The application of Sugeno fuzzy to control active power load and remaining battery usage time modelling

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ABSTRACT

This study aimed to propose a control scheme to optimize the active power load using the pulse-width adjustment technique and the MOSFET driver. The power used and stored in the battery is an input for the fuzzy system whose information is obtained through the current (ACS 712) and voltage sensor readings. The use of fuzzy to control the power of two 5-watt lamps is more efficient than the manual technique using an ordinary switch. This is because fuzzy only consumes 3.25 Watt/hour while the manual technique requires 5.7 Watt/hour. Based on the linear regression-based estimation, the fuzzy technique lasts ±17 hours from the initial power of 55.82 Wh, or 5.5 hours longer than the manual technique that lasts only ±11.5 hours from the initial power of 65.62 Wh. Therefore, this study adjusted the load power to extend battery life and increase solar energy use efficiency and innovations in load control based on available resources.

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1. INTRODUCTION

Indonesia's electrification ratio reaches 99.2% [1], with 433 villages without electricity, necessitating renewable energy as the best solution in the country’s tropical climate. In 2018, the use of renewable energy for power plants reached 8.8 Gigawatt (GW), while the total potential is 442 GW [2]. Indonesia has many types of potential renewable energy, such as hydropower, geothermal, bioenergy, wind, marine, and solar energy, which has the greatest potential of 207.8 GW [3]. Photovoltaics (PV) components or solar panels receive and convert solar energy into a direct or DC voltage output power supply. This energy is strongly influenced by natural conditions such as solar radiation, temperature, wind, and humidity, causing the power output to be unstable and fluctuating [4].

Energy saving solar lamp (LTSHE) is a government's assistance in ensuring the communities in remote, underdeveloped, and populated areas are connected to the electric power network. LTSHE consists of a lamp's integrated battery with energy sourced from photovoltaics. Its preparation enforced in 2017 through the Presidential Regulation of the Republic of Indonesia Number 79 of 2014 [5].

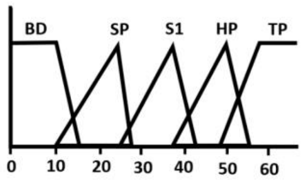
Previous studies designed a power-saving street light system that uses a motion sensor and scheduling to ensure that the lights turn dim at midnight when there are no vehicles around and vice versa. This system also uses LED luminaries as a lamp because it has a 50% lower power consumption than street lights [6]. Studies on a light intensity and motion sensor system that uses scheduling have not considered the power obtained from solar panels and stored in batteries. Adjustments must be made when the weather changes or during cloudy conditions to increase the efficiency of active power use based on the available voltage source from the battery and the load usage. This helps observe and measure the power usage pattern and the availability of a voltage source, respectively. Therefore, this study aimed to propose a voltage frequency regulation method for active loads based on fuzzy logic to increase the efficiency and effectiveness of battery use. The power regulation technology extends battery life and increases its usage time for LED light loads. Additionally, it supports battery management studies for renewable energy applications.

This study aimed to adjust the power used by a lamp, where load power could be regulated using the pulse-width adjustment technique and the MOSFET driver. The power used and stored in the battery is an input for the fuzzy system, whose information is obtained through the current sensor reading (ACS 712) and the voltage sensor. This study adjusted the load power to extend battery life and increase solar energy use efficiency and innovations in load control based on available resources. The novelty in this study is the use of zero-order Sugeno fuzzy to adjust the MOSFET driver's pulse width and the input voltage on the LED lamp. It also used simple linear regression to predict battery remaining time, a new concept in applied statistics.

2. METHOD

2.1. Zero order fuzzy Sugeno design

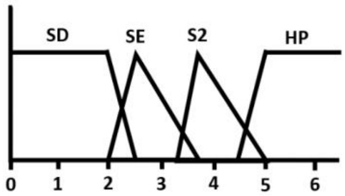
This study used singleton or zero-order Sugeno fuzzy for the defuzzification process, while fuzzification employed the stored power in the battery and the power used as inputs. The first five membership functions for the power stored in the battery are BD (needs charging), SP (slightly full), S1 (medium), HP (almost full), and TP (fully charged). BD and TP variables are trapezoid memberships, while SP, S1, and HP are triangles. Figure 1 is a number range for each membership function. Figure 2 shows the variable power used by the lamp divided into four membership functions, including SD (very little) with range of values between 0-2.5 W, SE (a little) from 2- 3.8 W, S2 (medium) with the value interval between 3.4-5 W. In addition, HP (high) with a value more than 4.5 W. SD and T are trapezoid memberships, while SE and S2 are triangles.



BD : 0-15 Wh
SP : 13-28 Wh
S1 : 25-42 Wh
HP : 37-Wh
TP : >=49 Wh

Figure 1. Membership function for stored power variable

Each input results in the degree on a scale of 0-1 of the membership functions. The output membership functions are PWM values divided into SR (very dim), R (dim), S3 (medium), T (bright), and ST (very bright). Since this study used zero-order Sugeno fuzzy, the defuzzification declaration is singleton or only includes constants. Figure 3 shows the constant values for each membership function.



SD : 0-2.5 W
SE : 2-3.8 W
S2 : 3,4-5 W
T : >=4.5 W

Figure 2. Membership function for the power variable used

The defuzzification constant based on linear measurements using a lux meter. The lighting value measured by sampling the PWM signal from the smallest to the maximum value. Figure 4 shows the relationship between the PWM signal and the resulting lux value for two 5-watt LED lamps with a measurement distance of 30 cm.

Figure 3. Membership function for the output variable

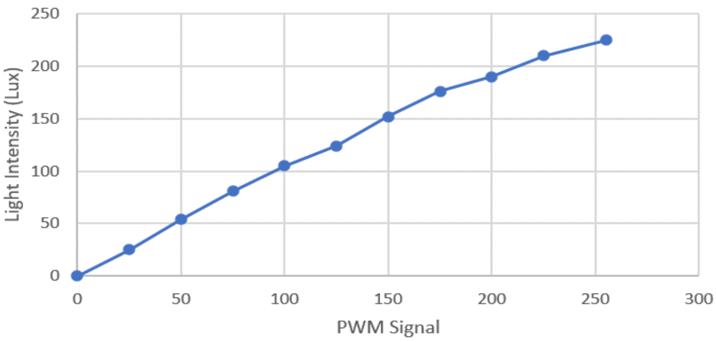


Figure 4. PWM signal response vs light intensity (Lux)

The basic rules in this study were adjusted to the possibilities when the membership functions of the stored power (DT) and the power used (DG) variables are interrelated. The number of possibilities obtained from the product of the DT and DG membership functions, resulting in 20 basic rules. Table 1 shows the basic rules for a zero-order Sugeno fuzzy load control system.

Table 1. Rule base

		DT				
		BD	SP	S1	HP	TP
DG	SD	SR	R	S3	S3	ST
	SE	SR	S3	S3	T	ST
	S2	SR	R	R	T	ST
	T	SR	SR	R	R	T

The basic difference between Sugeno and Mamdani fuzzy lies only in the defuzzification process. Mamdani defuzzification searched by finding the centre of gravity on the membership form area, while Sugeno defuzzification is determined by looking for a relatively simple average weight value [7]-[11] with (1).

$$z' = \frac{\sum u_i z_i}{\sum \mu_i} \quad (1)$$

z': Sugeno's defuzzification PWM value
μi: the degree of membership for each rule
zi: constant value for each rule

2.2. Prototype design

The fuzzy design stage followed by the hardware design shown in Figure 5. The hardware design uses solar panels with a 50-watt peak (WP) capacity. The battery charged from 05.30 in the morning to 17.00 in the afternoon. While discharging takes place from 17.00 to 05.30. The load used is two LED lamps with a capacity of 5 watts activated simultaneously as the discharging process. ACS712 [12]-[16] current and voltage sensors were used to get fuzzy input parameters. Figure 6 shows an electrical circuit design for a zero-order Sugeno-based load control system.

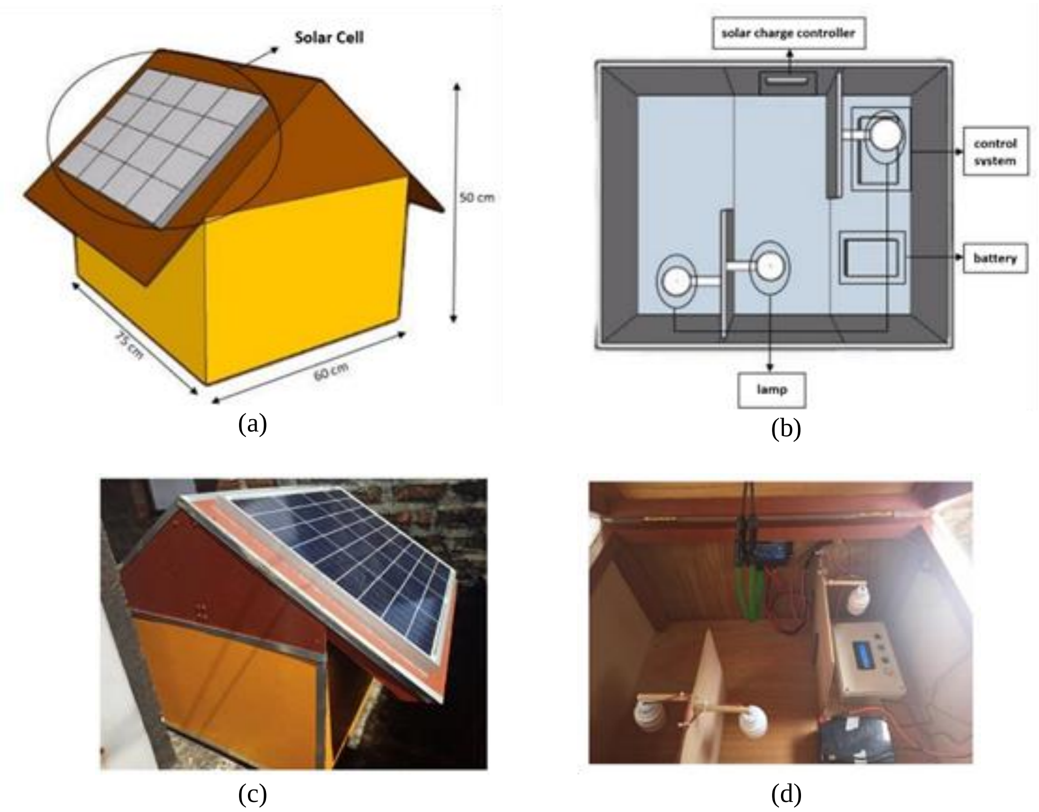


Figure 5. The fuzzy design stage: (a) outer prototype design, (b) interior prototype design, (c) outer realization and (d) inner realization

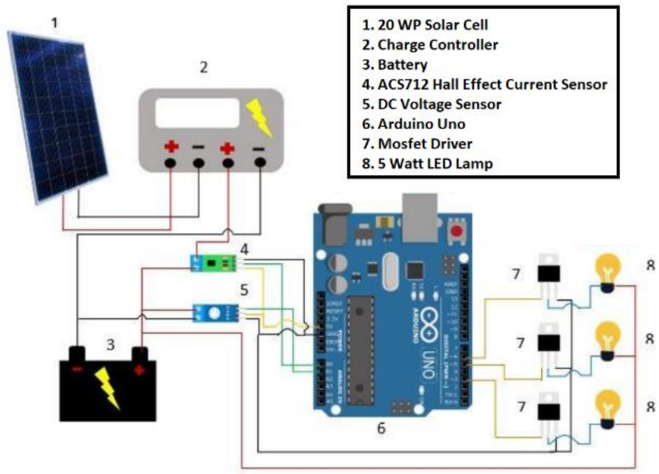


Figure 6. Electrical design

A MOSFET driver [17]-[21] used to manipulate power consumption by LED lights. The MOSFET was used as an input voltage regulator based on the pulse width reference given by the defuzzification results [22], [23]. The resolution of the PWM setting facility is 8 bits or the equivalent of 0-255 decimals [24].

3. RESULTS AND DISCUSSION

The system reliability was determined by conducting the following testing procedures: i) Comparing battery power consumption while using lights during discharging with and without fuzzy; and ii) Estimating the battery is remaining time usage using the fuzzy method based on linear regression.

3.1. Comparing battery power consumption testing when lights during discharging with and without fuzzy

The charging process starts from 05.30 to 17.00. In addition, both lights activated from 17.00 to 05.30. This sub-chapter compares the power usage between the fuzzy method and the manual technique, similar to activating a switch to turn on LED lights. In the manual technique, the voltage used by LED lights is a maximum of 220 VAC or a PWM signal of 8 bits equivalent to 255 decimals. Figure 7 compares the power consumption response between fuzzy and manual techniques.

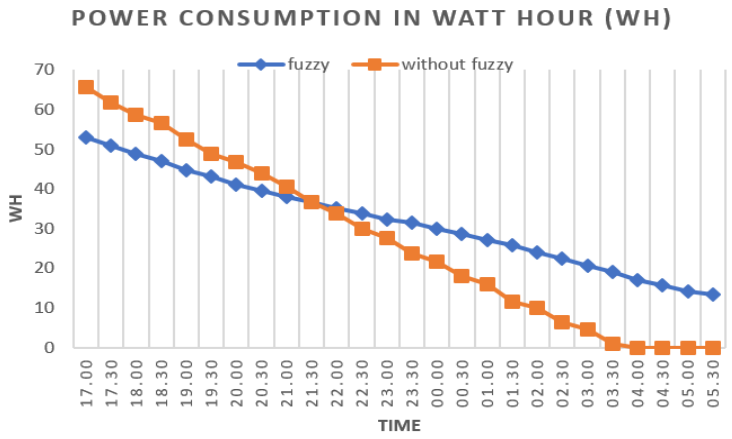


Figure 7. Power consumption response

The results in Figure 7 show the average hourly power consumption because the initial power stored in the battery between fuzzy and manual techniques is not the same. The stored power in the manual technique is 65.62 Wh at 16.30 and 0 Wh at 04.00. This means the technique only bears the load of two 5-watt lamps in 11.5 of 13 hours from 16.30-05.30. Therefore, the average power consumption per hour is 65.62 Wh/11.5 h=5.7 Watt. In contrast, the initial stored power in the fuzzy control technique is 55.82 Wh at 05.30, implying a remainder of 13.48 Wh. The means the use of fuzzy to adjust the lamp power consumption for 13 hours is 42.34 Wh or average hourly power consumption of 42.34 Wh/13 h=3.25 Watt.

The results show that using fuzzy for power regulation of two 5-watt lamps is more efficient than manual techniques using ordinary switches. Fuzzy only consumes 3.25 Watt/hour while the manual technique requires 5.7 Watt/hour. As a result, using fuzzy increases the efficiency of battery use by 57.13%.

3.2. Estimating the remaining battery usage time when using a fuzzy method based on linear regression

The comparison of the power consumption response of manual and fuzzy techniques found that the fuzzy technique had 13.48 remaining power out of 13 hours. Simple linear regression modeling conducted to estimate the remaining battery usage time. This helps determine the hours taken for the maximum use of battery power from 55.82 Wh to 0 Wh. The basic linear regression (2) [25]-[27] used is:

$$Yest = A.X + B \tag{2}$$

Yest : saved power estimate (Wh)
X : time (h)
A, B : regression coefficient

when using the data for 13 hours sampled every 0.5 hours equivalent to 26 data, the regression modeling obtained as:

$$Yest = -3.1341X + 53.3141$$

Figure 8 explains the average RMSE deviation from the modeling results is 0.8425 Wh. This is the value of the remaining power difference estimated using linear regression with the actual remaining power. Linear regression produces an estimation error of ±0.8425 Wh of the actual stored power. Therefore, further observations conducted to determine the data sampling needed to reach the Yest value equal to 0 Wh. Sampling data added in increments of 1 sampling or half an hour until Yest showed 0 Wh.

Figure 9 shows that the observation was stopped at the 34th data sampling (n-1), with a Yest value equal to 0 Wh. Since the sampling was performed every 0.5 hours, the total estimated remaining battery usage time with the initial 55.82 Wh is 34 sampling x 0.5 hours = ±17 hours. Therefore, fuzzy control is 5.5 hours longer than manual techniques, with only ±11.5 hours of use.

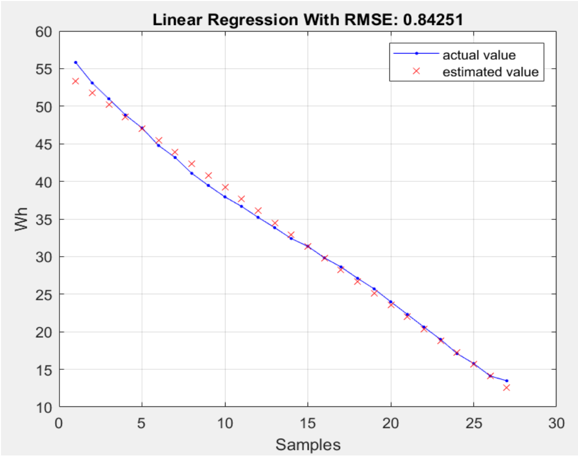


Figure 8. Linear regression

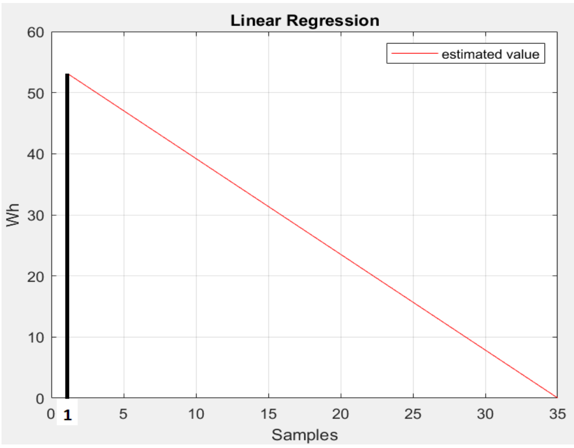


Figure 9. Estimated remaining time

4. CONCLUSION

Using fuzzy to control the power of two 5-watt lamps is more efficient than the manual technique using an ordinary switch. Fuzzy only consumes 3.25 Watt/hour while the manual technique requires 5.7 Watt/hour. Therefore, using fuzzy increases the efficiency of battery use by 57.13%. The regression estimator was used to forecast the remaining battery usage time using fuzzy Yest = -3.1341X + 53.3141 with an RMSE of 0.8425 Wh. The estimates showed that the fuzzy technique has a usage time of ±17 hours from the initial 55.82 Wh. This is 5.5 hours longer than the manual technique with a duration of use of only ±11.5 hours from the initial 65.62 Wh.

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