Journal of Electrical Technology UMY (JET-UMY), Vol. 7, No. 1, June 2023
ISSN 2550-1186 e-ISSN 2580-6823

Design of Battery Charging System with CC-CV Method Using Interleaved Buck-Boost Converter

I Gusti Agung Ayu Devi Anjani*, Moh Zaenal Efendi, Ony Asrarul Qudsi

Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, East Java, Indonesia

*Corresponding author e-mail: gekdevi99@gmail.com

Abstract – *The transition of renewable energy has become an interesting issue and a worldwide concern that is frequently discussed. Solar panels are regarded to have the most potential in tropical areas like Indonesia. However, weather and sunlight intensity have a substantial impact on the amounts of electricity generated by solar panels. Therefore, a battery which functions as a backup supply is required. Lead acid batteries are used in numerous applications. The performance of lead-acid battery is commonly influenced by temperature and charging time, which makes it vulnerable to overcharging. Multistage charge methods, namely Constant Current-Constant Voltage (CC-CV), are used to extend battery life, reduce charging time, and avoid the risk of overcharging. Fuzzy Logic Controller (FLC) is used to adjust charging current and voltage on the battery based on the setpoint. Based on the CC-CV charging system simulation results, a constant current value can be obtained when the CC condition is 4.5 A, and a transition to the CV condition occurs when the voltage value on the battery reaches 14.4 V. When the battery reaches its maximum capacity, the current is reduced to 3% of the battery's capacity. The rate of fully charged current triggers the relay to turn on, to ensure that the charging process has been completed.*

Keywords*: Battery Charging, Fuzzy Logic Controller, Interleaved Buck-Boost Converter, Solar Panel, Lead-Acid.*

I. Introduction

Electrical energy has become an essential necessity for society in applications across the industrial, office, business, and residential sectors. The involvement of electrical energy is becoming increasingly dominant, due to the rapid advancement in technology. Most of the electricity is still generated using fossil fuels, which are becoming unsustainable. Besides, fossil fuels have a detrimental effect on the environment, which can lead to global climate change [1].

The government regulates a target for the contribution of renewable energy to national primary energy implementations in PP No. 79 of 2014 concerning the national energy policy, which is set at a minimum of 23% in 2025 and 31% in 2050. [2]. This contribution supports the realization of the energy transition. Indonesia is well-known for its tropical climate and abundant potential of renewable energy source. According to data from the Ministry of Energy and Mineral Resources (2018), the potential for solar energy is 207.8 GWp, far exceeding the potential of other renewable energy sources. [3]. The power generated by solar panels is unpredictable because it is determined by solar radiation and weather conditions. As a result, we need a device that can properly store electrical energy so that it can be distributed to the load optimally and efficiently. [4].

Manuscript received November 2022, revised March 2023

Batteries require the proper charging method in order to maintain its lifetime and avoid overcharging, which can potentially damage the battery. To optimize charging process of battery, a monitoring system is required, as well as the suitable charging method. [5]. Referring to these problems, this research project studied the development of valve-regulated lead acid (VRLA) battery charging technology using the Constant Current-Constant Voltage (CC-CV) method. For this CC-CV method, the charging current is maintained constant at the beginning of the battery charging cycle. The battery charging will switch to Constant Voltage (CV) mode when the charging voltage reaches the specified voltage limit, where the charging current will steadily decrease until it reaches zero [7]-[8]. An interleaved buck-boost converter controls how the battery is charged, and a fuzzy logic controller keeps the converter output steady in regard to the set point. Batteries can be used as an emergency power source to supply simple residential lighting.

II. Research Method

II.1. *Main System Planning*

Lead-acid batteries are applied as electrical energy storage in this study along with solar panels as electrical energy generators. The DC-DC converter that is used is a interleaved buck-boost converter. See Fig. 1 for further information. The block diagram system illustrates the function of each connected component.

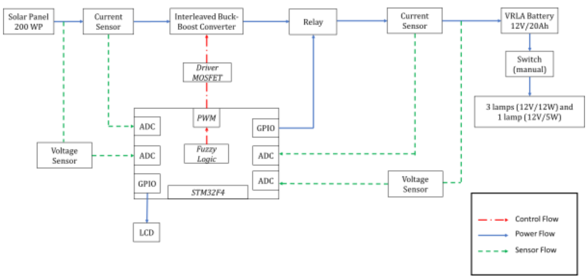

Fig. 1. Block Diagram System

As seen in Fig. 1, this charging system consists of two solar panels that are connected in parallel to obtain a 200 Wp total capacity. By adjusting the duty cycle value of the MOSFET driver, the output voltage and current from the solar panel can be increased or decreased through the interleaved buck-boost converter and obtained the appropriate set point value for charging batteries using the constant current-constant voltage method [5]. The relay will turn on to stop charging when the battery is full. In the situation that there is a disruption or blackout at the PLN source, a fully charged battery will operate as a backup supply for basic household lighting demands.

II.2. *Battery Design*

In this research, we used a VRLA battery as a backup source for loads, with a total power demand of 41 watts when a blackout occurs. This VRLA battery is very suitable for solar cell systems because it can discharge an electric current at a consistent rate for a considerable amount of time. The ideal current when charging a VRLA battery is 10% to 30% of the battery's capacity [7]. The charging voltage for VRLA batteries with a nominal voltage of 12V is limited to 14.4V. Deep-cycle batteries often have a discharge rate of up to 80% of their capacity. The life of a VRLA battery can be extended to ten years with proper capacity planning and maintenance [9]-[10]. Lead-acid batteries have the following qualities, which are mentioned in Table 1.

TABLE 1
CHARACTERISTIC OF LEAD ACID BATTERY

Characteristic	Value
Specific Energy (Wh/kg)	30-50
Internal Resistance (mΩ)	Very Low
Cycle Life (80% discharge)	200-300
Fast-Charge Time	8-16 hours
Overcharge tolerance	High
Self-Discharge per month	5%
Voltage cell	2V
Voltage cut-off charge (V/cell)	2.40V
Voltage cut-off discharge (V/cell, 1C)	Float 2.25V
Load Peak current best result	1.75V
Charging temperature	5C
Discharging temperature	0.2C
Maintenance	-20-50ºC
Safety	-20-50ºC
Used since	3-6 months

The battery has a capacity of 12V/20Ah. The VRLA battery used for this research has the following parameters, which are shown in Table 2.

TABLE 2
VRLA BATTERY12V/20AH

Lead-Acid Battery	Specification
Merk	SMT-Power
Capacity	20 Ah
Nominal Voltage	12V
Standby use charging voltage	13.6 – 13.8 V
Cycle use charging voltage	14.5 – 14.9 V
Maximal charging current limit	6 A
Dimension	180 x 78 x 170

The ideal charging current value is between 2A and 6A based on the characteristics and specifications of the battery, hence in this study the charging current setting for the battery is 4.5A (22.5% of battery capacity). Meanwhile for the charging voltage, paying attention to the cycle use conditions, so the battery is set with a charging voltage value of 14.4V.

II.3. *Solar Panel Design*

A solar panel is a device consisting of solar cells that convert light into electricity. The temperature and intensity of the sunlight entering the solar cell have an impact on the performance of photovoltaics with silicon material [11]. The ability of the solar panel device to produce voltage when given a load and current through the load at the same time is the source of the electrical power generated by the solar panel when it obtains solar radiation. The amount of current produced by a photovoltaic is directly proportional to the intensity of sunlight entering the solar cell [12]. This capability is represented in characteristics of the current-voltage (I-V) curve as shown in Fig. 2.

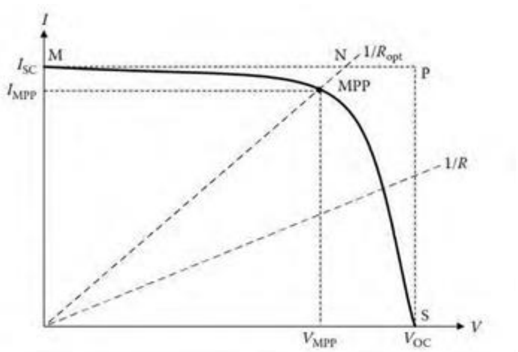

Fig. 2. Characteristics of the I-V Curve Solar Panel

Each solar cell produces such a little amount of output voltage and power, so it is necessary to assemble several solar cells into a solar cell module. Knowing the factors relating to the requirement for charging the 12V/20 Ah battery therefore it is crucial for planning the solar panel capacity. Considering the features of solar panels is essential for maintaining battery performance [13]. Due to varying irradiance and temperature factors, it will affect the output voltage and current of the solar panel. Testing the characteristics of solar panels with different levels of irradiation is important to ensure optimization during the battery charging process. The solar panels used in this research are represented in Table 3.

TABLE 3
SPECIFICATIONS OF SOLAR PANELS

Monocrystalline Solar Panel 100Wp	
Rated Maximum Power (Pmp)	100 W
Maximum Power Voltage	17.8 V
Maximum Power Current	5.62 A
Open Circuit Voltage	21.8 V
Short Circuit Current	6.05 A
Power Tolerance	±3%
Maximum System Voltage	1000 V
Operating Temperature	-4ºC to +85ºC
Dimensions	1000 x 670 x 30 mm
Standard Test Conditions	Irradiance: 1000 W/m^2

The current of the solar panels is observed to be directly proportional to the sun irradiation based on analysis of studying the characteristics of the solar panels. The output current of the solar panel will decrease as the irradiance drops. To optimize the need for battery charging current, 2 solar panels of 100 Wp are used, which are arranged in parallel.

II.4. *Interleaved Buck-Boost Converter Design*

The interleaved buck-boost converter is the development of one type of DC-DC converter circuit. The input voltage can be increased or decreased in this type of circuit depending on the PWM duty cycle that is triggered in the switch component, similar to a buck-boost converter. The switch components are set up in parallel, so the input current may be divided in half, making the circuit more dependable and durable. The switching signal for the interleaved buck-boost converter has the same switching frequency and duty cycle with a 180º phase shift between them [14]-[17]. The circuit of the interleaved buck-boost converter is shown in Fig. 3.

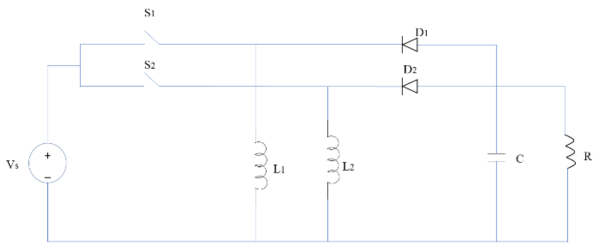

Fig. 3. Interleaved Buck-Boost Converter Circuit

There are two switching conditions for each switch, known as the open and closed switch conditions. When the switch is closed, the inductor current increases and stores energy while the capacitor supplies the load. When the switch is open, the inductor will allow current to flow to the load through diode. It should be noted that the conditions for diodes D_1 and D_2 are always opposite to the conditions of switches S_1 and S_2, respectively. The following describes the operating modes of the interleaved buck-boost converter: [15]

Mode1:

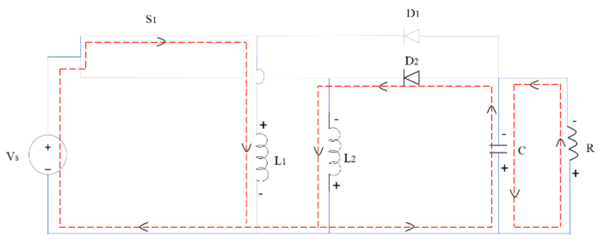

Fig. 4. Mode 1 operation of Interleaved Buck-Boost Converter, switch S_1 closed

In Fig. 4 shows when switch S_1 is in the closed (ON) position, current will flow from Vs to S_1, then L_1 will be charging (stored energy), while inductor L_2 will be discharging to supply the load through capacitor C and diode D_2. Then, the capacitor will be discharging and supplying the load [16].

Mode 2:

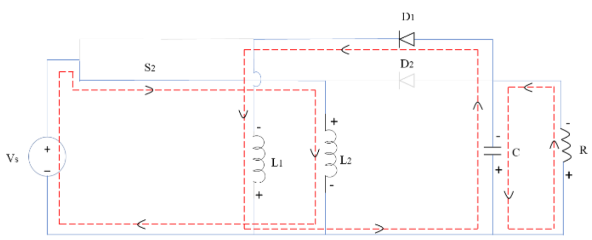

Fig. 5. Mode 2 operation of Interleaved Buck-Boost Converter, switch S_2 closed

In Fig. 5 shows when switch S_2 is closed (ON), current flows from Vs to S_2, L_2 charges to store energy, and inductor L_1 discharges to supply the load through capacitor C and diode D_1. The capacitor will discharge and provide the load after that [16].

Mode 3:

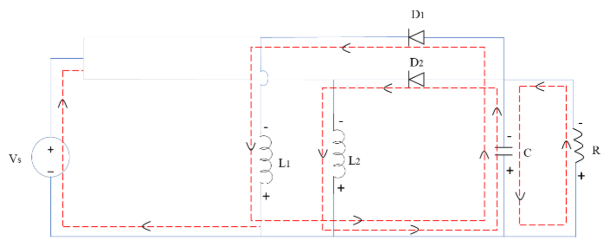

Fig. 6. Mode 3 operation of Interleaved Buck-Boost Converter, switch S_1 and S_2 open

In Fig. 6 shows when switches S_1 and S_2 are both in the open (OFF) position, both inductors L_1 and L_2 will release the stored energy (discharging), then allowing current to flow to the load through the diodes D_1 and D_2 [16].

Equation 1 is used to determine Vo.

$$V_o = -V_s \frac{D}{(1-D)} \quad (1)$$

The following equation is used to calculate the duty cycle:

$$D = \frac{|V_o|}{V_s + |V_o|} \quad (2)$$

To calculate the average inductor current can be obtained by the following equation:

$$I_{L(avg)} = \frac{V_s D}{(1-D)^2 R} \quad (3)$$

So that the value of the inductor where $L_1 = L_2 = L$ under non-ideal conditions can be calculated by the following equation [14]:

$$L = \frac{1}{f} \times (V_o + V_f) \times \left[\frac{V_{s(min)}}{V_{s(min)} + V_o + V_f} \right] \times \frac{1}{\Delta i_L} \quad (4)$$

Meanwhile, to calculate the output ripple voltage generated by the capacitor, it can be calculated by the following equation:

$$C = \frac{V_o \times D}{R \times \Delta V_o \times f} \quad (5)$$

The capacitor value is calculated as follows:

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf} \quad (6)$$

Where:

V_L : Inductor voltage (V)
Vs : Input voltage (V)
Vo : Output voltage (V)
L : Inductor's value (H)
T : Period (ms)
D : Duty Cycle
Δi_L : Inductor current variation
Δt : a shift in time
f : switching frequency (kHz)

The proper component values must be obtained in order to create the optimal interleaved buck-boost converter, so that optimal output can be produced on the system. The following parameters for designing the interleaved buck-boost converter are explained in Table 4.

TABLE 4
DESIGN OF INTERLEAVED BUCK-BOOST CONVERTER CALCULATIONS

Parameter	Value
Input Voltage (Vs)	10 V
Input Current (Is)	11.04 A
Output Voltage (Vo)	14.4 V
Output Current (Io)	4.5 A
Duty Cycle (D)	59%
Frequency Switching (F)	40 kHz
Resistor (R)	3.2 Ω
Inductor (L1, L2)	139.90 mH
Capacitor (C)	4609.38 µF

II.5. *Fuzzy Logic Controller*

Fuzzy logic is an uncertainty system that utilizes the input space mapping method to the output space, with a continuous value [18]. This method does not require accurate mathematical modeling to design the system to be controlled. There are three main steps in fuzzy logic, namely fuzzification, fuzzy inference system, and defuzzification.

This fuzzy logic method will produce an output in the form of a duty cycle, which is used to regulate PWM generation on the interleaved buck-boost converter so that the voltage and current for charging the battery are generated according to the set point value. There are two fuzzy input variables, namely error and delta [19]. Membership function for input error and delta error used in research is divided into 7 parts, each consisting of Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) [18]. The membership function of error and delta error have a triangular curve representation as shown in Fig. 7 and Fig. 8.

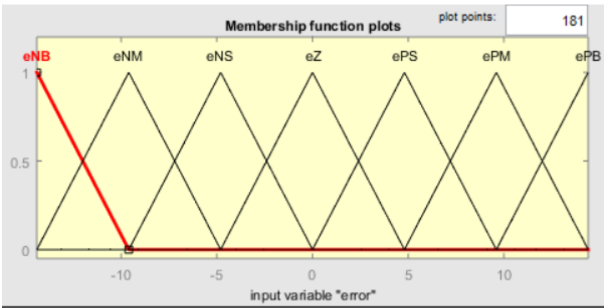

Fig. 7. Membership Function Input Fuzzy Variable Error

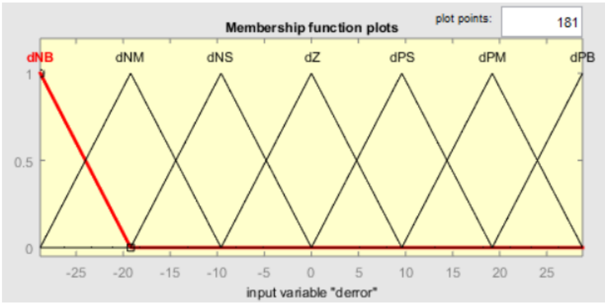

Fig. 8. Membership Function Input Fuzzy Variable Delta Error

The output membership function in Fig. 9 has the same mapping as the input, but uses a singleton function, which is a membership function that has a membership value of 1 for a single actual function and 0 for another actual function.

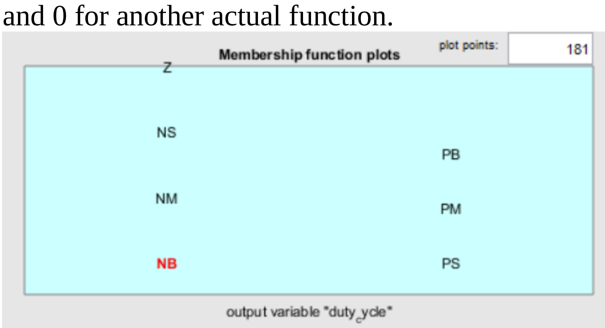

Fig. 9. Membership Function Output Fuzzy Variable Duty Cycle

At the fuzzy inference system stage, the fuzzy input results from the fuzzification process then will be interpreted by considering the specified rule base

[19]. This project uses the Sugeno type of inference. The following describes the planning of the rule base on the fuzzy logic controller in Table 5.

TABLE 5
RULE BASE OF FUZZY LOGIC CONTROLLER

dE/E	NB	NM	NS	ZO	PS	PM	PB
dNB	NB	NB	NB	NB	NM	NS	ZO
dNM	NB	NB	NB	NM	NS	ZO	PS
dNS	NB	NB	NM	NS	ZO	PS	PM
dZO	NB	NM	NS	ZO	PS	PM	PB
dPS	NM	NS	ZO	PS	PM	PB	PB
dPM	NS	ZO	PS	PM	PB	PB	PB
dPB	ZO	PS	PM	PB	PB	PB	PB

Weighted Average is the defuzzification method adopted. In Sugeno's fuzzy logic, the system is a constant, not a fuzzy set. This method was chosen since it's more effective computationally, performs well with linear techniques, as well as optimization and adaptive systems, and ensures continuity of results.

II.6. *Charging Constant Current-Constant Voltage Method*

The Constant Current-Constant Voltage method is to charge the battery with Constant Current first, then continuing with Constant Voltage until the battery voltage reaches its maximum voltage and decreasing according to the cut off current. Fig. 10 illustrates these stage conditions for lead-acid battery [7], [18]-[20].

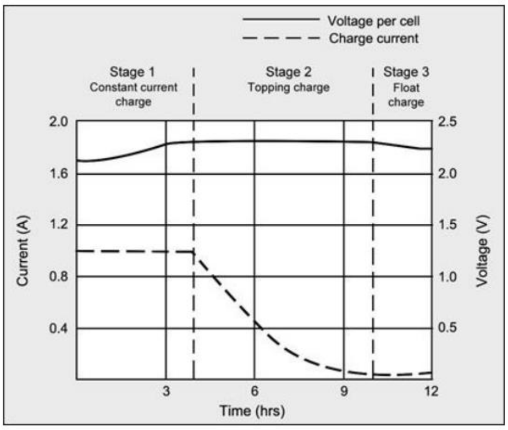

Fig. 10. Charging Stage Conditions for Lead-Acid Battery

III. Simulation Result and Discussion

MATLAB software is used for simulation during this integration test. A simulation test is run without using controls before being integrated into the main system (open loop). This simulation connects a battery load to a solar panel source. Data collection is carried out by varying the irradiation value from 400 W/m^2 to 1000 W/m^2, while the temperature value for the solar panel is given as 32ºC, this value is assumed to be the temperature at the actual test location.

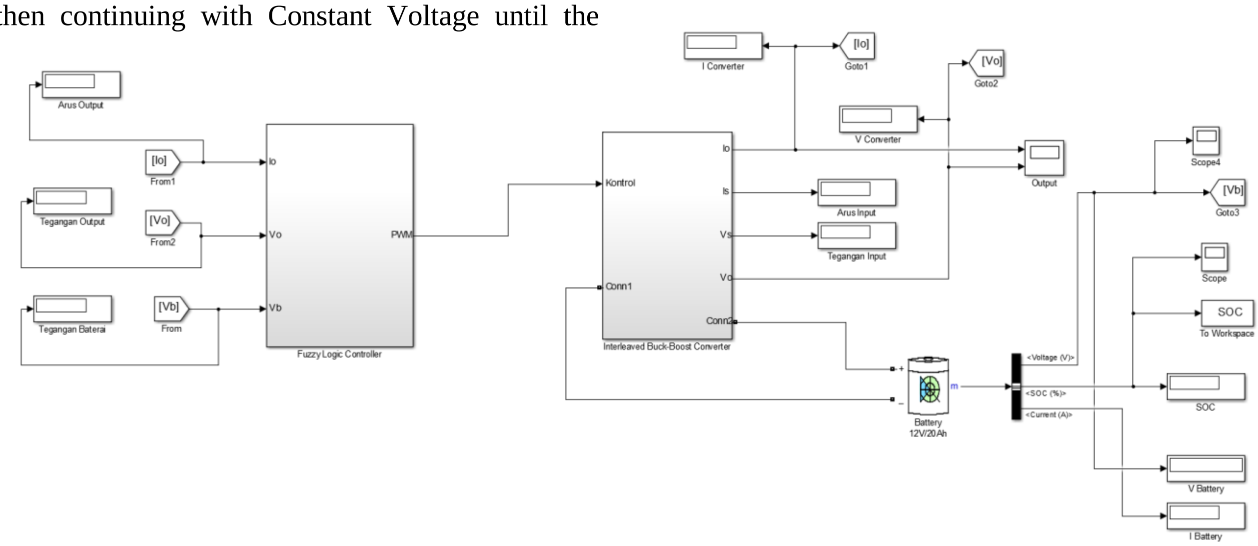

Fig. 11. Close Loop Integration Simulation Circuit in MATLAB

Fig.11 shows a charging system close loop integration test. The charging process is monitored by the fuzzy logic controller in this simulation when the constant current (CC) mode switches to the constant voltage (CV) mode, ensuring that the output stays at the setpoint charging voltage and current levels. The value of the State of Charge (SOC) variable is conditioned to remain at full charge, which is 100%.

TABLE 6
BATTERY CHARGING SIMULATION RESULTS DURING OPEN LOOP

Iradiance	Open Loop			
	Vin	Iin	Vout	Iout
1000	12.34	12.50	15.36	8.64
900	12.18	11.30	15.18	7.77
800	12.00	10.12	15.00	6.94
700	11.83	8.94	14.82	6.11
600	11.66	7.78	14.64	5.28
520	11.52	6.87	14.50	4.61
500	11.49	6.64	14.47	4.44
400	11.32	5.55	14.29	3.60

TABLE 7
BATTERY CHARGING SIMULATION RESULTS DURING CLOSE LOOP

Iradiance	Close Loop				I full-charge
	Vin	Iin	Vout	Iout	
1000	7.70	11.78	14.40	4.54	0.85
900	8.26	10.60	14.40	4.49	0.88
800	9.01	9.40	14.40	4.52	0.78
700	9.98	8.20	14.40	4.51	0.75
600	11.36	6.99	14.40	4.51	0.73
520	12.86	6.02	14.40	4.47	0.75
500	13.31	5.78	14.40	4.46	0.74
400	16.32	4.61	14.40	4.46	0.71

Based on Table 6 and Table 7, it is known that during integration testing without using control (open loop), where the given duty cycle is fixed. The value of the output voltage and current for charging will fluctuate depending on the level when there is a change in irradiation. The lead-acid battery charging setpoint target might be exceeded or missed depending on the current and voltage values supplied to the battery. Meanwhile, the duty cycle is set in integration with the fuzzy logic controller (closed loop) so that the output of the interleaved buck-boost converter can produce a voltage value based on the charging setpoint value.

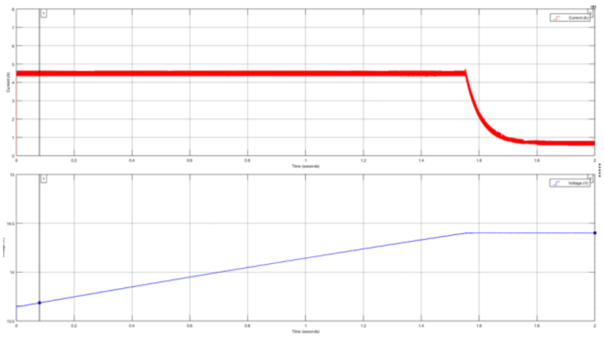

Fig. 12. Battery Charging Simulation Results with the Constant Current-Constant Voltage (CC-CV) Method

Fig. 12 illustrates how the battery is initially charged while in the constant current phase. Keeping the charging current constant at 4.5 A will cause the charging voltage to rise steadily until it reaches the full charge condition of 14.4 V, at which point the charging voltage transitions to a constant voltage phase. According to the typical lead-acid battery full charge current, which is between 3% and 5% of the battery capacity, the charging current will drop to 0.71A when the battery is fully charged.

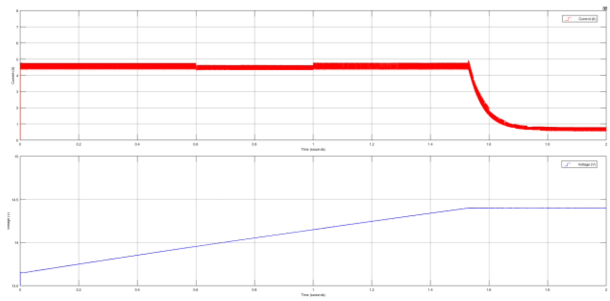

Fig. 13. CC-CV Curve with Irradiation Variation from 900 W/m^2 to 400 W/m^2

In Fig. 13, it can be shown that the charging current value is constant at 4.49A when the charging process is in a Constant Current (CC) state, with the initial condition of irradiation at 900 W/m^2. When the irradiation is reduced to 400 W/m^2, the charging current is maintained at 4.46A in accordance with the setpoint. However, as irradiance drops, the input current towards the solar panel drops, which reduces the charging current ripple. When FLC is applied, the ripple of the battery charging current gets reduced as the irradiation level decreases, protecting the battery and preserving its lifetime. As the charging voltage condition reaches steady state when the CV condition occurs, the charging voltage remains stable even when the irradiation changes.

TABLE 8
SOC VALUE VARIATIONS ON BATTERY CHARGING CONDITION

SOC (%)	Vch (volt)	Ich (A)
99,9	14,04	4,48
99,91	14,07	4,56
99,92	14,1	4,62
99,93	14,13	4,54
99,94	14,17	4,67
99,95	14,21	4,50
99,96	14,25	4,56
99,97	14,3	4,55
99,98	14,35	4,59
99,99	14,4	3,44
100	14,4	0,82

According to Table 8, charging starts when the initial SOC condition is between 99.9% and 100%. Where the charging state transitions from CC to CV when the SOC reaches 99.99% and the charging voltage reaches its set point. The battery is fully charged when SOC 100% is reached, and the current value will drop to 0.819A. Charging the battery when the CV condition is faster, so protecting the battery from overcharging.

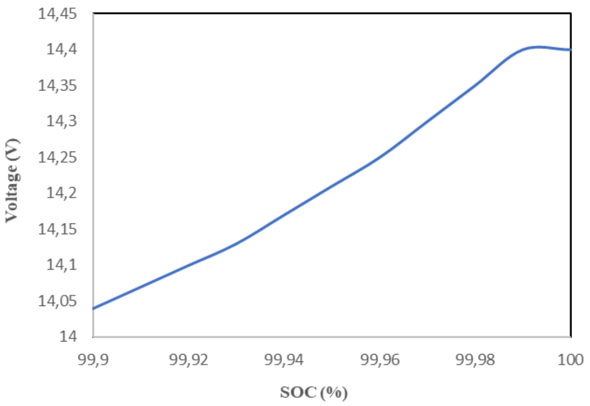

Fig. 14. The Impact of SOC Variation on Charging Voltage

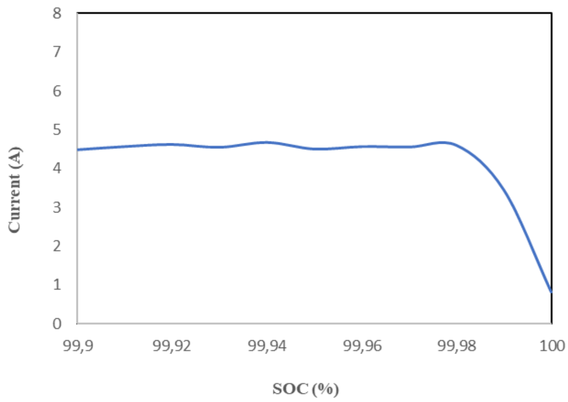

Fig. 15. The Impact of SOC Variation on Charging Current

To explain the effect of SOC on current and voltage, it can be illustrated in Fig. 14 that the voltage rises linearly as the SOC value rises. While in Fig. 15, shows that the battery charging current is constant as the SOC increases, but when SOC approaches 100%, the current will decrease linearly.

IV. Conclusion

The simulation of charging a lead acid battery with a capacity of 12V/20Ah using MATLAB software reveals that the output value of the interleaved buck-boost converter is less stable when the battery is charged in a condition without a control circuit (open loop), along with changes in irradiation conditions of 400 W/m^2-1000 W/m^2, which can cause the charging voltage to reach 15.36V as well as the charging current to reach a maximum condition of 8.64A. Where, this condition has passed the maximum current and voltage rating for charging the 12V/20Ah lead acid battery. The battery can be charged steadily by using the CC-CV technique under the control of a fuzzy logic controller. The simulation uses a constant current value of 4.5A. The voltage is maintained constant at 14.4V during the transition to the CV condition. When the battery is fully charged, the charging current will drop to a range of about 3% to 5% of its capacity. Approximately 0.7A when fully charged. The advantage of this CC-CV method is that it can speed up battery charging time and avoid damage to the battery due to overcharging.

Acknowledgements

This research was supported by the Power Electronics and Energy Conservation Research Group at Electronic Engineering Polytechnic Institute of Surabaya.

References

[1] A. I. Ramadhani, "Desain dan Implementasi Battery Charger Valve Regulated Lead Acid dengan Monitoring State of Charge Menggunakan Metode Coulomb Counting Pada Lampu Taman". *Power Elektronik: Jurnal Orang Elektro,* Vol. 11, No. 1, 2022. https://doi.org/10.30591/polektro.v11i1.3226

[2] V. P. Lestari, "Permasalahan dan Tantangan Program Peningkatan Kontribusi Energi Baru dan Terbarukan dalam Bauran Energi Nasional". Badan Keahlian Dewan DPR RI: Pusat Kajian Akuntabilitas Keuangan Negara.

[3] S. J. Dewan Energi Nasional, *Outlook Energi Indonesia 2019*. (Jakarta: Sekretariat Jenderal Dewan Energi Nasional).

[4] S. Soedibyo, R. Delfianti, F. A. Pamuji, M. Ashari, "Kontrol Tegangan pada Sistem Hybrid Panel Surya-Turbin Angin Menggunakan Manajemen Penyimpanan Baterai". *Jurnal Rekayasa Elektrika,* Vol 16, No. 3, 2020. https://doi.org/10.17529/jre.v16i3.16010

[5] M. Mufty, W. Dany, D. O. Anggriawan, M. Z. Efendi, "Baterai Charger VRLA dengan Metode Constant Current Constant Voltage Berbasis Kontrol PI". *Prosiding Seminar Nasional Terapan Riset Inovatif (SENTRINOV),* Vol. 6, No. 1, 2020.

[6] S. D. Nugraha, N. C. Ersha, E. Sunarno, O. A. Qudsi, L. Ferdiansyah, G. Prabowo, "Desain Baterai Charger Kendaraan Listrik dengan Metode Constan Current dan Constan Voltage". *JTT (Jurnal Teknologi Terpadu),* Vol. 9, No. 2, 2021.

[7] I. Buchmann, "*Batteries in A Portable World A Handbook on Rechargeable Batteries for Non-Engineers"*. Third Edition, 2011.

[8] M. Nizam, N. A. Ali, "Design and Development of Fast Charging Battery using Fuzzy Logic Control Technique". *Journal of Electrical, Electronic, Information, and Communication Technology,* Vol. 1, No. 1, 2021.

[9] H. Heryanto, Y. Rahmawaty, T. Manurung, "Performance Analysis of VRLA Battery for DC Load at Telecommunication Base Station". *ELKHA: Jurnal Teknik Elektro,* Vol. 13, No. 2, 2021.

[10] I. P. G. I. Dwipayana, I. N. S. Kumara, I. N. Setiawan, "Status of Battery in Indonesia to Support Application of Solar PV with Energy Storage". *Journal of Electrical, Electronics and Informatics,* Vol. 5, No. 1, 2021.

[11] K. M. R. Pebriningtyas, A. Musyafa, K. Indriawati, "Penelusuran Daya Maksimum Pada Panel Photovoltaic Menggunakan Kontrol Logika Fuzzy di Kota Surabaya". *Jurnal Teknik ITS,* Vol. 2, No. 1, 2013.

[12] F. I. Pasaribu, M. Reza, "Rancang Bangun Charging Station Berbasis Arduino Menggunakan Solar Cell 50 WP". *RELE (Rekayasa Elektrikal dan Energi): Jurnal Teknik Elektro,* Vol. 3, No. 2, 2021.

[13] H. R. Iskandar, C. B., Elysees, R. Ridwanulloh, A. Charisma, H. Yuliana, "Analisis Performa Baterai Jenis Valve Regulated Lead Acid pada PLTS Off-grid 1 kWp". *Jurnal Teknologi,* Vol. 13, No. 2, 2021.

[14] S. Vijayalakshmi, E. Arthika, G. S. Priya, "Modeling and Simulation of Interleaved Buck-Boost Converter with PID Controller". *In 2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO),* 2015.

[15] G. Sivanagaraju, S. Samata, L. M. Kunzler, K. R. Feistel, A. K., Rathore, L. A. Lopes, "PFC Interleaved Buck-Boost Converter for Telecom Power Application". *In IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society.,* 2017.

[16] S. T. Siddharthan, J. Gnanavadivel, S. J. Christa, "Design and Analysis of Interleaved Buck-Boost Converter for Household Appliances". *In 2020 4th International Conference on Trends in Electronics and Informatics (ICOEI) (48184),* 2020.

[17] D. W. Hart, "*Power Electronics"*. 2021. New York. The McGraw-Hill Companies.

[18] Z. Zachari, E. Purwanto, S. D. Nugraha, "Rancang Bangun Battery Charger CC-CV dengan Forward Converter". *Power Elektronik: Jurnal Orang Elektro,* Vol. 11, No. 1, 2022.

[19] F. Rahmatullah, "Desain dan Simulasi Battery Charger Metode CC-CV (Constant Current-Constant Voltage) dengan Kontrol Logika Fuzzy Menggunakan MATLAB". *CYCLOTRON,* Vol. 4, No. 2, 2021.

[20] I. Sudiharto, E. Wahjono, N. F. R. Lugiana, "Design and Simulation of Utilization of Solar Cells as Battery Chargers CC-CV (Constant Current-Constant Voltage) Method with Fuzzy Control". *Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control,* Vol. 7, No. 2, 2022.

Authors' information

I Gusti Agung Ayu Devi Anjani is an undergraduate student that currently pursuing a Bachelor's Degree in Applied Engineering at Polytechnic Institute of Surabaya (EEPIS). Her interests are in power electronics, renewable energy and control system.

Moh. Zaenal Efendi received his bachelor degree dan master degree in Electrical Engineering. Both from Institut Teknologi Sepuluh Nopember (ITS) Surabaya. He has been with Departement of Electrical Engineering, Politeknik Elektronika Negeri Surabaya (PENS), Surabaya, Indonesia since 1993. His researches are interested in power converter technology, especially PFC converter, dc-dc converter, MPPT converter and inverter.

Ony Asrarul Qudsi was born in Probolinggo, Indonesia on June 15, 1990. The author completed his bachelor's degree in 2012 at Institut Teknologi Sepuluh Nopember. Then the author continued his Master's Education at Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. The author completed the Master's program in 2014. He was joined Politeknik Elektronika Negeri Surabaya, Indonesia in 2013 as lecture. The author's love for the concentration of the Power System Engineering, made the author do a lot of research and publicize both journals and seminars in the field of Power Systems Engineering.