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Current Stabilisation of Lithium Polymer Electric Vehicle Battery Using Fuzzy Logic Control

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ABSTRACT Renewable energy in electric vehicles (EVs) is crucial and requires careful consideration. To determine the initial capacity of lithium polymer batteries used in electric vehicles development, the batteries must be tested under various load and discharge conditions. The issue is that an increase in the level of load typically results in a corresponding decrease in battery lifespan. To extend the operational lifespan of the battery, it is necessary to conduct a variety of loading tests. These procedures involve monitoring battery voltage, current, and temperature during discharge with a 5-watt lamp load. The results of the study demonstrate that fuzzy control is an effective method to minimize the increase in battery temperature by stabilizing the current used by the battery. The fuzzy control system effectively regulates the battery with a capacity of 3300 mAh and a voltage of 11.1 Volts, maintaining a stable current of 0.3 A from the 3rd minute until the battery reaches its maximum capacity at 63 minutes. Fuzzy control delays the battery's temperature rise by approximately 14 minutes compared to a system without it. Temperature rise significantly affects the discharge speed of lithium polymer batteries.

KEYWORDS: battery discharge, current stabilising control, fuzzy logic, lithium polymer

I. INTRODUCTION

The development of alternative energy sources has been driven by the need to replace petroleum energy, which is finite in supply [1]. Alternative energy resources, with a particular emphasis on electrical energy, have been utilized in a range of fields, including the automotive industry, with the aim of reducing reliance on petroleum [2]. Electric vehicles (EVs) represent one of the most significant developments in the field of alternative energy utilization. An electric vehicle (EV) is a vehicle that utilizes electricity as the primary energy source, stored in a series of rechargeable batteries, for propulsion, without the use of other energy sources. The electrical energy storage system, in the form of batteries, represents a critical component of electric vehicles (EVs). Typically, the battery utilized is of the secondary variety, allowing for both utilization and recharge [3]. The optimal battery selection is the lithium battery, which offers advantageous features such as fast charging, high energy and power density, and durability when the charging process is properly executed [4]. Consequently, lithium polymer batteries have been the subject of extensive research, with the latest developments exhibiting high energy capacity, low weight, and high current capability, rendering them suitable for use in electric vehicles [5], [6].

Nevertheless, the development of lithium polymer batteries is currently occurring without consideration of the original capacity of lithium polymer batteries currently available on the market. It is essential to evaluate the original capacity of the lithium polymer batteries that will be utilized in the development of electric vehicles (EVs) through testing the batteries in discharge conditions with varying loading. It is imperative that the initial capacity of each battery cell be a minimum of 90% of the rated capacity. Conversely, the initial stage of battery damage when the storage function is maximized is only up to 70-80% [7], [8].

As electric vehicle (EV) technologies continue to evolve, the characteristics of the lithium polymer battery, which serves as the primary energy storage source, remain a crucial consideration. Consequently, battery capacity testing is a vital aspect of the development process. Prior research has examined the optimal voltage for driving a BLDC electric motor from a LiPo battery with a capacity of ±2,184 Wh. The optimal voltage was found to be 48 volts, with an electric voltage of 54.6 volts. This was observed in as many as 13 pieces of research [9]. A further examination of the battery performance in electric vehicles with varying loading conditions revealed that the greatest reduction in battery voltage occurred at a 50 kg driver load of 3.6 Volts, while at a 55 kg driver load of 3.3 Volts and a 60 kg driver load of 3.15 Volts, the decrease in voltage was less pronounced. Furthermore, this study evaluated the optimal battery charging duration, establishing that 1.33 hours represents the optimal charging interval [10].

Additionally, the properties of lithium batteries can be evaluated through the utilization of a series of test lamps with varying powers, specifically 10, 20, and 30 watts. The findings of this research enabled a comparison to be made between the loading of batteries using a conventional method and another method which employed fuzzy logic control. The temperature increase differs depending on whether the battery is loaded without control or with fuzzy logic control. As an illustrative example, at a load of 10 watts, the temperature increase without control is 2.71°C, but with fuzzy control, it is 2.44°C. The results illustrate the efficacy of fuzzy logic control in regulating temperature rise and optimizing battery power usage [4]. The findings of previous research indicate that the process of using batteries is not currently optimized. It is possible to regulate the temperature during the use of batteries by stabilising the current in the battery discharge process. Previous research focused on stabilizing the voltage and discharge time but in this study the focus was on stabilizing the current during the battery discharge process.

The method employed for the regulation of battery current stabilization is the Fuzzy Inference System. The Fuzzy Inference System (FIS) is a control method whose function is to solve mathematical problems by representing linguistic uncertainty using fuzzy logic. The concept of fuzzy logic provides a means of quantifying the degree to which a given value can be considered to be either true or false Fuzzy methods have been employed for the regulation of voltage in batteries [4], the control of water pumps [11], the measurement of water discharge and river depth [12], and the automatic control of current-based electronic components [13]. FIS was used in previous research to regulate the voltage on the battery so FIS should be able to be used in stabilizing the current on the battery.

II. METHOD

The current control system for stabilizing the lithium polymer battery is subjected to testing in which lamp loading characteristics with power variations of 5, 8, and 16 watts are employed. The battery is in a state of discharge to facilitate the monitoring of the current, voltage, and temperature generated by the battery. To regulate the current to maintain it below the specified set point using PWM technology. Figure 1 illustrates the block diagram design of the current stabilization control system.

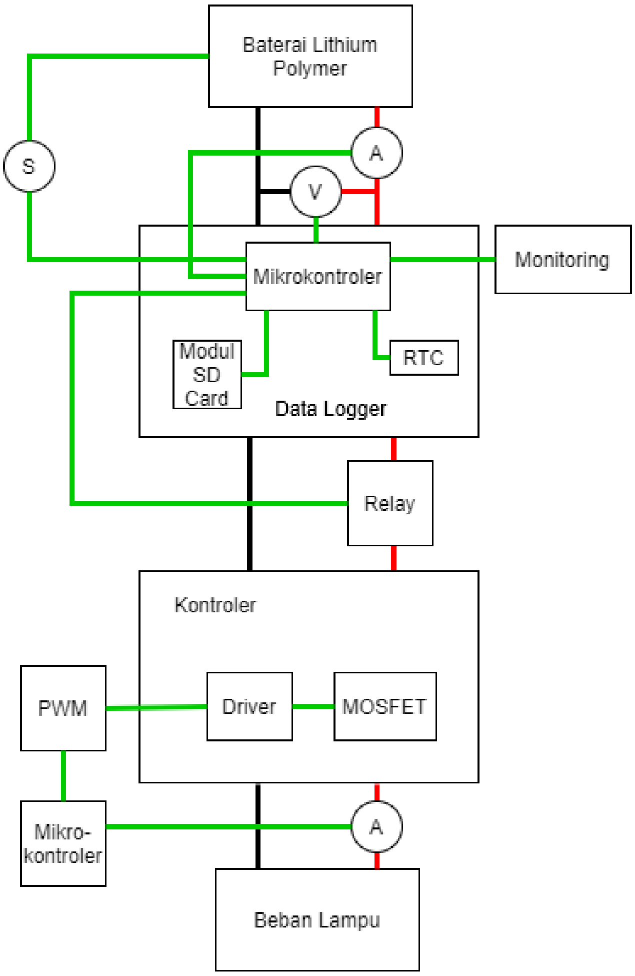


FIGURE 1. Block diagram of lithium battery current stabilisation system

2.1. LITHIUM POLYMER BATTERY AND LAMP LOADING

Revolectrix 3S brand Lithium Polymer batteries are arranged in series with a total of three, each with a voltage of 3.7 Volts. Consequently, the total battery voltage is 11.1 Volts with a battery capacity of 3300 mAh. Three loading lights with power variations of 5 watts, 8 watts, and 16 watts are employed (See Figure 2).

(a) (b)

FIGURE 2. (a) Lithium Polymer battery and (b) Loading lamp.

2.2. DATA LOGGER

The data logger in this study has the function of storing data [14] that will subsequently be read by sensors for the measurement of current, voltage, temperature and time. The data logger is integrated by several sensors such as ACS712 sensor, DC voltage sensor, LM35 temperature sensor and Arduino UNO R3 as a microcontroller.

2.3. THE DISCONNECT RELAY

The disconnect relay serves as a protective mechanism, disconnecting the electric current when the lithium battery undergoing testing fails to exhibit a decline in voltage. During the discharge test, the relay will interrupt the electric current when the battery has reached a voltage of 9 volts.

2.4. FUZZY INFERENCE SYSTEM (FIS) CONTROL SYSTEM

A fuzzy inference system (FIS) is a control method that employs fuzzy logic as a means to represent linguistic uncertainty and provide solutions to mathematical problems. Fuzzy logic is a method of indicating the extent to a value is true or false [15]. The fuzzy control system employed in this study utilises an adaptive fuzzy controller that automatically adjusts parameters in response to fluctuations in voltage conditions as illustrated in Figure 3. Furthermore, the determination of the set point serves to regulate the current intensity to align it with the desired value.

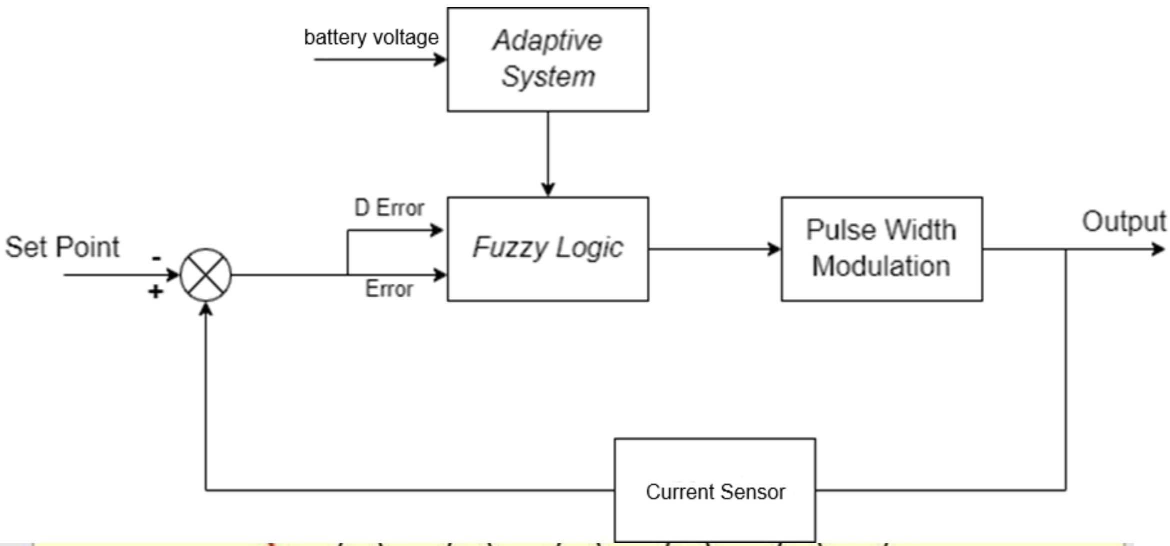


FIGURE 3. Block Diagram of FIS Control System

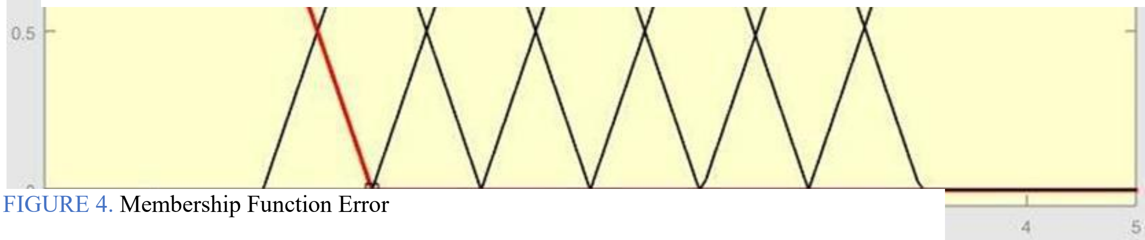


FIGURE 4. Membership Function Error

The adaptive fuzzy controller employs an error signal, derived from the discrepancy between the prescribed set point and the actual output current. The fuzzy output will modify the PWM by increasing or decreasing the switching to the controller. The value of the PWM is directly correlated with the magnitude of the current generated by the control, and vice versa. Furthermore, the delta error is determined by subtracting the previous error value from the current error value.

The fuzzy logic method employs seven error membership functions, as depicted in Figure 4, which encompass a spectrum of potential outcomes, ranging from Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), to Positive Small (PS), Positive Medium (PM) and Positive Big (PB).

2.5. BATTERY DISCHARGE TESTING

Battery discharge testing with no control and fuzzy control was performed by determining the current set point with an estimated margin of error of 5%. Additionally, the energy and battery capacity were evaluated through the application of the following formula equation:

$$I = \frac{P}{V} \tag{1}$$

$$E = P\ x\ t \tag{2}$$

$$E\ (Wh) = \frac{E\ (Joule)}{3600} \tag{3}$$

$$Kapasitas\ (Ah) = \frac{E\ (Wh)}{Tegangan\ Bate:} \tag{4}$$

I: set point current (Ampere);
P: energy (Watt); V: battery voltage (Volt); E : Energy (Joule); t: time (seconds).

III. RESULTS AND DISCUSSION

It is recommended that the voltage, current, and temperature be measured prior to testing. The calibration process was conducted on the various sensors utilized in this research, including the ACS712 sensor, DC voltage sensor, and LM35 temperature sensor.

3.1. VOLTAGE SENSOR

The objective of this voltage sensor test is to obtain a voltage sensor reading value that is accurate as well as consistent with the measuring voltage displayed on a voltmeter, which serves as a reference instrument. The voltage sensor employs two resistors, with values of 1K Ω and 2K Ω, to facilitate the division of the voltage. The output of this voltage sensor is an analogue data, converted by the microcontroller into a digital value (Table 1).

The sensor voltage calibration test was validated by analysing 14 samples with an initial voltage of 8.83 volts, which were increased to a final voltage of 12.60 volts. In order to ascertain the percentage of error rate, the reduction of the sensor voltage with the voltmeter voltage must be divided by the sensor voltage. The mean percentage error was 0.22%, indicating that sensor voltage readings are sufficiently accurate to be considered comparable to those obtained by the voltmeter.

TABLE 1. Voltage Sensor Testing

No	Voltage Sensor (V)	Voltmeter (V)	Error (%)
1	8,83	8,87	0,45
2	9,10	9,15	0,55
3	9,42	9,45	0,32
4	9,72	9,77	0,51
5	10,00	10,03	0,30
6	10,31	10,31	0,00
7	10,63	10,62	0,09
8	10,90	10,87	0,27
9	11,22	11,19	0,27
10	11,50	11,50	0,00
11	11,78	11,76	0,17
12	12,09	12,07	0,16
13	12,29	12,28	0,08
14	12,60	12,60	0,00
	Mean Error		0,22

3.2. CURRENT SENSOR

The objective of this current sensor test is to obtain a precise reading for the current sensor value, which will be compared with the reading obtained on the multimeter, which is used as a reference instrument for measuring current. The current sensor employs an ACS712 current sensor. The output of the ACS712 sensor is in the form of analogue data, and this will be converted by the microcontroller into digital value data (Table 2).

TABLE 2. Current Sensor Testing

No	Current Sensor (A)	Multimeter (A)	Error (%)
1	0	0	0
2	0,40	0,40	0
3	0,61	0,61	0
4	0,80	0,81	1,25
5	1,01	1,01	0
6	1,20	1,21	0,83
7	1,40	1,41	0,71
8	1,60	1,60	0
9	1,80	1,81	0,55
10	2,02	2,02	0
11	2,21	2,22	0,45
12	2,40	2,42	0,83
13	2,60	2,61	0,38
14	2,80	2,81	0,35
	Mean Error		0,38

The sensor current calibration test was validated by analysing 14 samples with an initial current of 0.40 ampere, which were increased to a final current of 2.80 ampere. In order to ascertain the percentage of error rate, the reduction of the sensor current with the multmeter current must be divided by the sensor current. The mean percentage error was 0.38%, indicating that sensor current readings are sufficiently accurate to be considered comparable to those obtained by the multimeter.

3.3. TEMPERATURE SENSOR

The objective of testing the temperature sensor (LM35 sensor) is to obtain an accurate temperature sensor reading value comparable to the temperature measured by the thermocouple, which serves as a reference instrument. The output of the LM35 sensor is in the form of analogue data, which is then converted by the microcontroller into digital data (Table 3).

TABLE 3. Temperature Sensor Testing

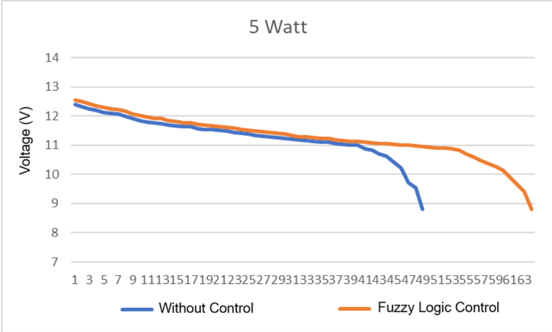
No	Temperature Sensor (°C)	Multimeter (°C)	Error (%)
1	23	23	0
2	23.5	23.57	0.297
3	24	24.03	0.125
4	24.5	24.52	0.081
5	25	25	0
6	25.5	25.5	0
7	26	26.01	0.038
8	26.5	26.49	0.037
9	27	27.01	0.037
10	27.5	27.51	0.036
11	28	27.99	0.0357
12	28.5	28.49	0.035
13	29	29	0
14	29.5	29.5	0
	Mean Error		0,036

Testing was conducted by collecting 14 temperature samples with a range of 23°C to 29.5°C. As illustrated in Table 3, the highest percentage error was 0.297%, occurring at a temperature of 22 degrees Celsius. Conversely, the lowest percentage error was 0%, observed at temperatures of 23°C, 25°C, 25.5°C, 29°C, and 29.5 °C.

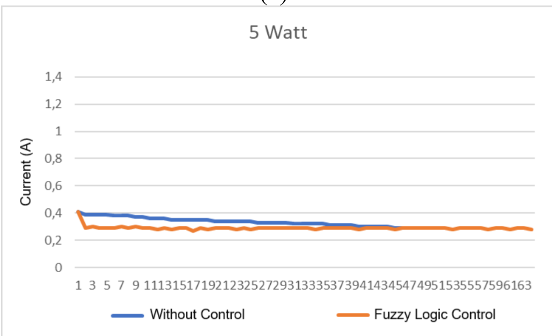
This study employs three loading lights with 5 watts, 8 watts, and 16 watts of power, respectively, and employs both no control and fuzzy control to stabilize the current of a lithium polymer battery with a voltage of 11.1 Volts and a capacity of 3.3 Ah. The relay will automatically deactivate the battery when the voltage reaches a minimum of 8.8 volts and 80% of the battery's original voltage. The battery exhibited a maximum voltage of 12.6 volts during a test conducted for this purpose.

3.4. INCREASE IN BATTERY DISCHARGE

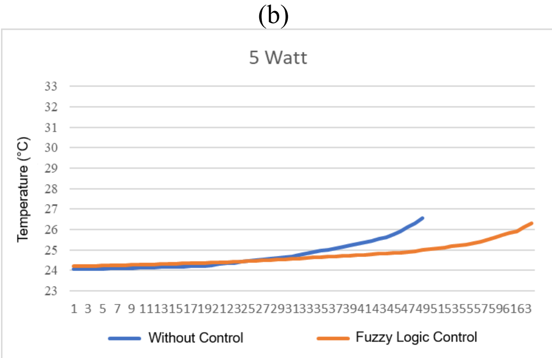
The characteristics of the battery should be determined by testing the voltage, current, and temperature under discharging conditions with 5, 8, and 16 watts of lamp loading, as illustrated in Figure 5.



(a)



(b)

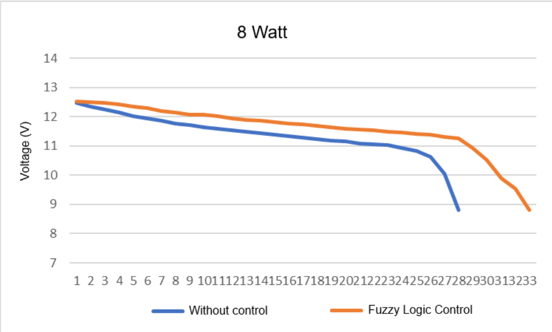


(c)

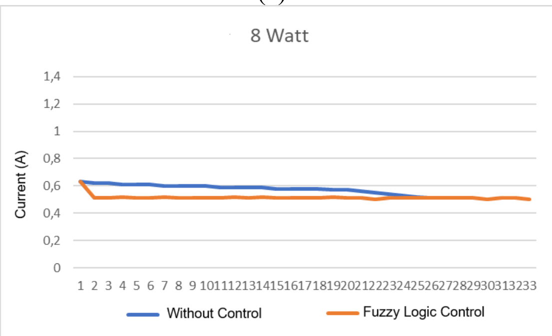
FIGURE 5. Test result graphs of (a) voltage, (b) current and (c) temperature in lithium polymer batteries.

Testing is conducted by stabilizing the current using fuzzy logic (Figure 5b). The fuzzy logic-based system can stabilize the current at the third minute following the discharge process, stabilizing at 0.3A until the battery capacity is no longer available at the 63rd minute. As illustrated in Figure 5a, the implementation of fuzzy logic control enables the prolonged regulation of battery capacity in comparison to the system lacking such control. Without the control system, battery usage results in a remaining capacity of only 49 minutes. This is distinct from testing the system with fuzzy control.

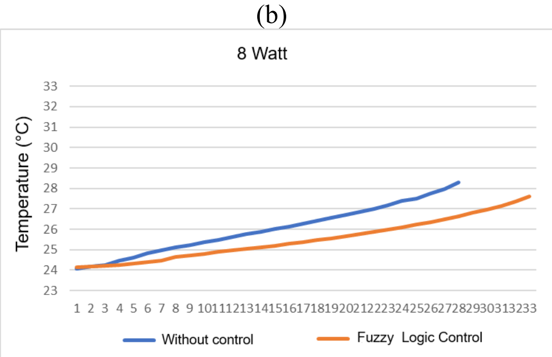
The battery can operate until the 63rd minute, thereby extending the battery usage time by 14 minutes with a 5-watt lamp load. It is evident that the system without fuzzy control is more wasteful in its use of battery power. Furthermore, the application of fuzzy control directly correlates with temperature, resulting in delayed temperature increases during the battery discharge process. The temperature of the battery rises at the 31st minute in the system that lacks control, while in the system with fuzzy control, the temperature increase occurs at the 53rd minute (Figure 5c).



(a)



(b)



(c)

FIGURE 6. Test result graphs of (a) voltage, (b) current and (c) temperature in lithium polymer batteries

As illustrated in Figure 6, the discharge process in the lamp loading test is characterised by an increase in power. Upon examination of the voltage test results, it becomes evident that the speed of the battery voltage drop is influenced by the level of loading, as demonstrated in both Figure 5a and Figure 6a. It is evident that the implementation of fuzzy logic can effectively mitigate voltage fluctuations, thereby enhancing the stability and reliability of the system. In regard to the increase in battery temperature (Figure 6c), the lack of control results in a more significant rise in temperature than is observed when fuzzy logic control is employed. Nevertheless, upon examination of the current control applied to the system, it becomes evident that there is a similarity in the graph patterns observed in Figure 5b and Figure 6b.

3.5. BATTERY TEMPERATURE CHARACTERISTICS

The results of the discharge test on the lithium polymer battery, conducted with a lamp load of 5, 8, and 16 watts, are presented in Table 4. The objective was to determine the increase in battery temperature without control and with fuzzy control.

TABLE 4. Rising discharge temperature of lithium polymer batteries

Lamp Load (watts)	Battery Temperature Increase (°C)	
	Fuzzy Control	Without Control
5	2.11	2.52
8	3.46	4.23
16	7.97	8.69

The results of the battery discharge characteristic testing indicate that an increase in temperature occurs when the lamp loading is tested without control. For a lamp power of 5 watts, the temperature increase is 2.52°C. However, when control is carried out with fuzzy logic, the temperature increase is reduced to 2.11°C. Furthermore, similar conclusions can be applied to lamp power of 8 and 16 watts. A comparison of the test results from previous studies on 10-watt, 20-watt, and 30-watt lamp loading (see Table 5) reveals an increase in battery temperature.

TABLE 5. Previous research battery temperature rise [4].

Lamp Load (watts)	Battery Temperature Increase (°C)	
	Fuzzy Control	Without Control
10	2.44	2.52
20	3.47	4.23
30	8	8.69

As illustrated in Table 5, the implementation of fuzzy control enables the reduction of temperature rise in comparison to systems without control. This observation applies to lamp power loading of 10, 20, and 30 watts.

3.6. BATTERY CAPACITY CHARACTERISTICS

Moreover, the battery capacity is calculated in battery discharge testing with 5 watts, 8 watts, and 16 watts of lamp power loading using the equations and formulas presented in sections (3) and (4). Battery utilization is quantified at the outset of the testing period and at 10-minute intervals thereafter. Once the capacity value has been obtained at each 10-minute interval until testing is complete, the total capacity will be calculated to ascertain the capacity utilized, as delineated in Table 6.

TABLE 6. Previous research battery temperature rise [4].

Lamp Load (watts)	Battery Capacity (Ah)	
	Fuzzy Control	Without Control
10	5	3.073
20	8	2.808
30	16	2.631

Table 6 illustrates that the battery discharging test with a load of 8 watts in uncontrolled conditions produces a battery capacity of 2.581 Ah, whereas the use of fuzzy control results in a capacity of 2.808 Ah. The maximum battery capacity was calculated by testing at a load of 16 watts without fuzzy control, resulting in a battery capacity of 2.358 Ah. However, the calculated test battery capacity with fuzzy control is 2,631 Ah at a 16-watt load.

IV. CONCLUSION

This research indicates that fuzzy control is an effective method for delaying the increase in battery temperature by stabilizing the current, thereby prolonging the battery discharge process. To illustrate, in a testing scenario with a 5-watt lamp load, the fuzzy control system can stabilize a 3300 mAh battery with a voltage of 11.1 Volts and a current of 0.3 A from the 3rd minute until the battery is no longer operational in the 63rd minute. Furthermore, the implementation of fuzzy control has been observed to delay the temperature increase in the battery. In comparison to the system without control, the use of fuzzy control has been shown to delay the temperature rise by 14 minutes. An increase in temperature has a significant impact on the rate of battery discharge, which in turn affects the overall discharge process.

ACKNOWLEDGMENT

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