Design Of Battery Charger With Cc-Cv Method For Series Connected Lithium-Ion Batteries Using Fuzzy Logic Controller

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***Abstract*— Given the vast number of human needs that require electricity, solar energy is considered very suitable to help meet the energy needs consumed by humans. All the energy generated by solar panels can be stored using batteries, which can then be converted into electricity. The battery will work when the energy stored in it is full, but if it is used on a sustainable basis, it will cause the energy to run out, so the energy must be recharged immediately so that it can still be used again. Unfortunately, the charging power used to charge the current battery still takes quite a while to recharge. Through the description of the problem, this study is about a fast charging device using a buck converter using the Constant Current-Constant Voltage (CC-CV) method on a lithium-ion battery. Buck conversion is necessary because the source used in this research is a solar panel that produces a very high voltage, so the voltage has to be lowered using buck converters. Using 11.1V/2.2Ah lithium-ion batteries. To keep the current and voltage constant, the charging process is carried out by filling this current, and the output voltage will be stable by the fuzzy logic controller (FLC). From the results of the simulations that have been done, it seems that FLC has been able to stabilize the 2.2Ah and 11,1V charging currents.**

Keywords*— *CC-CV, fast charging, fuzzy logic controller (flc)

I. INTRODUCTION

Indonesia is a country with a tropical climate, solar energy is an unlimited source of energy. However, in its use, there are many things to consider, including: weather, temperature, humidity, and the position of the solar cell relative to the sun. So far, most of the energy needs for human consumption use fossil fuels which are non-renewable energy. In the next few years, this fossil-derived fuel may still be used because the supply of alternative energy sources cannot be used to meet human needs [1]. Therefore, utilizing solar energy is considered very appropriate to help meet the energy needs for human consumption. All energy produced by solar panels can be stored using batteries which can then be converted into electrical energy by connecting the two poles to electrical equipment.

For now, an example of one of the things that shows that humans consume energy is in the use of batteries. The battery will work when the energy stored in the battery is fulfilled, but if the battery is used continuously, the energy in the battery will run out and cannot be operated [2]. Continuous use

causes the energy in the battery to run out, so it must be recharged immediately so that it can still be used again. The current charging process unfortunately still takes a long time. Therefore, for now, fast charging technologies for lithium batteries have presented novel and stringent requirements for the electrodes, electrolytes, and external equipment [3].

Through the elaboration of these problems, a study was made entitled design battery charger with CC-CV method for series connected lithium-ion batteries using fuzzy logic controller**.** The purpose of this research is to design a system battery charger by fast charging method sourced from solar panels. Solar panels produce a very high voltage, so if used in the battery charging process, the voltage needs to be lowered using a buck converter. Using a 11.1V / 2.2 Ah lithium-ion battery. For designing the battery charging fast charging method rated lithium-ion battery is used charging of 2.2A.

One of the most widely used battery charging methods is CC-CV [4]. The most commonly used charging protocol is a constant-current (CC) process, often combined with a constant voltage (CV) trickle charge, to recharge a battery [5]. Due to its simplicity and ease of implementation, this approach is often used to charge li-ion batteries [6]. CC and CV are the two operating modes available. In CC mode, a constant current is constantly applied to the battery until the terminal voltage is reached voltage set maximum cut-off. The cut-off voltage on the battery is maintained in CV mode, and the current will continue to decrease [7].

Another disadvantage of this method is that it causes the battery temperature to rise high. In addition, this method is not suitable for fast charging as it takes longer to fully charge the battery and reduces battery life [8]. To keep the current and voltage constant, the charging process is carried out charging this current and output voltage will be stabilized by the FLC [9]. FLC is a method used to regulate and stabilize output from a buck *converter* in order to match the set *point*

How to cite: Sutedjo., Rakhmawati, R., Putih, B.P.P., Adila, A.F., Irianto., Yanaratri, D.S. (2025). Design Of Battery Charger With Cc-Cv Method For Series Connected Lithium-Ion Batteries Using Fuzzy Logic Controller. *JAREE (Journal on Advanced Research in Electrical Engineering), 9(1).*

of voltage and current CC-CV. This paper proposes a fast charging method charging system with constant current charging controlled using FLC [10][11]. Likewise the constant current method will also be controlled using FLC. Charging using the constant current method causes a faster charging time and keeps the charging temperature below the limit.

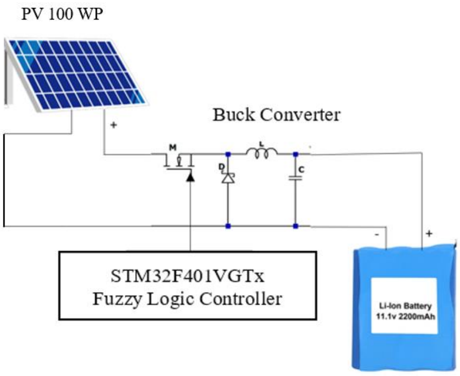

Fig. 1. System overview

II. Methods

The aim of this research project is to develop a device to charge a lithium-ion battery with a capacity of 11.1V or 2.2 Ah. The battery will then use a 100 WP solar panel as a source of charge. This time, the research was done through simulation using MATLAB software and experimental setup.

Then for the converter used this time, which uses the buck converter, the output voltage value of buck's converter this time is obtained from the battery's charging voltage, so the buck converter's output this time was 12.6 V with a 2.2 A charging current. The charging current value is quite high because the charging process this time uses a fast charging system using the CC-CV method, where the current value is derived from 100% battery capacity [12].

The CC-CV method works during the fast charging process, which at the start of the charging uses the maximum charging current constantly (as required) in the initial charging phase when the voltage tries to reach its maximum point. After reaching SOC 85%, the charging method will change to the CV method, and the current will slowly decrease.

And the research programming this time will use the FLC method. FLC is the method used to adjust and stabilize the buck converter output to match the specified voltage point and the CC-CV time [13]. The FLC will work by observing the data generated by the bucks converter, which will then match the task cycle. And if there are differences, the system will automatically change the job cycle values to suit the set point.

A. *Fuzzy Logic Controller (FLC)*

Fuzzy logic control is a control method which follow linguistic approach, if-then rules. This control system has its own set, namely a fuzzy set that has a certain degree of membership [14]. In FLC there are three main processes which can be seen in the picture below:

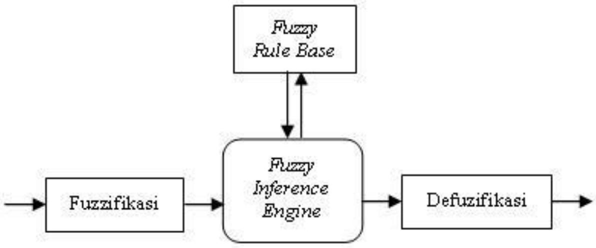

Fig. 5. Fuzzy logic controller block diagram

From the block diagram above, there are stages to determine the fuzzy control output, namely:

1. Fuzzification
   Fuzzification is a process carried out to convert real variables into fuzzy variables, this is intended so that fuzzy controller input can be mapped to the type corresponding to the fuzzy set.
2. Rule Base
   The basic rule of selection in decision making, the basic rule of fuzzy uses an IF-THEN rule-based system, where IF is the cause, and THEN is the effect.
3. Inference Process
   Fuzzy inference is a process of formulating input to output mapping using fuzzy logic.
4. Defuzzification
   Defuzzification is a process used to convert fuzzy variables back into real variables.

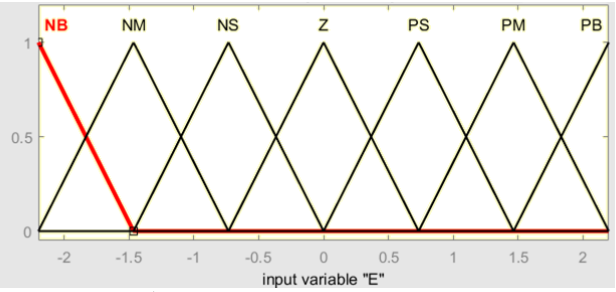

Fig. 5. Membership function input design (error)

In Figure 6 and Figure 7, fuzzy controls use two inputs namely error (set point-present value) and delta error (current error – previous error).

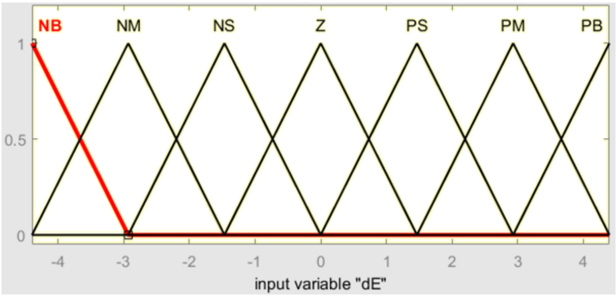

Fig. 6. Membership function input design (delta error)

An overview of the design battery charger with CC-CV method for series connected lithium-ion batteries using fuzzy logic controller is shown in Figure 7 below:

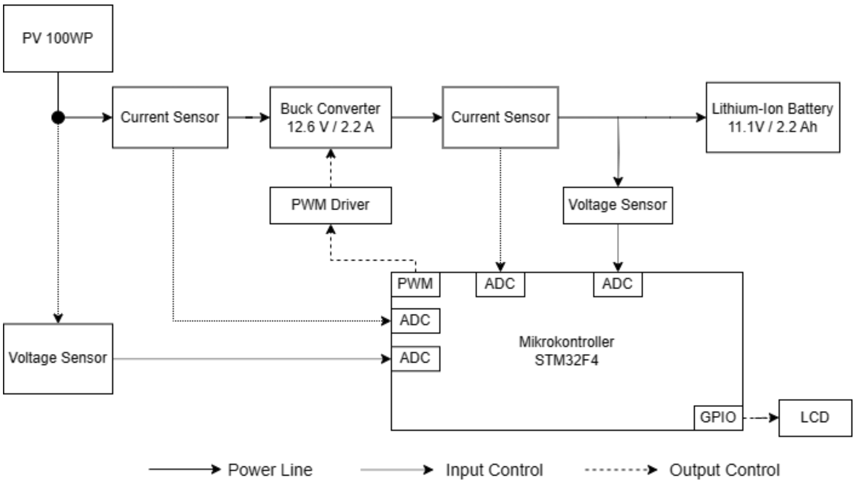

Fig. 7. Block diagram of battery charger system

The if-then statement is frequently employed in fuzzy logic to delineate the actions taken in response to various fuzzy inputs. These rules are typically articulated within the framework of a linguistic table of membership functions, reflecting the overall behavior of the system. For instance, in a control system with an output work cycle, there might be two primary inputs: errors and delta errors, and two outputs. The fuzzy rules governing this system can be systematically organized into a matrix format, as illustrated in Table II. By considering seven membership functions for each input (errors and delta errors), we can construct a comprehensive set of 49 rules. These rules effectively determine the output response values, enabling the system to respond to a single tone value derived from the combination of error inputs. [15]. Table I is the base rule table used for FLC in this study:

TABLE I. RULE BASE

DE **E**	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PS	PB	PB	PB	PB

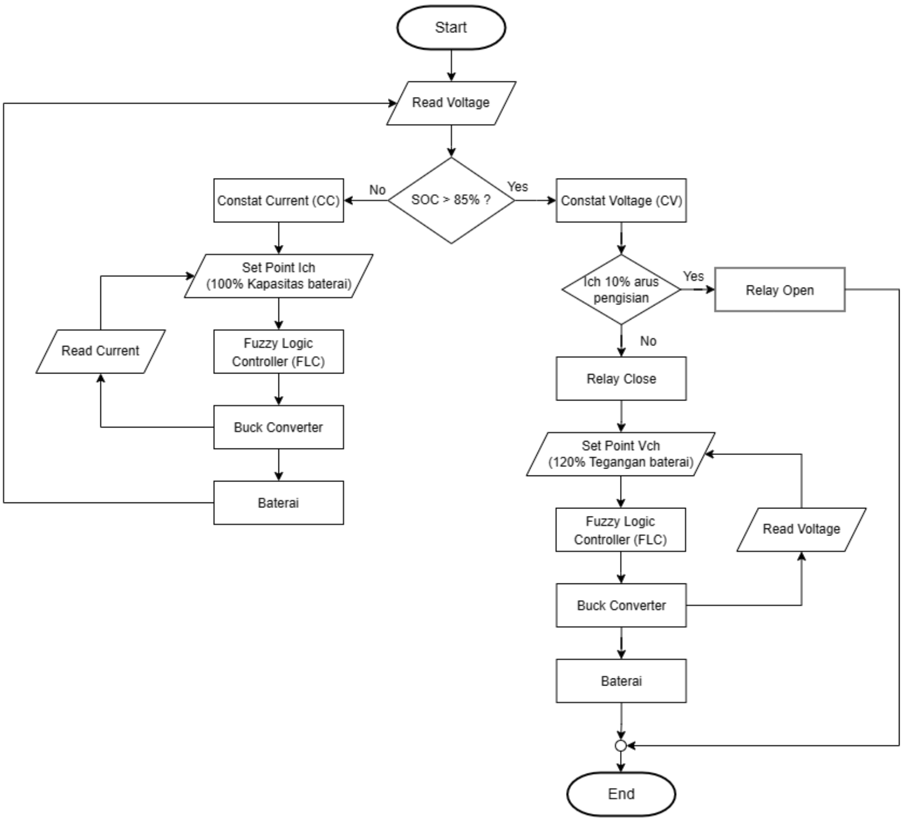

Fig. 8. Flowchart of battery charger using FLC

In this paper, FLC used as current and voltage control output from buck converter for process charging. Flowchart of control flow starts with reading the voltage value input, charging voltage and charging current in the battery [16][17]. Then from the buck *converter* when the battery charging voltage has not reached 12.6V, the output current buck *converter* or the battery charging current will be read and processed on FLC, on FLC has a fuzzification process, drafting rule base, inference, and defuzzification. Then the output current from FLC will set the value duty *cycle* via PWM *driver* which is switched to mosfet buck *converter* to issue a constant battery charging current of 2.2 A. The process will run again by reading the battery charging voltage value. When the voltage charging battery reaches 12.6 V, then FLC will instruct so that the charging method changes to state constant *voltage*. The battery will be charged with a constant voltage of 12.6V until the battery is fully charged. In Figure a above is a flowchart of flow planning FLC on the system fast *charging battery* lithium-ion 2.2 mAh/11.1 V. On table II, here are the buck converter parameters needed:

TABLE II. DESIGN SPECIFICATION OF BUCK CONVERTER

Parameter	**Value**	**Unit**
Voltage Input (V_{in})	35.2	V
Voltage Output (V_o)	12.6	V
Current Output (I_o)	2.2	A
Capacitor Voltage Ripple (ΔV_o)	1	%
Current Ripple (ΔI_o)	20	%
Switching Frequency (f_s)	40	kHz
Inductor	486.08	µH
Capacitor	109.127	*µF*

III. RESULT AND DISCUSSION

A. *Buck Converter Simulation*

After calculations are carried out on the buck converter planning, then a buck converter simulation is carried out based on the calculation of the components that have been done. And from the simulation, a simulation data table is obtained as follows:

TABLE III. BUCK CONVERTER SIMULATION DATA

Duty Cycle	**Vin (V)**	**In (A)**	**Vout (V)**	**Iout (A)**	**Pin (W)**	**Pout (W)**	**Effisiency (%)**
35.70%	10	0.225	3.58	0.625	2.25	2.23	99.32
	20	0.452	7.15	1.250	9.04	8.94	98.87
	30	0.678	10.73	1.875	20.34	20.12	98.91
	35.2	0.792	12.58	2.200	27.88	27.68	99.27
	40	0.898	14.30	2.500	35.92	35.75	99.53

Table III presents the results obtained from the Buck Converter simulation, in which the input voltage (Vin) varies. This table provides detailed data on how different levels of input voltages affect the performance and efficiency of the buck converter.

TABLE IV. BUCK CONVERTER SIMULATION DATA

Vin (V)	**Duty Cycle**	**In (A)**	**Vout (V)**	**Iout (A)**	**Pin (W)**	**Pout (W)**	**Effisiency (%)**
35.2	10%	0.0730	3.797	0.664	2.570	2.520	98.087
	20%	0.2654	7.291	1.275	9.342	9.296	99.507
	30%	0.582	10.700	1.883	20.486	20.148	98.349
	35.7%	0.7899	12.58	2.200	27.804	27.676	99.538
	40%	1.013	14.250	2.492	35.658	35.511	99.589

On the other hand, Table IV contains the results of a series of other simulations, but this time it focuses on the variation of the duty cycle. The table describes the effect of the change in the duty cycle and gives the result, even though the different duty cules that are entered affect the performances and efficiencies of Buck converters. However, from both the above simulation results, it is apparent that Buck conversors have fairly stable efficiency values. With the efficiency calculation formula as follows:

$$\text{Efficiency } \textit{converter} = \frac{V_{out} \times I_{out}}{V_{in} \times I_{in}} \times 100\%$$

With the output wave shown in the following figure:

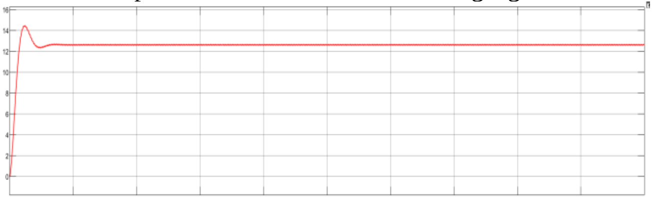

Fig. 9. Buck converter output current

The wave image above is the output voltage waveform from the buck converter simulation circuit. From the resulting wave it can be seen that it has shown good results, with there being an initial overshoot caused by the switching effect used on the converter.

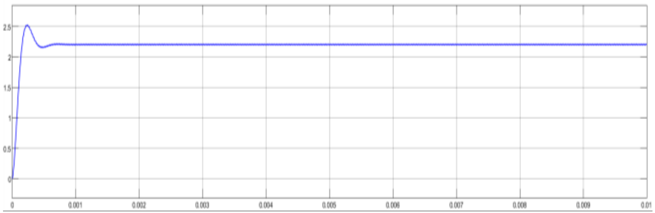

Fig. 10. Buck converter output voltage

The wave image above is the output current waveform from the buck converter simulation circuit. Just like the voltage waveform, the current waveform also shows good results, with an initial overshoot caused by the switching effect used in the converter.

B. *Close Loop Simulation*

In the research planning this time, a close loop simulation was also carried out. This simulation includes a circuit using a 100 WP PV source as the primary power source and a 2.2 mAh / 11.1 V battery that will perform to fast charging.

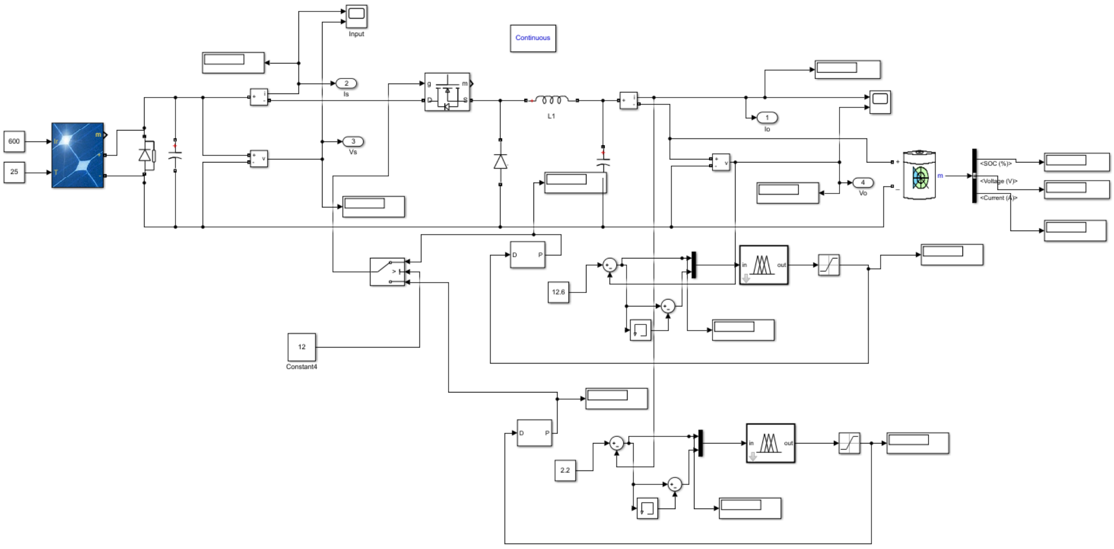

Fig. 11. Close loop simulation circuit

The picture above is a series of close loops of the system, using a solar panel source that has been set according to the calculation, which is equal to 100WP. From this 100WP solar panel it will produce a voltage of 35.2 V and this value will be lowered using a buck converter. Then for the load on this circuit directly use a battery that has been adjusted to the specifications of the battery used, namely lithium-ion 2.2 Ah / 11.1 V. This time the fast charging method is used, so for the first process, which uses a stable current value of 2.2 A with a voltage value that continues to rise until it reaches a charging voltage value of 12.6V, charging method move to the CV mode. To stabilize the value of the voltage and charging current this time FLC is used [13]. .LC is a method used to regulate and stabilize output from buck *converter* in order to match set *point* of voltage and current CC-CV, and it can be seen in the circuit that 2 FLC circuits are used for the control of the constant current method and for the control of the constant voltage method. The working principle is on the process fast *charging battery* using constant maximum charging current (*constant current*) in the initial phase of charging and the charging method will switch to CV mode (*constant voltage*) when the battery SOC reaches 85% value. And when the charging method switches to CV mode (*constant voltage*) the current will slowly decrease.

a) Constant Current Graph (CC)

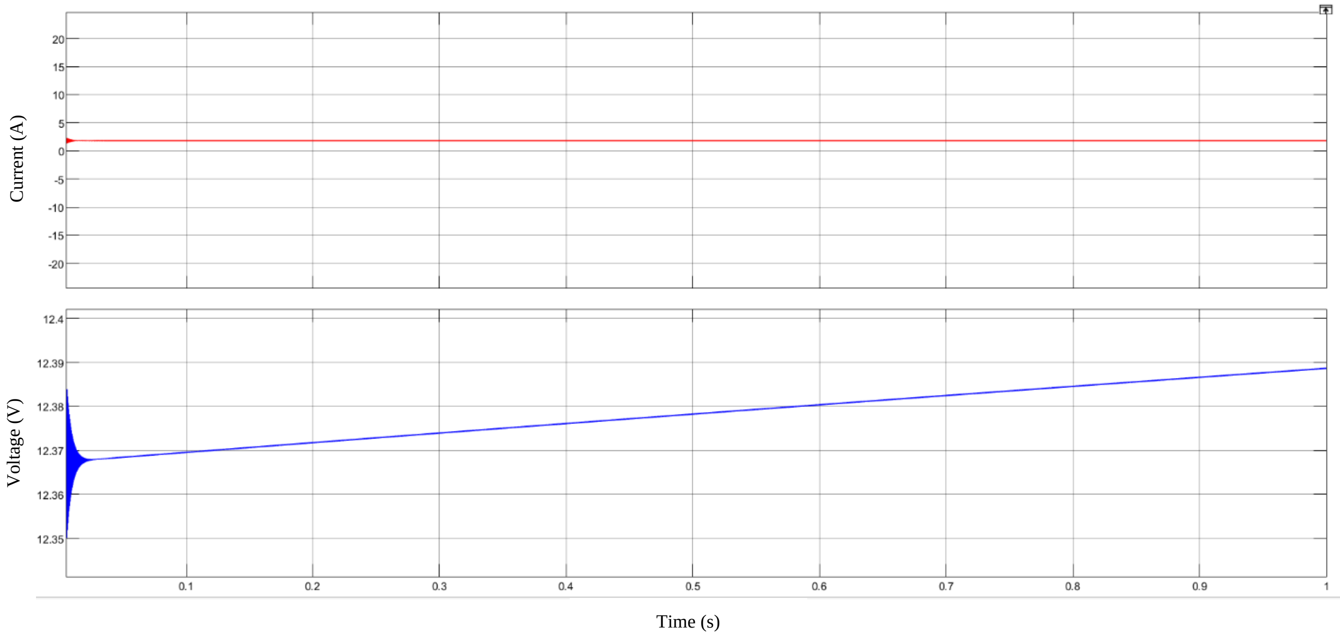

Fig. 12. Constant current mode

The picture above is an image of the current and voltage waves from the closed loop simulation of the system in this study. It can be seen from the wave above that shows the process of the first battery charging method, namely constant current. From the resulting wave it can be seen that it has shown results that are in accordance with the theory, namely when the value of the charging current is constant, the value of the charging voltage will continue to show an increasing value.

b) Constant Voltage Graph (CV)

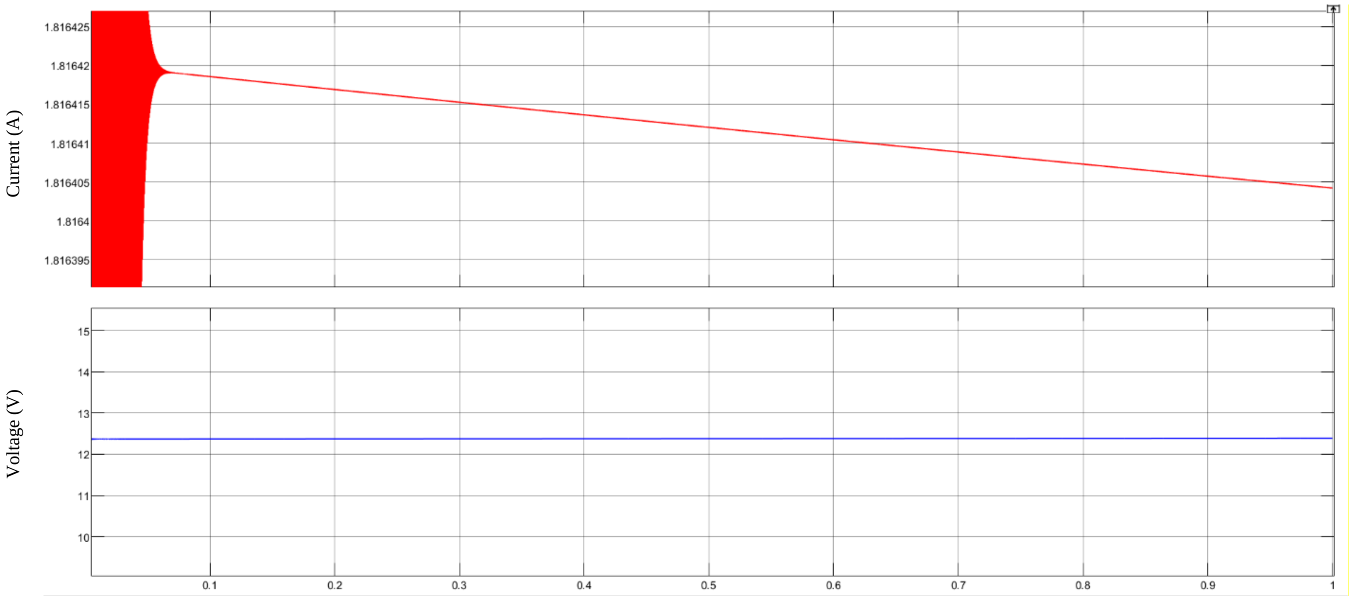

Fig. 13. Constant voltage mode

Same as in the previous picture, on the picture above is also an image of the current and voltage waves from the closed loop simulation of the system in this study. And the wave above shows the process of the second battery charging method, namely constant voltage. And from the resulting wave it can be seen that it has shown results that are in accordance with the theory, namely when the charging voltage value is constant, the charging current value will continue to show a decreasing value.

c) Constant Current (CC) - Constant Voltage (CV) Graph

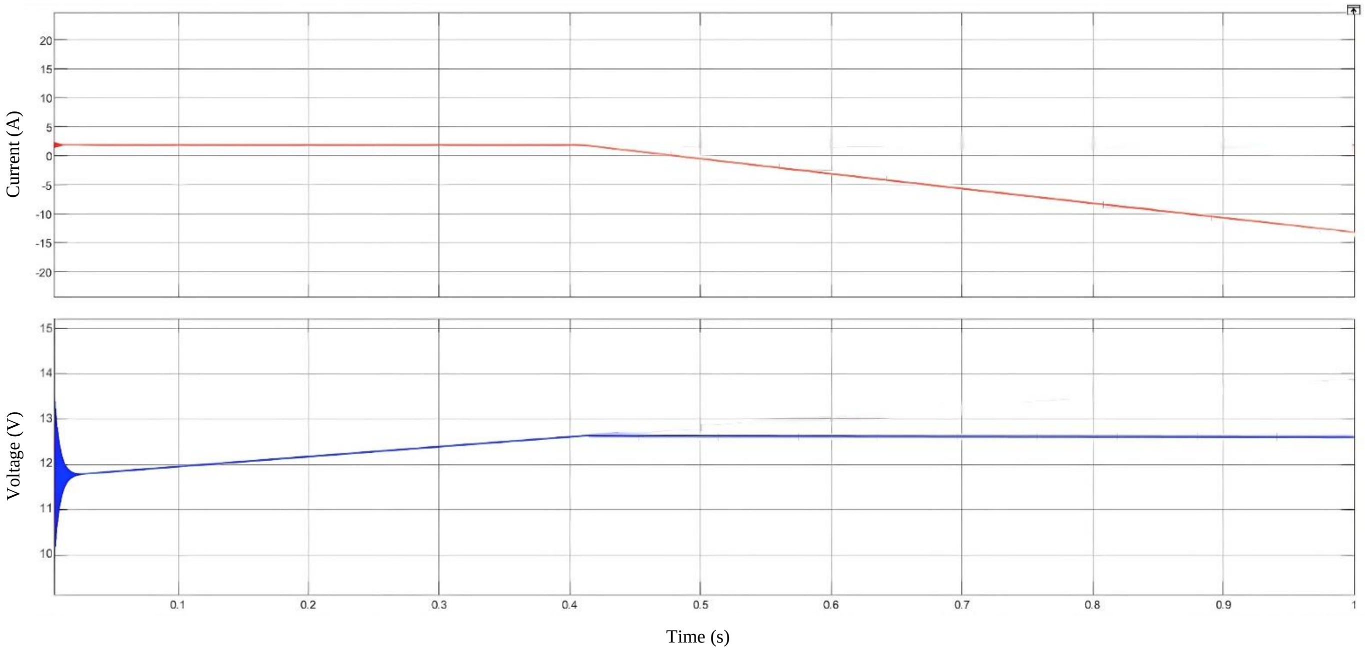

Fig. 14. Close loop simulation circuit

The above image shows the output wave shape of the system used in this study using the CC-CV charging method. The CC-CV charging method is used to maximize charging power in a short time and prevent overload of the battery. The working principle is that in the process of fast charging, the batteries use a constant maximum charging current at the initial stage of charging with continuously increasing voltage values, as shown in the picture. The voltage value continues to increase until it reaches the charging voltage value, and the charge method will switch to the CV (constant voltage) method.

Then you can see in the chart above that it takes less than 0.1 seconds in a simulation to reach the set point position. If compared with other studies using ANFIS control, it was found that ANFIS controls observed faster responses for 3 milliseconds. However, when compared to the output, FLC controls produced more stable outputs compared to the ANFIS control [9]. This was influenced by the FLC controllers that were designed for FLC rule bases. In addition to simulating using MATLAB software, this study also carried out hardware data capture. Using a 100 WP solar panel source, where 100WP solar panels will generate 35.2 V voltage and this value will be lowered using buck converters. And table V is the data obtained during hardware charging.

TABLE V. HARDWARE DATA

Time (Minute)	**Iin (A)**	**Vin (V)**	**Iout (A)**	**Vout (V)**	**Efficiency (%)**
11.10	0.45	36.4	1.11	11.89	80.57
11.20	0.45	36.4	1.11	12.13	82.20
11.30	0.44	36.3	1.11	12.34	85.76
11.40	0.44	36.3	1.12	12.46	87.37
11.50	0.39	36.3	0.96	12.59	85.37
12.00	0.34	36.2	0.81	12.59	82.86
12.10	0.29	36.2	0.73	12.61	87.69
12.20	0.28	36.6	0.68	12.62	83.74
12.30	0.26	36.4	0.63	12.6	83.88
12.40	0.24	36.8	0.6	12.6	85.60
12.50	0.17	37.1	0.43	12.62	86.04
13.00	0.13	37.2	0.33	12.62	86.12
13.10	0.1	37.2	0.25	12.61	84.74

From the data table V, it can be seen the result of battery charging from the hardware test. The CC method process lasted 40 minutes, with the CC method set point of 1.1 A. In this condition the charge voltage continued to rise until it reached the setpoint of 12.6 V, then the charging mode changed into the CV method. In this experiment, the average efficiency reached of 84,07%. Figure 15 shows the shifting mode from CC to CV mode.

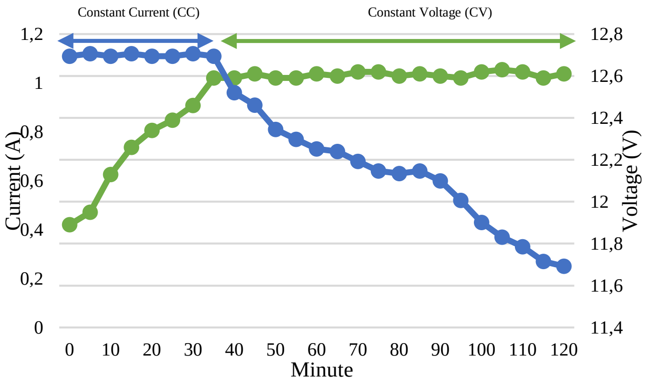

Fig. 15. Hardware data test for CC-CV method

IV. CONCLUSIONS

The conclusion that can be drawn in the design of this simulation is that at the beginning of the charge using the constant current (CC) method with a set point value of 2.2 A and under these conditions the voltage value will continue to increase until the charging voltage level reaches 12.6 V in accordance with the given set point. After reaching the set point voltage of 12,6 V, the charge method will switch from constant current (CC) to constant voltage (CV). And under the condition of constant voltage charging (CV), the current value continues to decrease until the battery is fully charged.

Using FLC produces a fairly stable output when compared to ANFIS controls. And using FLC results in a response that can be said to be fairly fast for 0.1 seconds, but if this response is compared with ANFIS controls then it can be called FLC response is slower, because using ANFIS controls produces response for 3 milliseconds.

V. REFERENCES

[1] Hein, T., Oeser, D., Ziegler, A., Montesinos-Miracle, D., & Ackva, A. (2023). Aging determination of series-connected lithium-ion cells independent of module design. Batteries, 9(3), 172.

[2] Suryoatmojo, H., Hidayah, E. R., Adila, A. F., Fahmi, D., Riawan, D. C., Pamuji, F. A., & Mardiyanto, R. (2023). Design Isolated Half-Bridge Converter for Electric Vehicle Battery Charger Using CCCV Method. ICIC Express Letters, 17(10), 1169-1176.

[3] R. Rakhmawati, Z. Rana Khalisa Permana, R. Prilian Eviningsih, and P. Elektronika Negeri Surabaya, “Fast Charging on Li-ion Batteries with ANFIS Control,” *Renny Rakhmawati: Fast Charging on Li-ion …*, vol. 12, 2023.

[4] A. B. Khan and W. Choi, “Optimal Charge Pattern for the High-Performance Multistage Constant Current Charge Method for the Li-Ion Batteries,” *IEEE Transactions on Energy Conversion*, vol. 33, no. 3, pp. 1132–1140, Sep. 2018, doi: 10.1109/TEC.2018.2801381.

[5] K. K. Duru, C. Karra, P. Venkatachalam, S. A. Betha, A. Anish Madhavan, and S. Kalluri, “Critical Insights into Fast Charging Techniques for Lithium-Ion Batteries in Electric Vehicles,” *IEEE Transactions on Device and Materials Reliability*, vol. 21, no. 1, pp. 137–152, Mar. 2021, doi: 10.1109/TDMR.2021.3051840.

[6] Z. Guo, B. Y. Liaw, X. Qiu, L. Gao, and C. Zhang, “Optimal charging method for lithium ion batteries using a universal voltage protocol accommodating aging,” *J Power Sources*, vol. 274, pp. 957–964, Jan. 2015, doi: 10.1016/j.jpowsour.2014.10.185.

[7] F. Faanzir, “Determining the shortest charging time of batteries using SOC set point at constant current – constant voltage mode,” *PRZEGLĄD ELEKTROTECHNICZNY*, vol. 1, no. 4, pp. 56–61, Mar. 2021, doi: 10.15199/48.2021.04.09.

[8] B. G. Kim, F. P. Tredeau, Z. M. Salameh. “Fast Chargeability Lithium Polymer Batteries.” University of Massachusetts Lowell. 2018.

[9] W. Xie *et al.*, “Challenges and opportunities toward fast-charging of lithium-ion batteries,” Dec. 01, 2020, *Elsevier Ltd*. doi: 10.1016/j.est.2020.101837.

[10] M. Nizam, H. Maghfiroh, A. Ubaidilah, Inayati, and F. Adriyanto, “Constant current-fuzzy logic algorithm for lithium-ion battery charging,” *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 2, pp. 926–937, Jun. 2022, doi: 10.11591/ijpeds.v13.i2.pp926-937.

[11] G. L. Zhu *et al.*, “Fast Charging Lithium Batteries: Recent Progress and Future Prospects,” Apr. 12, 2019, *Wiley-VCH Verlag*. doi: 10.1002/smll.201805389.

[12] Wijaya, Trendy Prima, et al. "Effective selection switching of battery state of charge equalization based on fuzzy logic algorithm." AIP Conference Proceedings. Vol. 2580. No. 1. AIP Publishing, 2023.

[13] Asrol, M., Djuana, E., Harito, C., Budiman, A. S., & Gunawan, F. E. (2023, April). Developing an Inference Engine for Estimating State of Charge of the Lead Acid Battery. In IOP Conference Series: Earth and Environmental Science (Vol. 1169, No. 1, p. 012001). IOP Publishing.

[14] Rachmad, R. A. I., Lomi, A., & Krismanto, A. U. (2024). RANCANG BANGUN DC/DC CUK CONVERTER BERBASIS FUZZY LOGIC CONTROL UNTUK KENDALI BATERAI PADA PLTS SKALA KECIL. Magnetika: Jurnal Mahasiswa Teknik Elektro, 8(1), 291-301.

[15] Syah, A. F., Mukromin, R. I., Asy’ari, M. K., Musyafa, A., & Noriyati, R. D. (2023, May). Implementation of multi-input buck converter voltage control system based fuzzy logic control. In AIP Conference Proceedings (Vol. 2580, No. 1). AIP Publishing.

[16] Tantowi, Z. N. (2022). Desain Dan Simulasi Cuk Converter Dengan Pi-Fuzzy Controller Untuk Pengisian Baterai. JTT (Jurnal Teknologi Terpadu), 10(1), 53-60.

[17] Yuniar, R. J., Ashari, C., & Nugraha, D. A. C. (2022). Pengendalian Tegangan Output Pada Buck-Boost Converter Dengan Metode Fuzzy Logic. Syntax Literate; Jurnal Ilmiah Indonesia, 7(12), 19837-19847.