Lithium-ion Battery Charging System using Constant-Current Method with Fuzzy Logic based ATmega16

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ABSTRACT
In this charging system, constant-current charging technique keeps the current flow into the battery on its maximum range of 2A. The use of fuzzy logic control of this charging system is to control the value of PWM. PWM is controlling the value of current flowing to the battery during the charging process. The current value into the battery depends on the value of battery voltage and also its temperature. The cutoff system will occur if the temperature of the battery reaches its maximum range.

Keyword: Charging, Constant-current, Fuzzy, Lithium-Ion Battery

1. INTRODUCTION
There are many charging methods for lithium battery such as constant-current method, constant-voltage method, conventional five-stage or proposed fuzzy-based algorithm method [1]. Charging Lithium battery with constant-current method is a technique to keep the value of the current when it flows into battery, while the value of its voltage is charging [2]-[5]. Even though the value of the current is fluctuating, but in this charging system, the maximum value will be 2Ampere. Here, the changing value of battery voltage is from range 2.7 volt to 4.2 volt.

The addition of fuzzy logic control of this Lithium battery charging system is the control of current flow into the lithium battery, so that it will meet its input and output requirements.

There are two inputs in this charging system, which are temperature and voltage of lithium battery. Temperature is the most vital parameter in lithium battery security that affected battery’s health. The lithium battery is easy to explode when it is overcharging that caused by over temperature.

The objective of this study is the current flows into the Lithium battery can be controlled, by changing the temperature and increasing the voltage of the battery.

2. CHARGING METHOD
There are many kinds of charging methods for battery, example constant-current, constant-voltage, and five-stage Li-ion battery charger [1]-[5]. During the constant current phase, the primary task of battery management is to control the flow of current to the maximum permissible battery current [4]-[5].

Battery use in this charging system is Panasonic CGR18650CG [6]. The specification of the battery shown in Table 1.
This charging system is using MOSFET’s transistor as an active instrument. MOSFET is an instrument which read the electric signal and controls the output voltage from the charger system onto the battery. In this charging system, MOSFET is use because it has better durable than other common transistors. This MOSFET can resist the flow of the current up to 10Ampere. In charging system the PWM (Pulse Width Modulation) technology is applied to set the function of charging system to battery.

3. RESULTS AND ANALYSIS

The key design of software from this charging system is Fuzzy Algorithm. The Fuzzy inference system of this charging system is Sugeno’s model. On Sugeno’s model, to bring out the output we need four steps, which: forming of Fuzzy’s set (fuzzification), function of implication, evaluation of rules, and defuzzification [7]. The evaluation rules use Max-Min mechanism and the defuzzification step use Center of Average (CoA) method. The flowchart of charging system is shown in Figure 1.

| Table 1. Battery Specification |
|--------------------------------|
| Measurements          | Quantity |
|-----------------------|----------|
| Nominal Voltage       | 3.6 v    |
| Nominal Capacity      | Minimum  | 2.150 mAh |
|                       | Typical  | 2.250 mAh |
| Dimension             | Diameter | 18.6 mm   |
|                       | Height   | 65.2 mm   |

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**Figure 1. Flowchart Charging System**
3.1. Fuzzification

This system uses two inputs which are voltage and temperature of the battery. First, ADC microcontroller read battery's voltage with sensor and set the linguistic form. Linguistic forms of battery voltage and battery temperature shown in Table 2 and Table 3.

| VOLTAGE (V) | LINGUISTIC  |
|-------------|-------------|
| 2.7 – 3.2   | Low2        |
| 3.0 – 3.6   | Low1        |
| 3.2 – 3.8   | Normal      |
| 3.6 – 4.0   | High1       |
| 3.8 – 4.2   | High2       |

Figure 2. Fuzzy Voltage’s range

Figure 2 shows the sets of voltage’s range. It consist of five areas, starting from 2,7 volt until 4,2 volt, naming low2, low1, normal, high1, high2. System will run cut-off, once the voltage of the battery reach above 4,2 volt.

| Temperature (°C) | Variabel Linguistik |
|------------------|---------------------|
| 18-24            | Inc1                |
| 21-29            | Inc2                |
| 24-34            | Inc3                |
| 29-37            | Inc4                |
| 34-40            | Inc5                |

Figure 3. Fuzzy Temperature’s range

Figure 3 shows the sets of temperature’s range. It also consists of five areas that starting at 18°C-40°C. System will also run cut-off, once the temperature reach above 40°C.
3.2. Rule Base

Rule base of this system is from each input of fuzzy logic. So that, there will be 25 rules, and shown in Table 4.

| No | Input       | Output |
|----|-------------|--------|
| 1  | Low2 Inc1   | Rapid  |
| 2  | Low2 Inc2   | Rapid  |
| 3  | Low2 Inc3   | Rapid  |
| 4  | Low2 Inc4   | Rapid  |
| 5  | Low2 Inc5   | Normal |
| 6  | Low1 Inc1   | Rapid  |
| 7  | Low1 Inc2   | Rapid  |
| 8  | Low1 Inc3   | Rapid  |
| 9  | Low1 Inc4   | Rapid  |
| 10 | Low1 Inc5   | Normal |
| 11 | Normal Inc1 | Rapid  |
| 12 | Normal Inc2 | Rapid  |
| 13 | Normal Inc3 | Rapid  |
| 14 | Normal Inc4 | Normal |
| 15 | Normal Inc5 | Normal |
| 16 | High1 Inc1  | Normal |
| 17 | High1 Inc2  | Normal |
| 18 | High1 Inc3  | Normal |
| 19 | High1 Inc4  | Slow   |
| 20 | High1 Inc5  | Slow   |
| 21 | High2 Inc1  | Slow   |
| 22 | High2 Inc2  | Slow   |
| 23 | High2 Inc3  | Slow   |
| 24 | High2 Inc4  | Slow   |
| 25 | High2 Inc5  | Slow   |

3.3. Mechanism of Inference

Mechanism of inference in this system transform into three ranges of percents, in duty cycles of PWM will run, which are rapid, normal and slow and shown in Table 5, and its formula in Equation (1)

\[
\%PWM = \frac{\sum_{i=1}^{n} v_i \mu_R(v_i)}{\sum_{i=1}^{n} \mu_R(v_i)}
\]

Where : \% PWM is output, \( v_i \) is crisp’s value of i’s element, \( \mu_R(v_i) \) is degree of every elements in Fuzzy’s set of V. V is universe of Fuzzy, and n is quantization.

| Duty Cycle (%) | Linguistic | Information |
|----------------|------------|-------------|
| 30             | Rapid      | Max1        |
| 60             | Normal     | Max2        |
| 90             | Slow       | Max3        |

3.4. Defuzzification

Defuzzification of this system is using CoA (center of Average), by formula in Equation (2):

\[
y = \frac{\sum y \mu_R(y)}{\sum \mu_R(y)}
\]

Where : y is crisp’s value and \( \mu_R(y) \) is membership of y.
3.5. Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a method for using pulse width to encode or modulate a signal. The width of each pulse is a function of the amplitude of the signal. While ADC detect the battery voltage and LM35 detect the changing of temperature, microcontroller will deliver and group those inputs into Fuzzy’s set. Furthermore, microcontroller will control the IC to deliver the PWM signal into MOSFET series. The value of the current will depend on the mathematics calculation in the microcontroller.

![Flowchart of PWM](image)

Figure 6. Flowchart of PWM

4. RESULTS

4.1. First Experiment

In the first experiment (Figure 7), the room temperature was set at 25°C, in 2 hours (7200s) and the initial battery voltage was 2.7 volts. In the 1s, the battery temperature was 25.1°C, the current inflows was recorded at 2 amperes. At 238 second the voltage increase up to 2.8 volts, and the temperature was recorded at 25.5°C with a flow to the battery at 1.9 amperes. The decrease in flow occurs due to the temperature rise. At 469 second, the voltage increase up to 2.9 volts with battery temperature was 26.9°C and current was at 2 Amperes. At 3.0 volts, temperature was 27.3°C and the current was 1.9 Amperes. At 3.1 volts voltage of battery on 991 second, the temperature was at 29.2°C with current flows into the battery at 2 Amperes. At 1135 second voltage rise to 3.2volts with a recorded temperature of 29.8°C and the current flow of 1.8 Ampere.

It can be concluded that Fuzzy logic work when temperature is rising in the battery current flows. When the current flow increases, the temperature will increase, so the next current flow can be reduced, and the temperature can be decreased.

4.2. Second Experiment

In the second experiment (Figure 8), the room temperature was 25°C, experiments approximately with in 2 hours (7200s) with initial battery voltage at 2.7 volts. In the 1s, the temperature was 26°C, the flows of current was 2 amperes. At 240 second the voltage increased up to 2.8 volts, and the temperature was at 26.1°C with current flow to battery was 2 Ampere. At 500 second, the voltage increased up to 2.9 volts and the temperature was 26.3°C with current at 2 ampere. At 3.0 volts, temperature was 26.5°C and the current flows at 2 amperes. At 3.1 volts at 870 second, the temperature was at 27.1°C with current flows of 1.9 ampere. At 1019 second, voltage up to 3.2 volt and temperature was 27.2°C with the current flows at 1.9 amperes.

Similar to the first experiment: in conclusion the fuzzy logic control works similar to the first experiment.
4.3. Third Experiment

In the third experiment (Figure 9), the room temperature was 25°C, approximately within 2 hours (7200s) the initial battery voltage at 2.7 volts. In the first second, the temperature was at 25.1°C, the current flows to battery was 2 amperes. At 294 second the voltage increased up to 2.8 volts, and the temperature at 25.2°C with current flowed to the battery at 1.9 amperes. At 504 second the voltage increased to 2.9 volts with temperature was 25.4°C and the current was 2 amperes. At 3.0 volts, temperature 25.3°C and the current flow at 2 amperes. At 3.1 volts at 890 second, the temperature was 25.6°C and current flow at 2 Ampere. In 121 second the voltage rise to 3.2 volts and temperature was 26.1°C with the current flows at 1.8 Ampere.

In the charging system of the lithium-ion battery, the critical parameter that should be considered is temperature, due to this the comparison between experiments was plot in the graph as shown in Figure 10. The results show that the temperature batteries are below the data sheet.
At the end of the experiment, the averages of each battery parameters are shown in Table 6.

Table 6. The Average Battery parameter in Experiment

| Parameter | Battery 1       | Battery 2       | Battery 3       |
|-----------|-----------------|-----------------|-----------------|
| Temperature (°C) | 27.75           | 26.77           | 26.21           |
| Current (A)    | 1.65            | 1.68            | 1.62            |
| Average Temperature (°C) | 26.91           |                  | 1.65            |

From the Table 6 shows that the average value of experiments for each battery starting from the first to the third trial are: temperatures of 26.91°C and current of 1.65 Amperes. In this experiment the current flows into the Lithium battery can be controlled, by changing the temperature and increasing the voltage of the battery.

5. CONCLUSION

a) This system consists of two parts, which are: microcontroller series function to calculate the Fuzzy, and MOSFET function for charger series.
b) The design algorithm to control the flows of current use PWM. The output from the microcontroller calculation will be delivered through MOSFET to control the value of the current flowing into the Lithium battery.

c) The total of current flows into Lithium battery is affected by the value of voltage and temperature while it is charging.

d) Fuzzy is still working despite the temperature of the Lithium battery changing. The voltage of the battery will constantly rises until it reaches 4.2 volt.

e) The value of the current flowing into the lithium battery is depending on the value of the temperature of the battery, as it is formulated in the rule base of Fuzzy.

The average temperature of the lithium battery while charging process running is 26°C and the average of the current flowing into the battery is 1,75A.

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REFERENCES
[1] HoushyarAsadi, et al. Fuzzy Logic Control Technique in Li-Ion Battery Charger. International conference on electrical, electronics and civil engineering (iceece’2011) pattaya dec. 2011; 179-183.
[2] Huang, Jia-Wei, et al. Fuzzy-control-based five-step Li-ion battery charger. In Power Electronics and Drive Systems. PEDS. International Conference on. IEEE, 2009; 1547-1551
[3] Asadi, Houshyar. et al. Fuzzy-control-based five-step Li-ion battery charger by using AC impedance technique." In Fourth International Conference on Machine Vision (ICMV 11), pp. 834939-834939. International Society for Optics and Photonics. 2012.
[4] Hsieh, Ching-Hsing. Research on the Five Step Charging Technique for Li-ion Batteries Using Taguchi Method and Fuzzy Control. PhD diss., 2011.
[5] Manoj, Niranj Kumar, Vijay Pal Singh. Fuzzy Logic Based Battery Charger for Inverter." International Journal of Engineering. 2013; 2(7).
[6] Cgr 18650-cg. Datasheet lithium-ion rechargeable cell. Panasonic corporation energy company. Februari. 2010. Available:www.industrial.panasonic.com/wwwdata/pdf2/aca4000/aca4000ce234.pdf&sa=uei=gq9vuv6hbszkgf2 yhobq&ved =0cbmqfjad&usg=afqjcnemwazpsmqr9zuhrkvgyhga2367jda.
[7] Passarella, Rossi, et al. PerancanganSistemPenjadwalanBateraiBerbasisLogika Fuzzy MenggunakanMikrokontroler ATMega16. KonferensiNasionalInformatika (KNIF). 2013: 54-58.

APPENDIX
Experiment #1

| Time (s) | Battery Time (°C) | Volt (V) | Current (A) |
|----------|------------------|----------|-------------|
| 1        | 25.1             | 2.7      | 2           |
| 238      | 25.5             | 2.8      | 1.9         |
| 469      | 26.9             | 2.9      | 2           |
| 707      | 27.3             | 3        | 1.9         |
| 991      | 29.2             | 3.1      | 2           |
| 1135     | 30.8             | 3.2      | 1.8         |
| 1496     | 29.3             | 3.3      | 2           |
| 1855     | 28.5             | 3.4      | 1.7         |
| 2332     | 29.4             | 3.5      | 1.8         |
| 2706     | 28.9             | 3.6      | 1.6         |
| 3132     | 27.8             | 3.7      | 1.4         |
| 3557     | 26.9             | 3.8      | 1.5         |
| 3982     | 27.2             | 3.9      | 1.7         |
| 4421     | 27.8             | 4.0      | 1.7         |
| 5592     | 27               | 4.1      | 1.6         |
| 6737     | 27.6             | 4.2      | 1.5         |
| 6756     | 27.6             | 4.2      | 0.0         |
| Mean     | 27.75            | 4.2      | 1.65        |
### Experiment #2

| Time (s) | Battery |          |          |          |
|---------|---------|----------|----------|----------|
|         | Temp (°C) | Volt (V) | Current (A) |
| 1       | 26       | 2.7      | 2        |
| 240     | 26.1     | 2.8      | 2        |
| 500     | 26.3     | 2.9      | 2        |
| 610     | 26.5     | 3.0      | 2        |
| 870     | 27.1     | 3.1      | 1.9      |
| 1019    | 27.2     | 3.2      | 1.9      |
| 1393    | 27.3     | 3.3      | 2        |
| 1802    | 27.5     | 3.4      | 1.7      |
| 2350    | 27.4     | 3.5      | 1.8      |
| 2830    | 26.9     | 3.6      | 1.7      |
| 3201    | 26.8     | 3.7      | 1.7      |
| 3605    | 26.9     | 3.8      | 1.5      |
| 4002    | 27.2     | 3.9      | 1.7      |
| 4690    | 26.6     | 4.0      | 1.7      |
| 6001    | 26.1     | 4.1      | 1.6      |
| 7201    | 26.6     | 4.2      | 1.5      |
| 7220    | 26.6     | 4.2      | 0.0      |
| Mean    | 26.77    | 1.68     |

### Experiment #3

| Time (s) | Battery |          |          |          |
|---------|---------|----------|----------|----------|
|         | Temp (°C) | Volt (V) | Current (A) |
| 1       | 25.1     | 2.7      | 2        |
| 294     | 25.2     | 2.8      | 1.9      |
| 500     | 25.4     | 2.9      | 2        |
| 699     | 25.3     | 3.0      | 2        |
| 890     | 25.6     | 3.1      | 2        |
| 1121    | 26.1     | 3.2      | 1.8      |
| 1444    | 25.9     | 3.3      | 2        |
| 1801    | 26.1     | 3.4      | 1.7      |
| 2305    | 26.2     | 3.5      | 1.8      |
| 2599    | 26.3     | 3.6      | 1.6      |
| 3200    | 26       | 3.7      | 1.4      |
| 3501    | 26.3     | 3.8      | 1.4      |
| 4013    | 26.9     | 3.9      | 1.5      |
| 5404    | 27.4     | 4.0      | 1.5      |
| 6120    | 27.3     | 4.1      | 1.6      |
| 7580    | 27.3     | 4.2      | 1.5      |
| Mean    | 26.15    | 1.73     |          |

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BIBLIOGRAPHY OF AUTHORS

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