. The output of the FLC is used to regulate the electrical power of the lamp. Changes in lamp power will affect the percentage of lamp brightness. The brightness of the light affects the brightness of the room. The light sensor reads back data from the room light to be used as feedback to the control system.

2.3 Fuzzy Logic Control Design (FLC)

The advantage of FLC is that the control design can be carried out without a plant model [10]. Input and output are based on variables that directly affect the system. The FLC design uses 1 input which is the brightness value of the room. This input is read by the Light Dependent Resistor (LDR) sensor. There is 1 output which is the percentage of lamp brightness. The percentage of brightness of this lamp will affect the electrical power used. Fuzzy rules using the Mamdani method. Increasing the number of membership functions (*mf*) can improve the performance of the controller much faster to reach the settling time [11]. This study uses 5 membership functions on the input and output. The block diagram design for the FLC control is shown in Figure 2.

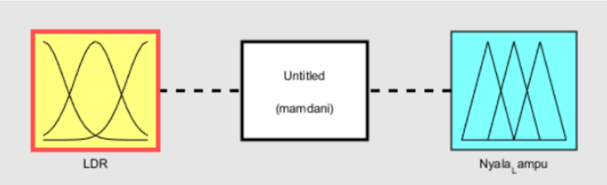
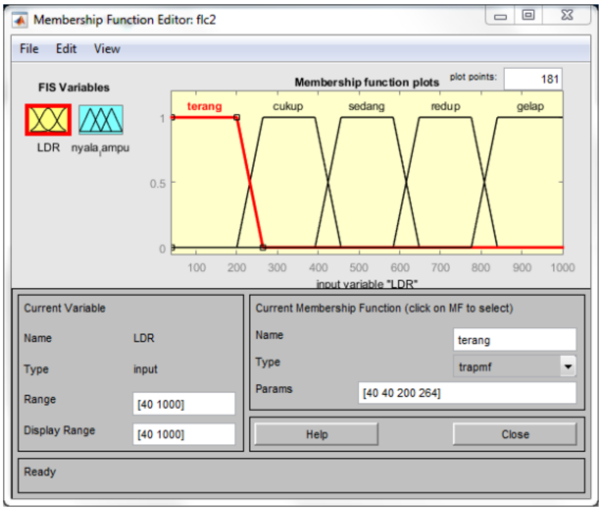


Figure 2 Fuzzy Logic Control Block Diagram

2.3.1 Membership Function Input

Membership function input is divided into 5 classifications using a trapezoidal model. They are “Terang”, “Cukup”, “Sedang”, “Redup” dan “Gelap”. With a value range from 40 to 1000. This figure is obtained from the value of the Analog to Digital Converter (ADC) LDR sensor. Membership function input LDR is shown in Figure 3.



plot points: 181

Current Variable

Name LDR

Type input

Range [40 1000]

Display Range [40 1000]

Current Membership Function (click on MF to select)

Name terang

Type trapmf

Params [40 40 200 264]

Ready

Figure 3 Membership Function Input

The table for the distribution of the membership function input values is shown in Table 1.

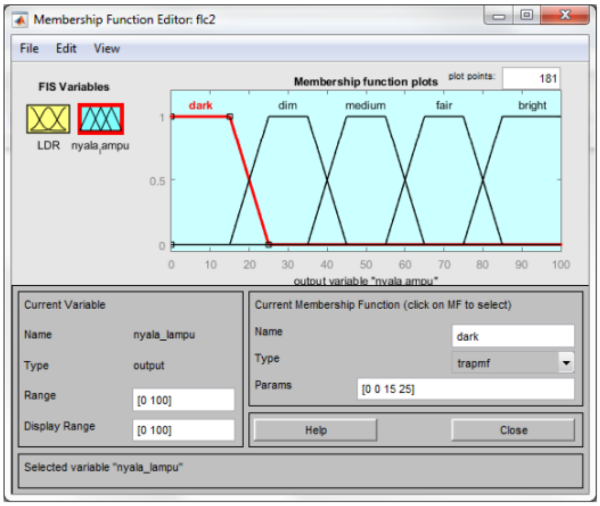
The brighter the light, the smaller the ADC value. Values less than equal to 40 to 264 represent the membership function "terang". Values 200 to 456 represent the membership function "cukup". Values 392 to 648 represent the "sedang" membership function. Values 584 to 840 represent the membership function "redup". And the last value 776 to more than 1000 represents a "gelap" membership function.

Table 1. Distribution of membership function input

Variable	*mf*	Value
LDR	terang	40, 40, 200, 264
	cukup	200, 264, 392, 456
	sedang	392, 456, 584, 648
	redup	584, 648, 776, 840
	gelap	776, 840, 1000, 1000

2.3.2 Membership Function Output

The membership function output is divided into 5 classifications using a trapezoidal model. They are "dark", "dim", "medium", "fair" and "bright". With a value ranging from 0 to 100. This number is a representation of the percentage of lamp brightness. Membership function output "nyala_lampu" is shown in Figure 4.



Current Variable
Name nyala_lampu
Type output
Range [0 100]
Display Range [0 100]

Current Membership Function (click on MF to select)
Name dark
Type trapmf
Params [0 0 15 25]

Selected variable "nyala_lampu"

Figure 4 Membership Function Output

The higher the percentage, the brighter the light will be. Values 0 40 to 25 represent the membership function "dark". Values 15 to 45 represent the membership function "dim". Values 35 to 65 represent the "medium" membership function. Values from 55 to 85 represent a "fair" membership function. And the last value 75 to 100 represents the membership function "bright". The table for the distribution of the membership function output values is shown in Table 2.

Table 2. Membership Function Output

Variable	*mf*	Value
Nyala Lampu	dark	0, 0, 15, 25
	dim	15, 25, 35, 45
	medium	35, 45, 55, 65
	fair	55, 65, 75, 85
	bright	75, 85, 100, 100

2.4 Rules Fuzzy

After compiling the input and output parameters, the next step is to create fuzzy rules. Fuzzy rules show how a system operates. The fuzzy rules in this system use functions that are conveyed linguistically, namely the IF-THEN rules. The rules that make up the fuzzy rules are as follows:

1. IF (LDR is Terang) THEN (Nyala_Lampu is Dark)
2. IF (LDR is Sedang) THEN (Nyala_Lampu is Medium)
3. IF (LDR is Gelap) THEN (Nyala_Lampu is Bright)
4. IF (LDR is Cukup) THEN (Nyala_Lampu is Dim)
5. IF (LDR is Redup) THEN (Nyala_Lampu is Fair)

3. RESULT AND DISCUSSION

This section is the system testing phase. The test consists of several tests: FLC design testing, sensor testing, and system implementation testing.

3.1 FLC Design Testing

FLC design is made in simulation and implementation. The test results are compared for validation. There are differences in the results of the simulation and implementation. The highest error reached 2.61% in the "Light" condition. The average error with 5 sample data is 0.64%. This value is very small so it does not have a big effect on the performance of the system implementation. A comparison of FLC design testing data is shown in Table 3.

Table 3. Comparison of FLC design testing

LDR Sensor	*mf* Input	Nyala Lampu (%)			Error (%)
		mf Output	Simulation	Implementation	
40	terang	dark	9.95	10.21	2.61
200	cukup	dim	30	20.00	0
500	sedang	medium	50	50.00	0
800	redup	fair & bright	76.7	76.44	0.34
1000	gelap	bright	90	89.79	0.23
Average error					0.64

3.2 Electric Power Sensor

The power sensor readings are validated by comparison with a power quality analyzer (PQR). The largest value difference is 0.6 watts. This refers to lamps with low power. Test results can be seen in Table 4.

Table 4. Comparison sensor and PQR

Lamp Power (Watt)	Sensor (Watt)	PQR (Watt)
7	7.6	8.2
10	9.5	10.1
11	11.9	12.2
15	16.5	17.0
20	20.5	20.7
average	13.2	13.64

Error is calculated using Equation 3.

$$error = \frac{\Delta P}{P2} \times 100\% \qquad (3)$$

The average percentage of error test results was obtained 3.2%. This result is quite small and does not interfere with the system in general.

3.3 Implementation FLC in the system

Electrical power was compared between using FLC and without FLC. The test was carried out for 6 hours on February 5, 2022. The test data was taken in Polman Babel (1°51'8"S 106°7'51"E) which is a campus with geographical conditions close to the coastline. The test results are shown in Table 5.

Table 5. Results of FLC Implementation

Time (AM)	LDR Sensor (ADC)	Nyala Lampu (%)	Power with FLC (W)	Power without FLC (W)
06.00	609	58.05	12.9	16.5
07.00	578	50	10.6	16.5
08.00	432	42.33	9.8	16.5
09.00	411	36.35	7	16.5
10.00	310	30	5	16.5
11.00	338	30	5	16.5
12.00	302	30	5	16.5
average			7.9	16.5

The test is done by setting up 2 separate rooms. One of the rooms uses a lighting system with FLC and the other only uses ordinary lights. Each room uses a lamp with a power of 15 watts. As the day approaches, the light will get brighter. In room 1, the light in the room is kept stable by adjusting the brightness of the lamp. The reduction in brightness results in less power consumption being used. In room 2, the test without FLC was carried out. The light is turned on continuously so that it will absorb maximum power. The brightness of the room does not change much due to the influence of external light. The comparison chart of control with FLC and without FLC is shown in Figure 5. X axis is the time from 06.00 to 12.00 AM. Y axis is the value of power.

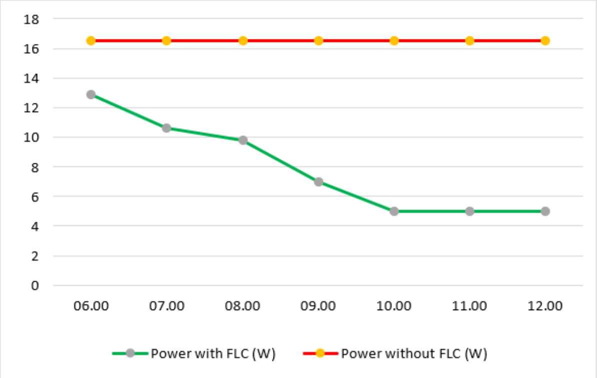


Figure 5 Comparison of Power with FLC and without FLC

Efficiency is calculated using Equation 4.

$$efficiency = \frac{\Delta P}{P2} \times 100\% \qquad (4)$$

In this study, the efficiency obtained was 52.12%. The amount of efficiency is greatly influenced by weather conditions and external light.

4. CONCLUSION

The design, simulation, and implementation of FLC on controlling the brightness of room lights have been done. The system design were following simulation and testing. The highest error reached 2.61% in the "Light" condition. The average error with 5 sample data was 0.64%. The electric power sensor has been tested valid with an error percentage of 3.2%. FLC can work well in adjusting the brightness of the lamp. System testing for 6 hours obtained an efficiency of 52.12%. This result was very influential on weather conditions and external light.

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