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CP2024-J-Hendi Sama-Simulation of Solar Panel Maximum Power Point Tracking Using the Fuzzy Logic Control Method

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Simulation of Solar Panel Maximum Power Point Tracking Using the Fuzzy Logic Control Method

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ABSTRACT:
The use of solar energy has begun to be developed in PLTS, but the photovoltaic module electricity produced is not at maximum output power. To increase the efficiency of the photovoltaic module, Maximum PowerPoint Tracking (MPPT) technology is used. Differences in the level of solar energy irradiation can cause the output power of the solar panels to vary and will not be maximized. Changing temperature and irradiation can be maintained with a maximum voltage of 40Volt and according to what is desired. In this study, MPPT consists of a Boost Converter whose function is to regulate the output voltage, while the algorithm used is the fuzzy logic which works based on Error (E) and Change Error (CE) from changes in the voltage and current of the photovoltaic module. The results showed that after using MPPT when input was given a change in load resistance with irradiation of 1000 W/m2 and a temperature of 25 ℃ resulted in a difference in power under different conditions compared to a system without MPPT. The power generated without the use of MPPT has a significant change with the results of 227.7W, 114.4W, 76.5W, 57W, and 45.5W. Testing the system after installing the MPPT when given an input change in irradiation with a load resistance of 20 Ω and a temperature of 25°C, a more stable power is produced with a value of 0.008W. Then when the input changes to irradiation with a load resistance of 20 Ω and a temperature of 25 ℃, the maximum power produced for each of the highest irrigation is 746.9 W/m2, 779.4 W/m2, and 839.4 W/m2 of 38.88 W, 42.07 W, and 47.8 W and compared to the system without MPPT only 21.76W, 21.96W and 22.28W.

KEYWORDS: Maximum Powerpoint Tracking, Photovoltaic Module, Boost Converter, Fuzzy Logic.

1. INTRODUCTION

Technology and science have experienced rapid development to date. One of them is electrical energy which is increasing and is proven by seeing the increase in demand in industry and households. Most of the electrical energy currently used is obtained from the conversion of conventional energy, namely fossil energy such as coal, oil, and gas[1]. The increase experienced certainly has an impact on fossil energy which will experience scarcity so alternatives are needed. Solar power plants with solar panels (solar photovoltaic) are renewable power plants that are increasingly playing an important role as a substitute for fossil energy[2]. Applications that have been carried out on conventional solar panels have drawbacks, namely the very low-efficiency side due to differences in the characteristics of solar panels with loads[3]. In addition, the electric power generated by solar panels is influenced by light intensity and the working temperature of solar panels, so technology is needed that can maximize output on solar panels[4].

The non-linear characteristic of solar panels causes difficulty in getting the maximum point of the solar panel. In dealing with this characteristic problem,

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modeling is needed by applying Maximum Power Point Tracking (MPPT) modeling in keeping the system operating at a fixed point[5]. MPPT itself is a stage that is arranged to achieve maximum power based on I-V characteristics or MPP points on the curve. So, we need a system that can realize the MPPT algorithm to achieve maximum power in conditions of irradiation and abnormal temperatures.

Fuzzy logic functions as a control algorithm that can help design and improve the response results of the system for the better, as has been done in previous studies. The research carried out certainly uses the fuzzy logic method as an algorithm for solving problems[6].

Previously, research had been carried out by improving MPPT performance using fuzzy PWM control with PID tuning. The PID controller is used to improve MPPT performance by taking into account the load capacity, and the design of fuzzy logic[7]. The implementation and realization in households resulted in an efficiency of 95.75% and lower than without fuzzy with an efficiency of 88.77%. In applying this method, the system can improve the voltage output on the boost converter.

Differences in the level of solar energy irradiation can cause the output power of the solar panels to vary and will not be maximized. The use of the Sliding Mode Controller method on the MPPT system is capable of producing an output voltage with an average of 51-22% of the average output voltage of 19.84 Volts before installing the system. After installation, the output voltage is 40.67 Volts[8]. Changing temperature and irradiation can be maintained with a maximum voltage 40Volt and according to what is desired.
Based on the explanation that has been explained, there are main problems that inspired the author to conduct research entitled "Simulation of Maximum Power Point Tracking (MPPT) of Solar Panels Using the Fuzzy Logic Control Method".

2. LITERATURE REVIEW

2.1. Solar Panels

Solar panels are a collection of solar cells in the same area. The solar panel is a photovoltaic light sensor that is capable of converting light intensity into an output voltage[9]. Reception of sunlight to the solar cell will issue a DC output voltage that will depend on the number of cells in a panel. The science of converting sunlight directly into electricity is known as photovoltaics (PV), referring to photons of light and electric volts. When light photons enter the solar cell, the light will be absorbed and excite electrons in the silicon layer, causing movement and will eventually continue to flow through the cables that enter the PV system[10].

Photovoltaic that produces electricity is Direct Current (direct current) which requires one or more inverters to convert DC electricity into electricity with AC power. All PV systems start with a collection of electric solar modules called a PV array. Arrays are usually linked together in groups, which are called series strings as shown in Fig. 1 below.

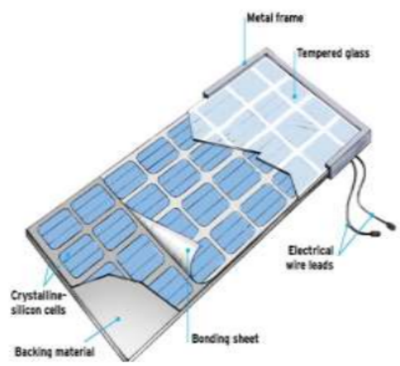

Fig. 1. Photovoltaic module.

2.2. Maximum Power Point Tracking (MPPT)

Maximum power path or maximum power point tracking is a system used in solar panels produce maximum output power by changing the voltage and current values at the input[11]. The MPPT control algorithm does not focus on track by following the sun's radiation, but the system offered at this MPPT is change the operating point so that it can maximize the output power of the solar panel. In addition, the mechanical system for tracking (tracking) the MPPT concept is also different in general[12].

In general, solar cells have a maximum point on each curve, both on the V-P curve and the V-I curve. The curve at this maximum point or commonly called the maximum power point of the solar cell will operate at the most efficient level and be able to produce the highest level of electrical power. In knowing the location of the highest point on the solar panel, you have to use a special algorithm, one of which is the tracking algorithm[13].

The application of the MPPT algorithm can be carried out if the DC-DC converter is already present in the solar panel by setting the operating current and voltage points on a solar panel[14]. The MPPT algorithm is of course used to keep the working operational point of a solar panel somewhat fixed at the maximum point. In its application, 19 MPPT methods are a strong foundation or strong foundation with different method characteristics as shown in Table 1 below.

Table 1. Main Characteristics of the MPPT Method.

MPPT technique	PV Array Dependent	True MPPT	Analog or Digital	Periode Turning	Converse nce Speed	Implementation Complexity	Sensed Parameters
Hill-Climbing/P&O	No	Yes	Both	No	Varies	Low	Voltage, Current
Incond	No	Yes	Digital	No	Varies	Medium	Voltage, Current
Fractional VOC	Yes	No	Both	Yes	Medium	Low	Voltage
Fractional ISC	Yes	No	Both	Yes	Medium	Medium	Current
Slide Mode Control	No	No	Digital	No	Fast	Medium	Voltage, Current
Neural Network	Yes	Yes	Digital	Yes	Fast	High	Varies
RCC	No	Yes	Analog	No	Fast	Low	Voltage, Current
Current Sweep	Yes	Yes	Digital	Yes	Slow	High	Voltage, Current
DC Link Capasitor Droop Control	No	No	Both	No	Medium	Low	Voltage
Load Ior V Maximization	No	No	Analog	No	Fast	Low	Voltage, Current
dP/dP or dP/dI Feedback Control	No	Yes	Digital	No	Fast	Medium	Voltage, Current
Array Reconfiguration	Yes	Yes	Digital	Yes	Slow	High	Voltage, Current
Linear Current Control	Yes	No	Digital	Yes	Fast	Medium	Irradiance
Impp dan Vmpp Computation	Yes	Yes	Digital	Yes	N/A	Medium	Irradiance Temperature
State-Based MPPT	Yes	Yes	Both	Yes	Fast	High	Voltage
OCC MPPT	Yes	No	Both	Yes	Fast	Medium	Current
BFC	Yes	No	Both	Yes	N/A	Low	None
LRCM	Yes	No	Digital	No	N/A	High	Voltage, Current
Fuzzy Logic Control	Yes	Yes	Digital	No	Fast	High	Varies

2.3. DC-DC Converter

The DC-DC converter is an electronic circuit that is capable of changing the value of a DC voltage with a low input to a higher DC voltage at the output point without changing the direction or polarity of the source[15]. This direct voltage converter uses the concept of charging a switch by giving space to the inductor component. The efficiency of this power system is much greater and higher than the concept of a linear power system. So that all current power sources or supplies work in switch mode or also known as a switched mode power supply (SMPS)[16].

The supply voltage for the DC voltage conversion process generally has a fixed input voltage. The basic concept of the output voltage in this conversion is to control the time between the entry and exit of the circuit as shown in Fig. 2 below.

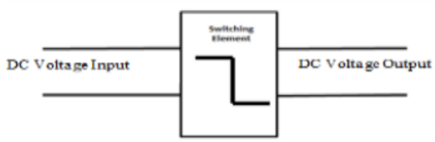

Fig. 2. The basic concept of direct voltage conversion.

2.4. Fuzzy Logic Controller

Fuzzy logic control or fuzzy inference is a performance system that forms the basis for using if-then rules with certain conditions so that better results are obtained with vague values and of course, carried out with confirmation of the decisions that have been taken[17].

The arrangement of the structure will be the start of the fuzzy relationship itself consisting of several structures which will be described in the points below:

a. Reasoning that contains if-then rules.
b. The input to be defined is a collection of several fuzzy set memberships.
c. Fuzzification will change the input to a certain level which will be adjusted to the rules that have been determined based on the membership they have.
d. Database that defines the membership function of fuzzy sets.
e. The decision-making unit that states the inference operating rules.
f. Defuzzification will carry out the stages of confirming the fuzzy results to a more classic output form.

The concept of fuzzy logic will certainly form an arrangement consisting of the structural relationships that have been described as shown in Fig. 3 below[18].

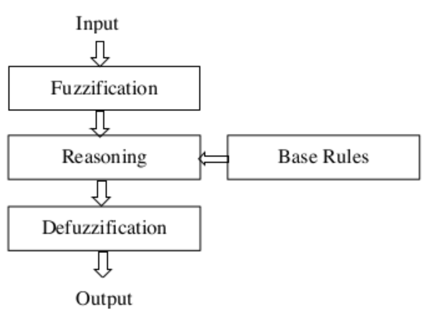

Fig. 3. The basic concept of fuzzy logic algorithms.

2.5. MATLAB

MATLAB (Matrix Laboratory) is a program for analyzing and calculating numerical data, MATLAB is also an advanced mathematical programming language based on premises that use the properties and forms of matrices. MATLAB is a programming language developed by The Mathwork Inc. in 1970[19]. This application is widely used in areas that require complex mathematical calculations, where all MATLAB arithmetic operations are matrix operations with calculation indicators in the form of graphic diagrams[20]. MATLAB software has several important parts that are used to run programs such as:

a. The command window is used to type the desired function.
b. Functional command history that has been used before can return.
c. Workspace is used to create variables in MATLAB

3. METHOD

3.1. Research Stage

The stages of this research discuss the methods, steps, or techniques used to realize the MPPT system on solar panels using the fuzzy logic method. The application of this simulation will be carried out with software in the form of MATLAB. The steps in completing this research are as follows:

1. Literature study, namely looking for references by reading books, scientific papers, articles, journals and so on that are relevant to this research related to problems in Simulink research on MPPT solar panel systems using the fuzzy logic method.
2. Preparing tools and materials, namely the stages of data collection that have been determined by using the variables in the hypothesis in the form of solar radiation intensity, panel temperature, voltage, and current on the panel.
3. The design of the system is to make a model consisting of solar cell modeling, Boost Converter, and the FIS algorithm in MATLAB software.
4. Simulink integration, namely combining the modeling that has been done into one Simulink and data input.
5. Testing and Implementation, namely testing the model that has been done by giving several case studies to get satisfactory results.
6. Analysis and Discussion, namely carrying out the analysis stage of the simulation test results whether they are functioning properly or not so that they can be used for the data collection process. Then after receiving the result data from the simulation that was run, a discussion stage will be carried out on the parameters used, namely voltage, current, and power in the battery.

7. Concluding, concluding the simulation results that have been completed.

3.2. Modeling the Boost Converter

The design of this circuit also requires parameters that will be used to determine the amount of resistance, capacitance, and inductance. This parameter will be adjusted based on the modeling that has been done on the solar panel so that the functionality of the boost converter can increase the voltage with a maximum scale of 21 Volts to 40 Volts. This component will also be compiled based on the library described in the previous point using the existing parameter blocks in the MATLAB software as shown in Fig. 4 below.

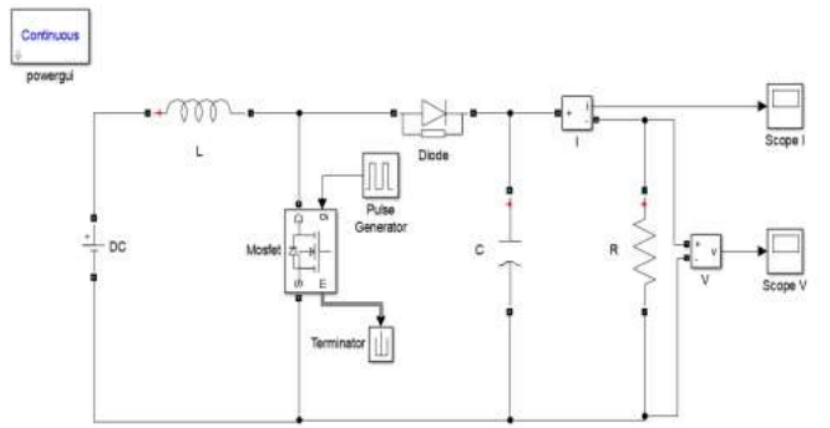

Fig. 4. The boost converter simulation circuit arrangement.

3.3. MPPT Fuzzy Logic Control System

Based on the block diagram in Fig. 3, the working process of the MPPT control system can be explained. The voltage source to be controlled comes from the PV voltage, then the FLC functions to control the size of the duty cycle value in the converter. Previously the FLC algorithm program was on Simulink using the Mamdani method. The display here functions only to display the PV input voltage (v), power (W), current (A), and output voltage as shown in Fig. 5 below.

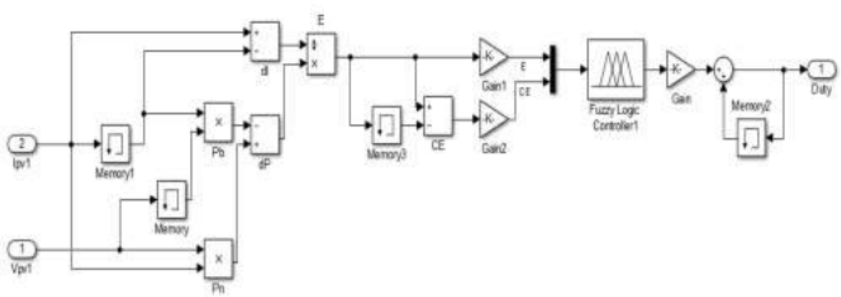

Fig. 5. MPPT Fuzzy Logic Control circuit.

3.4. Modeling Solar Panel Modules Using the MPPT System

The modeling that will be designed for the MPPT system as a whole is a collection of all the main and supporting blocks that have been designed and will be simulated as shown in Fig. 6 below.

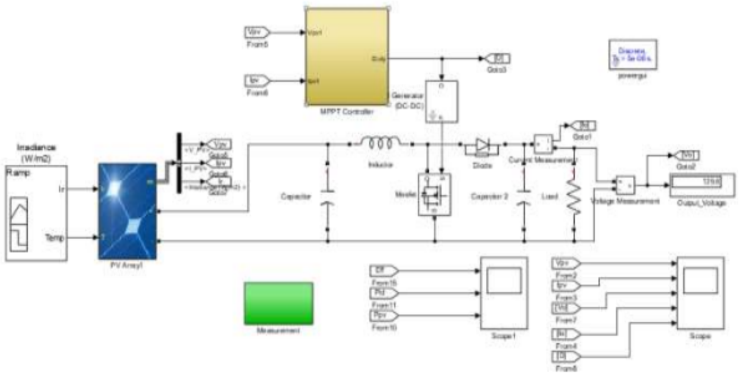

Fig. 6. The solar panel module system block uses MPPT.

All subsystems are merged into an MPPT system that is connected to other components. The data to be observed is the value of the output voltage and current from the solar panel to determine the value of the duty cycle through the FLC control to control the boost converter properly.

In this study, it will be used in testing when a photovoltaic system without MPPT and a photovoltaic system using MPPT. There are two types of input data to be used, each of which has fixed and variable input data parameters as follows:

a. Given data with variable parameters in the form of changing load values and data with fixed parameters in the form of module temperature and irradiation.

b. Given data with variable parameters in the form of changing irradiation values and data with fixed parameters in the form of module temperature and load.

4. RESULTS AND DISCUSSION

4.1. Fuzzy Logic Test Results

The tests that have been carried out next are tests in other conditions as shown in Fig. 7, Fig. 8, and Fig. 9 below.

Fig. 7. Conditions for PS results with E=-0.03 and CE=80.

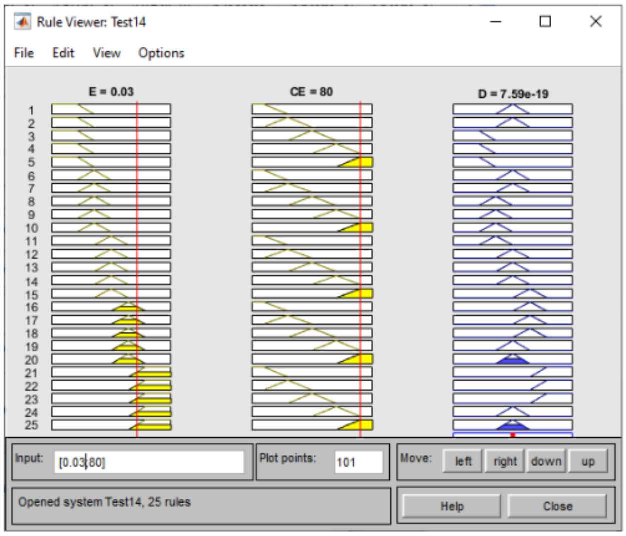

Fig. 8. Conditions for PS results with E=-0.03 and CE=80.

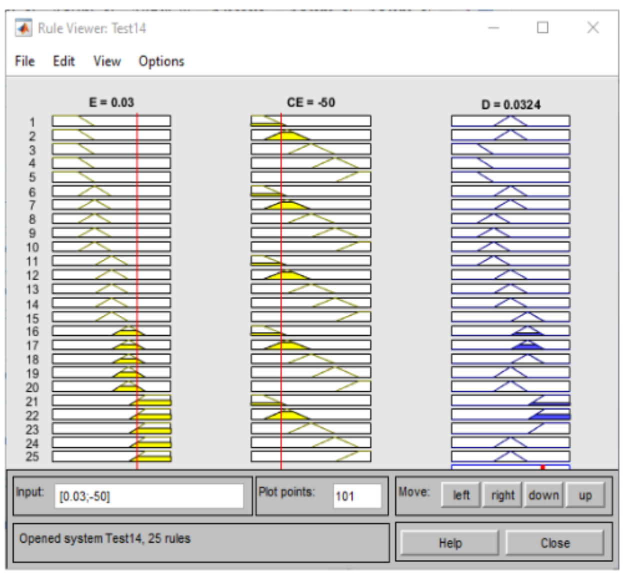

Fig. 9. Conditions for PS results with E=-0.03 and CE=80.

4.2. Test Results When Load Changes Without MPPT

Testing the solar cell system without MPPT when the load changes was carried out 5 times with a load consisting of 20Ω, 40Ω, 60Ω, 80Ω, and 100Ω. Then this test was carried out with an irradiation of 1000 W/m2 and a temperature of 25 ℃ as shown in Table 2 below.

Table 2. Output power to load changes without MPPT.

Load (Ω)	Variable					
	CM(A)	VM(V)	PM(W)	I_PV(A)	V_PV(V)	P_PV(W)
20	7,391	68,21	504,1	3,37	67,41	227,2
40	11,21	68,49	767,8	1,69	67,69	114,4
60	12,71	68,59	871,8	1,13	67,69	76,5
80	13,07	68,63	897,0	0,84	67,83	57,0
100	13,44	68,66	922,8	0,67	67,86	45,5

Based on Table 2, the output or power output that can be produced by solar panels without MPPT changes is decreasing. This decrease in power is caused by changes in the resulting load being unable to maintain the stability of the power output due to the resistive nature of the load which has a role as a reduction in the value of the current to the load which is getting bigger and is inversely proportional to the power generated by the solar panel

4.3. Test Results When Irradiation Changes Without MPPT

Tests are carried out by adjusting the irrigation that will enter the PV array starting with 200 W/m2, 400 W/m2, 600 W/m2, 800 W/m2, 1000 W/m2, and 1200 W/m2. The load used in the test without this MPPT is 20Ω and the temperature of the solar cell module is 25℃ as shown in Table 3 below.

Based on Table 3, when a change in irradiation is given to the solar cell system, the highest output power on the solar panel is at the time of irradiation of 893.4 W/m2 and the lowest power produced is 0.7W when the irradiation rate is 65.6 W/m2.

Table 3. Changes in output power in solar cell systems without MPPT.

Iridation (W/m^{2})		P(W)
Initial Value	Final Score	
800-1200	893,4	22,2
400-800	770,4	21,9
400-800	756,9	21,7
200-400	133,1	3,01
100-200	69,4	0,8
0-100	65,6	0,7

4.4. Test Results When Load Changes With MPPT

Testing the solar cell system using MPPT when the load changes was carried out 5 times with a load consisting of 20Ω, 40Ω, 60Ω, 80Ω, and 100Ω. Then this test was carried out with 1000 W/m2 irrigation and a temperature of 25 ℃ as shown in Table 4 below:

Table 4. MPPT system power to changes in load.

Load (Ω)	Variable					
	CM(A)	VM(V)	PM(W)	I_PV(A)	V_PV(V)	P_PV(W)
20	1,59	15,71	25,0	0,01	0,76	0,008
40	1,61	15,71	25,3	0,01	0,76	0,008
60	1,6	15,71	25,1	0,01	0,76	0,008
80	1,61	15,71	25,3	0,01	0,76	0,008
100	1,59	15,71	25,0	0,01	0,76	0,008

Based on Table 4 above, it can be seen that the MPPT system that was implemented was able to maintain a stable output power with different load changes. In the table above it can also be seen, the power generated by the panel itself is maintained with an average value of 25.1 W while the value after passing through the converter circuit is 0.008.

4.5. Test Results When Irradiation Changes With MPPT

The test is carried out by adjusting the irrigation that will enter the PV array and using a load of 20Ω and a solar cell module temperature of 25℃ as shown in Table 5 below.

Table 5. Changes in output power in solar cell systems without MPPT

Iridation (W/m^2)		P(W)
Initial Value	Final Score	
800-1200	839,4	47,8
400-800	779,4	38,12
400-800	746,9	38,8
200-400	133,1	1,18
100-200	65,6	0,26
0-100	69,4	0,3

Based on Table 5, when treated with a state of change in irradiation in the solar cell system, the highest power output produced was 47.8W when irradiated it reached 839.4 W/m2 and the lowest power output occurred when irradiated 69.4 W/m2 with power 0,3W.

4.6. Changes in the Power Output of the Solar Cell System

The power generated without MPPT and using MPPT can be seen significantly as shown in Table 6 below.

Table 6. Changes in Output Power.

Load	Power (W)			
	Without MPPT		With MPPT	
	Panel	Converter	Panel	Converter
20	504,1	227,2	25	0,008
40	767,8	114,4	25,3	0,008
60	871,8	76,5	25,1	0,008
80	897	57	25,3	0,008
100	922,8	45,5	25	0,008

In Table 6, the change in the output power produced after and before MPPT is visible as shown in Fig. 10 below.

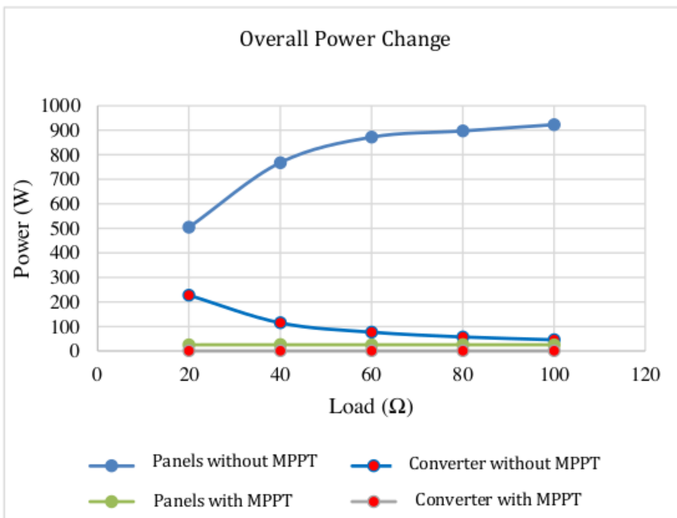

Fig. 10. Graph of changes before and after MPPT.

Based on Fig. 10 above, the change in power that occurs in the solar panel can be seen. The changes contained in the image above consist of the output power from the solar panels and converters. The results of changes after using MPPT, the resulting line looks parallel to the x-axis which indicates that the power generated against change in load is stable at 0.08W. While the power generated when not using MPPT has decreased power on the converter side with a value of 45.6W and the panel side has increased with a power of 922.8W

5. CONCLUSION

The conclusions that can be drawn from the description of the discussion and the results of the MPPT simulation using fuzzy logic are as follows:

a. Simulation of the Maximum Power Point Tracking (MPPT) module design for solar panels using the Mamdani method to produce a Duty Cycle (D) as output for the switch on the Boost Converter can be generated on the MPPT system design. Simulation was done with a maximum power output capacity of 65 Watt, irradiation of 1000 W/m2, and temperature of 25°C. Fuzzy logic design set rules consisted of Error (E) and Change of Error (CE) and output in the form of Duty Cycle (D).

b. Testing the system after installing the MPPT when the load resistance is changed with irradiation of 1000 W/m2 and a temperature of 25°C, the maximum power produced under the conditions of an input resistance of 20 Ω is 860.16W and 878.8W compared to a system without an MPPT of only 23 W. Testing the system after installing the MPPT when given an input irradiation change with a load resistance of 20 Ω and a temperature of 25°C resulted in the maximum power for each of the highest irradiation 746.9 W/m2, 779.4 W/m2, and 839.4 W/m2 of 38.88 W, 42.07 W, and 47.8 W compared to a system without MPPT of only 21.7692 W, 21.9613 W, and 22.2849 W.

c. Changes in load resistance with irradiation of 1000 W/m2 and a temperature of 25°C, result in a difference in power under different conditions compared to a system without MPPT. The power generated without the use of MPPT has a significant change with the results of 227.7W, 114.4W, 76.5W, 57W, and 45.5W. Testing the system after installing the MPPT when given an input irradiation change with a load resistance of 20 Ω and a temperature of 25°C, resulted in a more stable power produced with a value of 0.008W.

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