Design and Simulation of Asynchronous Buck Converter using Fuzzy Logic Controller (FLC)

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Abstract—Currently, Indonesia's energy is running out and has received serious attention so the Government targets that by 2050 the role of renewable energy will be at least 31%. This encourages the production of various alternative energy sources that are environmentally friendly and available, such as solar power plants. However, solar intensity and a dynamic environment strongly influence the output power generated by solar panels. So in this research, an asynchronous buck converter design using MPPT will be made to track the maximum power point of solar panels with the fuzzy logic controller method which will be applied to Monocrystalline solar panels with a capacity of 300WP. Fuzzy MPPT will adjust the duty cycle by PWM Arduino Nano on the asynchronous buck converter to keep reaching the maximum power point. The results show that the developed system can increase power conversion efficiency and maintain output voltage stability under various operational conditions. The implementation of FLC as MPPT on Asynchronous Buck Converter successfully optimizes the power absorbed from solar panels, thus supporting the reduction of electrical energy consumption from PLN in the Jakarta Global University student association secretariat building. This implementation is expected to be a reference for the implementation of a smarter and more sustainable energy management system in the future.

Keywords—Asynchronous Buck Converter, MPPT, Fuzzy Logic Controller, Solar Panel, Output Power

I. INTRODUCTION

With the advancement of science and technology and the rapid growth of the population, the electrical energy needed every day is increasing, while the availability of resources or fossil fuels such as coal and fuel is decreasing. Indonesia's energy verification has begun to receive serious attention after the issuance of Government Regulation No. 79 of 2014 concerning national energy policy. The government targets that by 2025 the role of New Energy and Renewable Energy will be at least 23% and by 2050 at least 31% [1], [2]. This encourages to produce various alternative energy sources that are environmentally friendly and also available all the time. One alternative energy that is widely utilized and continues to be developed is solar power plants. In a press release in 2021, the government through the Ministry of Energy and Mineral Resources targeted the installation of 3,600 MW of rooftop solar power plants until 2025. This rooftop PLTS policy not only affects the industry but also benefits the wider community because it optimizes savings on monthly electricity bills with an installed capacity according to household subscription power [3], [4].

Currently, many households use PLTS as an independent power generation source to meet household electricity needs. One of the studies conducted is entitled “Design and Implementation of Buck Converter in the Power Supply System for Washing Machines Using Solar Panels” [5] the research aims to utilize solar power as a source of electricity using a buck converter with a fuzzy method to stabilize the output voltage of the solar panel so that it can run the washing machine load. From several studies that have been conducted, the fuzzy logic controller (FLC) method has more optimal performance compared to other MPPT methods such as research conducted [6] the speed of the FLC method in tracking maximum power is faster, complexity and memory usage are more efficient and fuzzy logic is simpler than others so it is easier to understand. The research “Efficiency Comparison of Asynchronous and Synchronous Buck Converter with Variation in Duty Cycle and Output Current” conducted recently, namely compares the efficiency of use between asynchronous and synchronous buck converters by varying the duty cycle and current values. In the study, it was concluded that when both converters are operated with a duty cycle of 30% at low currents, the asynchronous buck converter has a better efficiency of 19.15% than the synchronous buck converter, but when both converters operate at high currents, the synchronous buck converter shows its efficiency of 6.56% against the asynchronous buck converter. On the other hand, in experiments using a duty cycle of 80%, both converters have an insignificant efficiency comparison [7].

Based on previous research, this study designed an asynchronous buck converter using the fuzzy logic controller (FLC) method on a power supply using solar panels. In this case using two solar panels with a capacity of 150WP assembled in series, which are then connected to an asynchronous buck converter using MPPT with the fuzzy logic controller method. The purpose of using the fuzzy logic controller method on the asynchronous buck converter is to produce maximum output power because according to [8] fuzzy control is more effective in increasing output power and also produces a fast response to weather changes, will be used

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in asynchronous buck converters that can operate well at low and high currents. So that the output power of the solar panel will be maximized and can become an independent source of electrical energy in the Jakarta Global University Student Association secretariat building. The purpose of this research is to find out the design and how to design an asynchronous buck converter connected to a solar panel to produce electrical power output at the JGU Student Association secretariat building, find out how much the potential utilization of the fuzzy logic controller method on the asynchronous buck converter in increasing the output power on the solar panel and to determine the effect of irradiation and temperature on the surface of the panel on output power. With the implementation of this research as expected, it will produce a renewable energy power plant that is environmentally friendly and available all the time, produce tools in the form of asynchronous buck converters that can be used to increase the output power of solar panels and can reduce the use of electrical energy from PLN at Jakarta Global University.

II. METHODS

This research begins with identifying problems and developing ideas for utilizing solar power as an alternative energy source, followed by a literature study that focuses on making an asynchronous buck converter using the MPPT fuzzy logic controller (FLC) method. After designing and assembling the components, researchers conducted trials and repairs to ensure the converter functioned optimally or not. After the device functions properly, data is taken and analyzed to get conclusions and suggestions for further development. Planning and making hardware refer to the system block diagram that will be used as follows.

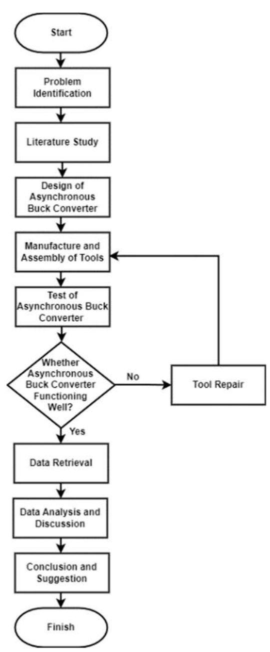

Fig.1. Research Flowchart

This research begins with identifying problems and developing ideas for utilizing solar power as an alternative energy source, followed by a literature study that focuses on making an asynchronous buck converter using the MPPT fuzzy logic controller (FLC) method. After designing and assembling the components, researchers conducted trials and repairs to ensure the converter functioned optimally or not. After the device functions properly, data is taken and analyzed to get conclusions and suggestions for further development. Planning and making hardware refer to the system block diagram that will be used as follows.

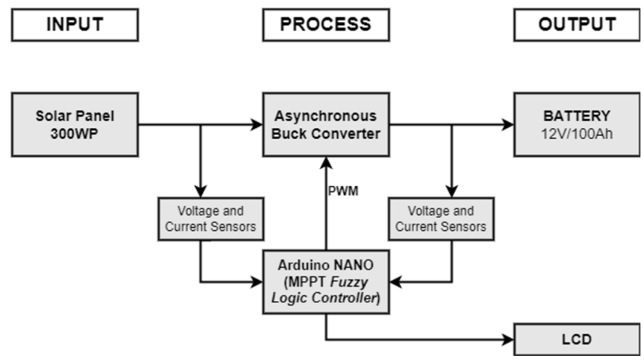

Fig.2. Diagram of the System

The system designed based on Figure 2 uses a 300WP solar panel as input. The process includes:

a) The asynchronous buck converter reduces the voltage from the solar panel according to the needs of the battery.
b) Voltage and current sensors measure the input and output of the converter, used by the Arduino to determine the duty cycle.
c) Arduino Uno controls the converter with an MPPT fuzzy logic controller to maximize the output power to the battery.

The output is the battery as a store of electrical energy and LCDs the output voltage and current data.

A. *Battery Charging Planning*

The battery used is a 12 Volt/100Ah lifefo4 battery. A battery can be larger if Vch>V battery. Determine the battery charging voltage and current: If each 12 Volt battery has 4 cells, then the battery must be charged with a voltage of :

$$
\begin{aligned}
Vch &= 3.3 \text{ x cell battery} \\
&= 3.3 \text{ x } 4 \\
&= 13.2 \text{ Volts}
\end{aligned}
$$

The amount of current used when charging or charging the battery is around 10% - 30% of the battery capacity. In this case the percentage of current to be used is 20%. Then the battery must be charged with a current of :

$$
\begin{aligned}
Ich &= \% \text{ x Ah} \\
&= 20\% \text{ x } 100 \text{ Ah} \\
&= 20 \text{ Ah}
\end{aligned}
$$

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$$\text{Charging time} = \frac{\text{Battery Capacity}}{\text{Charging Current}}$$

$$T = \frac{Ah}{Ich}$$

$$T = \frac{100}{20}$$

T = 5 jam

Description :

V_{ch} = Charging Voltage (Volt)
Ah = Charging Voltage (Ah)
I_{ch} = Battery charging current (A)
T = Battery charging time (*hour*)

B. Solar Panel

Solar panels are devices used to generate electrical energy from sunlight. Because solar panels use silicon as the main material, the working principle is based on semiconductor p-n junctions, solar panels consist of a semiconductor layer (n-doped and p-doped) that forms a p-n junction, an antireflection layer, and a metal substrate through which current from n-type (electron) and p-type (hole) semiconductors flows. The photovoltaic effect is the transformation of electrical energy resulting from light irradiation on semiconductor cells. An electric field can form when light hits a semiconductor, because photon energy greater than its band gap energy will break the valence electron bond, which causes current to flow in the electron-hole has an opposite charge, resulting in electricity. The electrical energy produced by solar panels depends on solar irradiation and the temperature on the surface of the solar panel. The hotter it is, the greater the electrical energy produced [8].

Fig.3. Solar Panel

In this case the output power is charging a 12 Volt battery with a capacity of 100 Ah with the following charging parameters: Vch = 13.2 Volts, Ich = 20 A, t = 5 hours. So the total energy required for battery charging is:

Wout = Vch x Ich x t
= 13.2 Volt x 20 A x 5 hour
= 1320 Wh

Referring to research [9] the effective length of time solar panels can produce maximum output power is 5 - 6 hours per day under full sun. With an output energy of 1440 Wh, the required solar panel capacity is:

$$P\ (peak) = \frac{Wout}{Tef}$$

$$= \frac{1320}{5}$$

= 264 WP

Description :

P (*peak*) = Required solar panel capacity
Wout = Output energy
Tef = Effective time solar panels can produce energy

So that in this study, a solar panel with a capacity of 300WP of Monocrystalline Cell or Monocrystalline silicon type will be used because it has the highest efficiency level of 15%-20% and its use is more durable than other types of solar cells. And also, Monocrystalline type solar panels have high absorption power at high solar intensity [10]. In this study, solar panels with a capacity of 300WP will be used. The specifications of the solar panels that will be used are as follows.

Table 1. Solar Panel Parameters

Pmax	300W
Vmax	36.6V
Imax	8.13A
Voc *(open circuit voltage)*	43.2V
Isc *(short circuit current)*	9.70A

C. Asynchronous Buck Converter

The DC-DC asynchronous buck converter topology is the most widely used converter type in power management applications and microprocessor voltage regulators. These applications require high frequency and transient response over a wide load current range. Asynchronous buck converters have the ability to convert high voltage to low voltage. The buck configuration has high efficiency, simple circuitry, no need for transformers and low stress levels on the switch. The output voltage produced by the buck method will be lower or equal to the input voltage so it does not require a lot of filters or filters [11].

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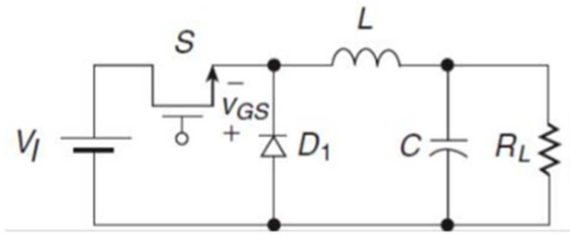

Fig. 4. Buck Converter circuit

The working principle of the asynchronous buck converter is to use a switch or switch that works continuously (ON-OFF). To control the switching process, the terms PWM (Pulse Width Modulation) and duty cycle are known which work to control the speed (frequency) of the switch work [5]. Figure 3 shows the switch on the asynchronous buck converter. The switch will work continuously. In realization, the duty cycle and frequency used will affect the speed of the switch. The component used as a switch is MOSFET. In the basic circuit of the asynchronous buck converter, there are two modes, namely ON switch mode and OFF switch [5]

When the switch position is ON, the MOSFET is on (closed) and the diode is off, so the current will flow from the source to the inductor (inductor charging), filtered by the capacitor, then to the load. Meanwhile, when the switch is in the OFF position, the MOSFET is off (open) and the diode is on so that the current will flow through L, C, the load, and the maximum diode. The inductor current will drop until the transistor is turned on again in the next cycle. The energy stored in the inductor L is transferred to the load.

D. Design of Asynchronous Buck Converter

The asynchronous buck converter that will be designed in this study functions as an output voltage reducer to match the battery charging needs by adjusting the duty cycle which will be controlled by fuzzy logic to increase the output power of the solar panel source.

Table 2. Asynchronous Buck Converter Parameters

Vmax	36 V
Imax	8,13 A
Vo(beban)	13.2 V
Io(beban)	20 Ah
η *buck converter*	80%
Frekuensi	40 KHz
Voltage Ripple	5%
Current Ripple	20%

Based on the asynchronous buck convereter parameters in Table 1, there are several components that must be calculated including:

Duty Cycle Calculation: $D = \frac{Vo}{Vin-max} X\ 100\%$ (1)

Calculation of resistor value: $R = \frac{Vo}{Io}$ (2)

Inductor calculation: $L = \frac{\text{Vin(max) x D x (1-D)}}{\text{f x } \Delta I_L}$ (3)

The ripple current in the inductor cannot be calculated if the value of the inductor is unknown. Thus, the estimated inductor ripple current is 20% to 40% of the maximum output current.

$$\Delta I_L = (0{,}2\ to\ 0{,}4) \times Iout(max) \quad (4)$$

Calculation of capacitor value : $C = \frac{\Delta I_L}{8\ x\ \Delta_{Vo\ x\ f}}$ (5)

Diode calculation : $\text{If} = Iout(max)\text{x (1D)}$ (6)

$$\text{PD} = \text{If x Vf} \quad (7)$$

Using the calculation formula above, the design of several components that will be needed in the asynchronous buck converter circuit is as follows:

Table 3. Asynchronous Buck Converter component requirement design results

Parameters	Symbol	Specifications
Duty Cycle (%)	D	36%
Resistor (Ω)	R	0.66 Ω
Inductor (H)	L	51 µH
Capasitor (F)	C	18,9 µF

E. ACS712 Current Sensor

In this study using two current sensors. The current sensor will be used to sense the output current of the solar panel and asynchronous buck converter, which will then be input into the Arduino Uno microcontroller so that the output current can be controlled by fuzzy logic. The current sensor used is an ACS712 current sensor of the 20A variety.

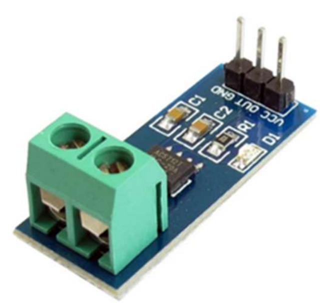

Fig. 5. ACS712 Current Sensor

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F. Voltage Sensor Design

In this study using two voltage sensors. Voltage divider will be used as a voltage sensor for sensing the output voltage of the solar panel and asynchronous buck converter, which is then entered into the Arduino Uno microcontroller so that it can determine changes in output voltage and can be controlled by fuzzy logic. The first voltage sensor on the solar panel is used to sense the output voltage of 5V and the second voltage sensor on the output voltage of the asynchronous buck converter senses an output voltage of 13.2V which will be used as input for battery charging.

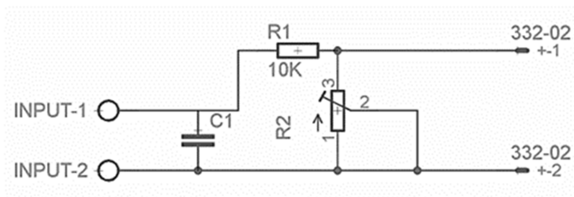

Fig. 6. Voltage Sensor Design

Voltage Sensor Design

1. The first sensor is to detect the output voltage of the solar panel as input to the asynchronous buck converter.

V_{in} = 36V

$$Vo = \frac{R2}{R1+R2} \text{ x Vin}$$

$$5 = \frac{R2}{10000+R2} \text{ x } 36$$

$36\ R_2 = 50000 + 5\ R_2$

$31\ R_2 = 50000$

$R_2 = \frac{50000}{31}$

R_2 = 1613 ohm

So that R2 to be used is 1800 ohms.

Description:

V_{in} = Input voltage to Asynchronous Buck Converter

V_o = Voltage that can be read by the Microcontroller

R_1 = The first resistor to be used, determined by the researcher

R_2 = Second resistor

2. The second sensor is to detect the output voltage of the asynchronous buck converter as input to the battery.

V_{in} = 13.2V

$$Vo = \frac{R2}{R1+R2} \text{ x Vin}$$

$$5 = \frac{R2}{10000+R2} \text{ x } 13.2$$

$13.2\ R_2 = 50000 + 5\ R_2$

$8.2\ R_2 = 50000$

$R_2 = \frac{50000}{8.2}$

R_2 = 6097ohm

So that R2 to be used is 61Kohm.

Description :

V_{in} = Battery input voltage

V_o = Voltage that can be read by the Microcontroller

R_1 = The first resistor to be used, determined by the researcher

R_2 = Second resistor

G. Mikrokontroller (Arduino Nano)

Arduino Nano can be supplied using a USB connection or DC adapter with a minimum range of 6 - 20VDC and has an ATmega 328 microcontroller on board [12]. This board has 14 digital I/O pins, 6 of which support PWM (Pulse Wide Modulation), and also has 8 analog input pins for reading analog signals, as shown in Figure 8.

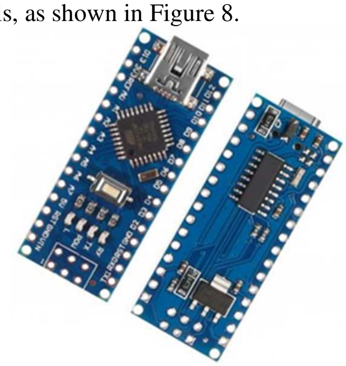
Fig. 7. Arduino Nano

H. MPPT Fuzzy Logic Controller

MPPT (Maximum Power Point Tracking) is a system used to find the optimal voltage and current points on solar panels to get maximum output power. The working principle of MPPT (Maximum Power Point Tracking) is to increase and decrease the voltage value on the solar panel [13]. The working point of the solar panel will change according to changes in the value of the load resistance and to reach the optimal working point must get the appropriate resistance value so that the power obtained is maximized [9]. In designing fuzzy logic, things that need to be considered include membership functions or calculating errors and delta errors, fuzzification, rule base and defuzzification. The value used as input is the value obtained based on the photovoltaic voltage and reference voltage.

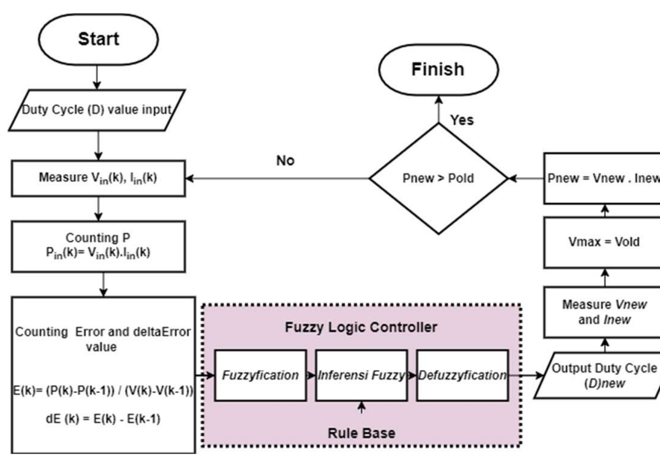

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Fig. 8. Flowchart of How the Fuzzy Logic Controller Works

The stages that need to be done in using the fuzzy logic controller method are as follows :

1. *Membership Function*

The fuzzification process is the stage of determining the set of each membership function for input and output variables. The input of the fuzzy algorithm is Error (E) and delta Error (dE). The Error value is obtained from the division between the difference between the current power and the previous power (ΔP) and the difference between the current voltage and the previous voltage (ΔV).

$$E(k) = \frac{\Delta P}{\Delta V} = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \quad (8)$$

$$dE(k) = E(k) - E(k-1) \quad (9)$$

Description :

E(k)	= Error value (%)
dE (k)	= Delta error value (%)
ΔP	= Change in power value (Watt)
ΔV	= Change in voltage value (V)

The output membership function is a duty cycle using the Sugeno method so that the type of variable is constant. In this system, the membership functions for input and output are divided into five fuzzy sets; NB (Negative Big), NS (Negative Small), ZO (Zero), PS (Positive Small), and PB (Positive Big), with a range of values between -1 to 1.

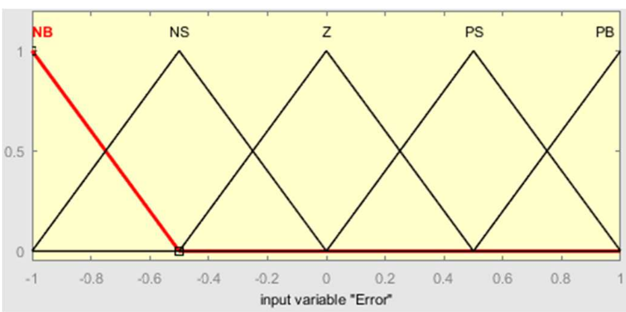

Fig. 9. Membership function of Error

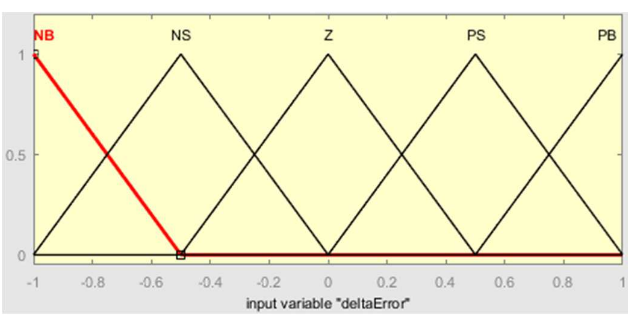

Fig. 10. Membership function of deltaError

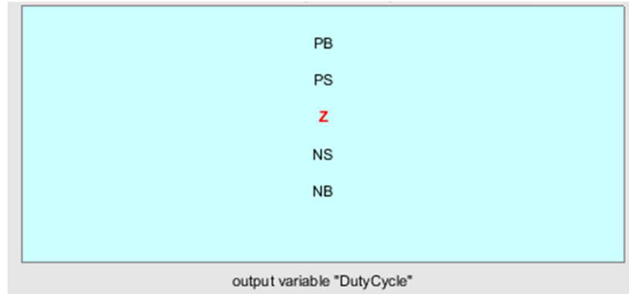

Fig. 11. Membership function of Duty Cycle

2. *Rule Base Design*

To determine the control action on fuzzy, it is used in the form of IF-THEN statements. With membership functions input Error and delta Error can be generated as many as 25 rules that can determine the output value in the form of duty cycle. Membership functions include NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small) and PB (Positive Big). The following is the rule base design table shown in table 4.

Table 4. 2. Rule Base Design

dE \ E	**NB**	**NS**	**Z**	**PS**	**PB**
NB	Z	Z	PB	PB	PB
NS	Z	Z	PS	PS	PS
Z	PS	Z	Z	Z	NS
PS	NS	NS	NS	Z	Z
PB	NB	NB	NB	Z	Z

It consists of 25 rules that will be used to determine the corresponding fuzzy output. By using a comprehensive rule base, the FLC can produce a smooth and adaptive response to changes in input conditions, thus ensuring optimal performance of the asynchronous buck converter, as follows :

1. *If (Error is NB) and (deltaError is NB) then (DutyCycle is PS) (1)*
2. *If (Error is NB) and (deltaError is NS) then (DutyCycle is PB) (1)*
3. *If (Error is NB) and (deltaError is Z) then (DutyCycle is NB) (1)*
4. *If (Error is NB) and (deltaError is PS) then (DutyCycle is NB) (1)*
5. *If (Error is NB) and (deltaError is PB) then (DutyCycle is NS) (1)*
6. *If (Error is NS) and (deltaError is NB) then (DutyCycle is PS) (1)*
7. *If (Error is NS) and (deltaError is NS) then (DutyCycle is PS) (1)*
8. *If (Error is NS) and (deltaError is Z) then (DutyCycle is NS) (1)*
9. *If (Error is NS) and (deltaError is PS) then (DutyCycle is NS) (1)*
10. *If (Error is NS) and (deltaError is PB) then (DutyCycle is NS) (1)*

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11. *If (Error is Z) and (deltaError is NB) then (DutyCycle is Z) (1)*
12. *If (Error is Z) and (deltaError is NS) then (DutyCycle is Z) (1)*
13. *If (Error is Z) and (deltaError is Z) then (DutyCycle is Z) (1)*
14. *If (Error is Z) and (deltaError is PS) then (DutyCycle is Z) (1)*
15. *If (Error is Z) and (deltaError is PB) then (DutyCycle is Z) (1)*
16. *If (Error is PS) and (deltaError is NB) then (DutyCycle is NS) (1)*
17. *If (Error is PS) and (deltaError is NS) then (DutyCycle is NS) (1)*
18. *If (Error is PS) and (deltaError is Z) then (DutyCycle is PS) (1)*
19. *If (Error is PS) and (deltaError is PS) then (DutyCycle is PS) (1)*
20. *If (Error is PS) and (deltaError is PB) then (DutyCycle is PS) (1)*
21. *If (Error is PB) and (deltaError is NB) then (DutyCycle is NS) (1)*
22. *If (Error is PB) and (deltaError is NS) then (DutyCycle is NB) (1)*
23. *If (Error is PB) and (deltaError is Z) then (DutyCycle is PB) (1)*
24. *If (Error is PB) and (deltaError is PS) then (DutyCycle is PB) (1)*
25. *If (Error is PB) and (deltaError is PB) then (DutyCycle is PS) (1)*

Based on these rules, a surface can be formed which is a three-dimensional visualization of the relationship between input variables in the form of Error and deltaError and output in the form of duty cycle in a fuzzy system. It is often used to analyze and understand how changes to the input affect the output. The following is the surface of the rule base of the fuzzy method to be used.

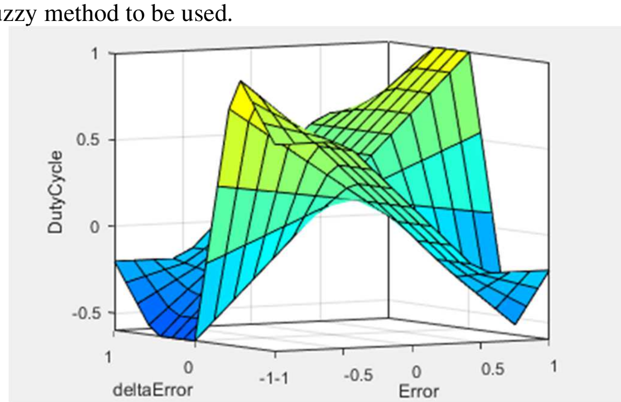

Fig. 12. Surface rule base Fuzzy

3. Defuzzification

To determine the output of the membership function in the form of a duty cycle, the defuzzification process is carried out. The defuzzification process in Sugeno-type fuzzy uses the weighted average method, the completion of this method is by summing the rule type value multiplied by its singleton and divided by the number of each rule value (Fiaga Apreka, 2022). The completion of this method is found in the equation below.

$$Defuzzifikasi = \frac{\sum m\ (i-1)\ x\ 1}{m} \quad (10)$$

Description :

∑m = Number of all rules

M = Number of each rule value

I. Simulation of Asynchronous Buck Converter

The following is a simulation circuit of an asynchronous buck converter designed in two modes, namely simulation with open-loop or without fuzzy method shown in Figure 14 and close-loop simulation or simulation using fuzzy logic controller method as MPPT to achieve the desired maximum power.

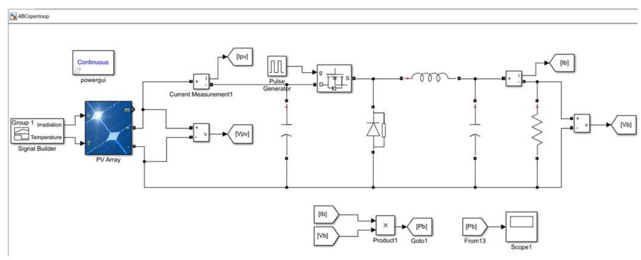

Fig. 13. Simulasi Asynchronous Buck Converter open-loop

The following is a simulation of an asynchronous buck converter with a fuzzy method as Maximum Power Point Tracking (MPPT) in MATLAB which involves the use of a fuzzy controller to optimize the PWM duty cycle so that the asynchronous buck converter can reach and maintain the maximum power point of the solar panel energy source. A 300WP solar panel is used, whose output power is dynamic because it is influenced by solar intensity and temperature, then the value of the voltage and current output of this solar panel will be used as a member function which will pass through a fuzzy circuit consisting of fuzzification, fuzzy inference and defuzzification which will produce an output in the form of a duty cycle to track the optimum output power point that will be generated from the asynchronous buck converter circuit. Where this fuzzy logic circuit will continue to track until it gets the optimum power point [14].

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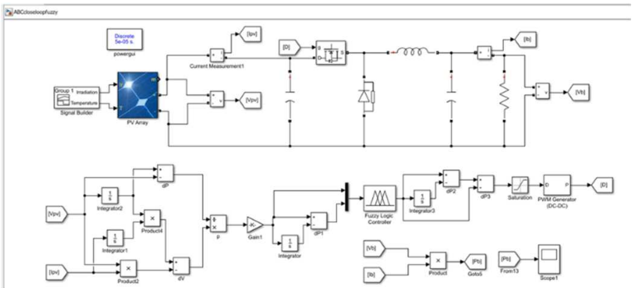

Fig. 14. Simulasi Asynchronous Buck Converter close-loop

III. CONCLUSION

Based on the simulations and tests that have been carried out, it can be concluded that:

1. A Fuzzy Logic Controller on asynchronous buck converter is an effective approach to tracking the optimum output power point from the solar panel source.
2. The initial simulation conducted shows the potential for successful implementation in real conditions. The next steps will include hardware implementation and physical testing to ensure that the proposed design can function optimally in the JGU Student Association secretariat building.

REFERENCES

[1] PP No. 79, “PP No. 79 Thn 2014.pdf.” pp. 1–36, 2014.

[2] B. W. Dionova, R. J. P. S, D. J. Vresdian, and L. P. Pratama, “Evaluation of 300 WP Solar Photovoltaic Panel Performance for Electric Vehicle Charging Station,” vol. 19, no. 03, pp. 80–84, 2023, [Online]. Available: http://dx.doi.org/10.32497/eksergi.v19i03.5008

[3] D. jenderal energi baru terbaharukan dan konservasi energi (EBTKE), “Indonesia Kaya Energi Surya, Pemanfaatan Listrik Tenaga Surya oleh Masyarakat Tidak Boleh Ditunda,” *Humas EBTKE*, 2021.

[4] D. Hendrawati *et al.*, “Design and Performance Evaluation of Analytic-Tuning Pid on Boost Converter for 200 Wp Photovoltaic,” *J. Eng. Sci. Technol.*, vol. 18, no. 4, pp. 1–16, 2023, [Online]. Available: https://www.scopus.com/record/display.uri?eid=2-s2.0-85174285670&origin=resultslist&sort=plf-f&src=s&sid=096276bf4bcc127109bbaf34753d8b49&sot=b&sdt=b&s=FIRSTAUTH%28Hendrawati%29&sl=17&sessionSearchId=096276bf4bcc127109bbaf34753d8b49&relpos=5

[5] F. Musahiroh, “Desain Dan Implementasi Buck Converter Pada Sistem Power Supply Untuk Mesin Cuci Dengan Menggunakan Panel Surya,” *JTT (Jurnal Teknol. Terpadu)*, vol. 11, no. 1, pp. 8–14, 2023, doi: 10.32487/jtt.v11i1.1506.

[6] P. Studi, M. Teknik, and J. Teknik, “Metode Maximum Power Point Tracking (MPPT) dan Boost Converter Menggunakan Fuzzy Logic Controller (FLC) pada Modul Surya,” vol. 17, no. 1, 2021, doi: 10.17529/jre.v17i1.17863.

[7] R. W. Rachmad and T. Abuzairi, “Efficiency Comparison of Asynchronous and Synchronous Buck Converter with Variation in Duty Cycle and Output Current,” vol. 5, no. 1, pp. 41–55, 2023, doi: 10.12928/biste.v5i1.7386.

[8] A. Adriani, “Analisis Teknologi Pembangkit Listrik Biomassa Pada Sistem Pencahayaan Peternakan Ayam Di Desa Borimatangkasa Kec. Bajeng Barat,” *Vertex Elektro*, vol. 1, no. 2, pp. 40–51, 2019, doi: 10.26618/jte.v1i2.2383.

[9] D. Elgi Octavianto *et al.*, “Analisa Perbandingan Daya Keluaran Solar Panel Dengan Pembangkit Listrik Tenaga Hybrid (Surya-Angin),” *Pros. Semin. Nas. Tek. Mesin Politek. Negeri Jakarta*, pp. 81–91, 2021.

[10] Partaonan Harahap, Inda Bustami, Rimbawati, and Benny Oktrialdi, “Pengaruh Intensitas Cahaya Matahari Dan Suhu Terhadap Daya Yang Dikeluarkan Oleh Modul Sel Surya Monocrystalline Dan Polycrystalline,” *J. MESIL (Mesin Elektro Sipil)*, vol. 3, no. 2, pp. 1–5, 2022, doi: 10.53695/jm.v3i3.791.

[11] O. Melfazen, “Stabilisasi Tegangan Keluaran Buck Converter Dengan Metode Fuzzy Logic Controller,” *J. Eltek*, vol. 16, no. 2, p. 125, 2018, doi: 10.33795/eltek.v16i2.104.

[12] B. A. W. Widhiawan, S. Handoko, and D. Darjat, “Perancangan Sistem Charging Baterai Menggunakan Buck-Boost Converter Dengan Sumber Panel Surya Berbasis Mikrokontroler Arduino Nano,” *Transient J. Ilm. Tek. Elektro*, vol. 10, no. 1, pp. 17–25, 2021, doi: 10.14710/transient.v10i1.17-25.

[13] S. T. Fiaga Apreka, “Desain Dan Implementasi Mppt Fuzzy Logic Control Menggunakan Boost Converter Untuk Penerangan Pada Peternakan Ayam,” *Power Elektron. J. Orang Elektro*, vol. 11, no. 1, p. 69, 2022, doi: 10.30591/polektro.v11i1.3227.

[14] H. Alwi, T. Widodo, S. Yahya, B. Setiadi, A. Rafi, and A. Tahtawi, “Simulasi MPPT Buck Konverter Menggunakan Logika Fuzzy Sugeno pada Sistem Panel Surya,” 2023.

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