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Optimization of PV Power Capacity of 10 KWp Capacity Based on P&O Algorithm and Boost Converter

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Abstract — Using solar panels as a power plant can reduce the dependence of fuel oil. To work always on maximum power points (MPP), Photovoltaic (PV) requires an optimization method. Therefore, the authors are interested in discussing the optimization method of the PV array model using the Maximum Power Point Tracking (MPPT) of the Perturbation & Observation (P & O) Algorithm and Boost Converter. In this case, PV capacity will be simulated on 10 kWp. That PV consists of 4 strings, which is each string consist of 10 PV modules. The output of PV modules will be sent to the Boost Converter circuit. Boost Converter wants to be controlled by P&O Algorithm. The voltage and current generated from the PV array modeling will be exercised by the P&O Algorithm as a reference. The function of the P&O Algorithm is to track the Maximum Power Point (MPP) of the PV model. The result of tracking power by the P&O Algorithm will be sent to the Pulse Width Modulation (PWM) circuit as a duty cycle generator. Duty cycle signal will be transmitted to the switching tool contained in the converter circuit. By that control system, PV model expected has maximum power according to the voltage. Based on the results of power test by 1000 W/m2 radiation, the maximum power obtained is equal to 9967 Wp with 99.6% efficiency at a voltage level of 400 volt. Therefore, it can be concluded that the design of the PV Array System utilizing P&O Algorithm and the Boost Converter can work well.

Keywords—Model PV Array, P&O Algorithm, Boost Converter, Optimization

I. INTRODUCTION

Renewable energy is a solution to replace electricity generation using fossil fuels. Renewable energy that is abundant in nature is sunlight. Sunlight can be converted into electrical energy by using solar panels or commonly called Photovoltaic (PV). Many PV modules are needed to complete the needs of electrical energy in a large enough scope. PV modules are arranged in parallel or in series to form a large-scale PV array. This large-scale PV array is called a PV farm. To optimize PV farm power plants, the Maximum Power Point Tracking (MPPT) method can be used. The method is used as a tracking power generated by PV farm is always optimal. Perturbation and Observation (P&O) work at the point of operation that moves to the point of peak power in the PV [1][10]. In this study, to optimize the output voltage from the PV farm a boost converter circuit is used. Boost converter is used to maintain a constant voltage during the power tracking process. The MPPT P&O algorithm produces duty-cycle. Duty Cycle functions as a switching controller signal generator in the boost converter circuit, to get the expected output voltage from the DC-DC Converter based on the input voltage. The duty cycle requires a PWM (Pulse with Modulation) control signal as a carrier signal [1][7]. In Indonesia, using PV system is still limited. One of reason for not using PV system is unstable and requires a high initial investment cost. To save fuel in other power plants, the PV can be connected to the inverter. To supply an inverter, the PV must have an output voltage of up to 400 Vdc. Based on the explanation, potential, and problems that have been explained, this research will discuss a 10 kWp capacity PV system based on P&O algorithm and Boost Converter. This researched has purposed to optimize the power output of the PV generator system.

II. RESEARCH METHODOLOGY

A. Solar Cell

One form of energy source that has great potential for the future is photovoltaic (PV). PV has unlimited primary energy availability and free pollution. However,

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photovoltaics still needs to be researched and developed to produce energy conversions that have greater efficiency. Solar panels consist of smaller parts called solar cells. The solar cells are connected in series and in parallel to get the required voltage and current value [6]. A collection of many solar cells called modules or solar panels. In its development, the PV model is not as simple as shown, but there are some parameters that must be added so that the PV model is getting closer to the actual conditions, as shown in Figure 1.

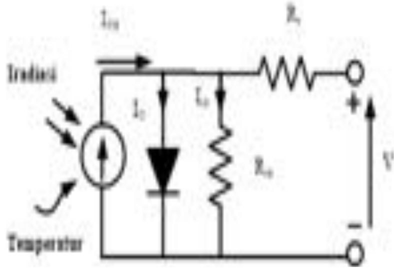


Fig. 1. Simple Illustration of Solar Panels

The addition of these parameters includes:
a. Diode saturation current (ID) depends on temperature.
b. Photocurrent currents (IPH) depend on temperature.
c. The series resistance (Rs) forms the voltage at the time of the open circuit.
d. Parallel resistance (Rsh) of resistance in a diode.
The basic equation of a PV can be formulated with Equation 1 (Hieu & Phuong, 2015):

$$I = I_{PH} - I_D \left[e^{q\left(\frac{V+IR_s}{nKT}\right)} - 1 \right] - \left(\frac{V+IR_s}{R_{sh}} \right) \quad (1)$$

where:
I : Current output PV (Ampere).
IPH : Photocurrent effect generated on PV (Amperes).
ID : Diode saturation current.
Q : Electron charge = $1.6*10^{-19}$ (Coulomb).
K : Boltzman's constant (Joule / kelvin).
T : Cell temperature (Kelvin).
Rs : Series resistance (Ohm).
Rsh : Parallel resistance (Ohm).
V : PV (Volt) output voltage.
N : is a diode quality factor that is valued between 1 and 2

B. Boost Converter

Boost Converter is an increase in DC voltage. Boost converter is used when the voltage required by a device or electronic circuit is higher than the available supply voltage. With the condition that the output voltage is always greater than the input voltage. And the output voltage has the same polarity as the input voltage. For the topology of Boost Converter can be seen in Figure 2.

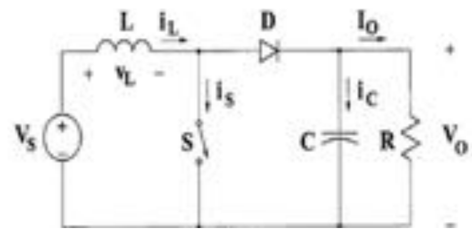
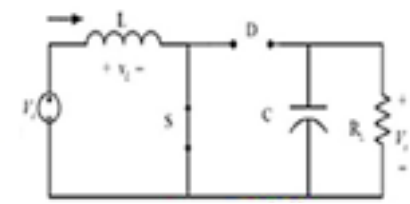
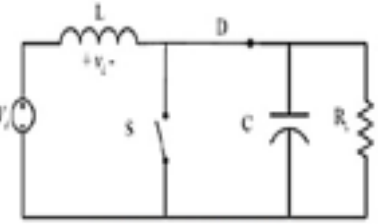


Fig. 2. Boost Converter (Hart, 2010)

From Figure 2 you can explain how the Boost Converter works. In the Boost Converter circuit there are two conditions. The condition of the circuit is on and off. These conditions can be seen in Figure 3.



a. ON State



b. OFF State

Fig. 3. The Condition of Circuits in On and Off State

The equation for determining duty cycle can be seen in Equation 2.

$$\text{Duty-cycle (D)} = \frac{\text{Ton}}{\text{Ton+Toff}} = \frac{\text{Ton}}{\text{T}} = \text{Ton.F} \quad (2)$$

First find the value of the duty cycle to determine the desired output voltage using Equation 3.

$$D = 1-\frac{V_S}{V_O} \quad (3)$$

Then the load that passes through the Boost Converter circuit is calculated using Equation 4.

$$R = \frac{\text{Vo}}{\text{Io}} \quad (4)$$

The minimum inductance value from the Boost Converter inductor is calculated using Equation 5.

$$L_{min} = \frac{D(1-D)^2 R}{2\,f} \tag{5}$$

L value must be greater than the minimum L value. To find the capacitor value calculated using Equation 6.

$$C = \frac{Vo\ D}{R\ \Delta Vo\ f} \tag{6}$$

C. Maximum Power Point Tracking

Maximum Power Point Tracking (MPPT) is a method used to keep a photovoltaic system working within a maximum power point (MPP). MPPT will maintain output at highest power, named the Voltage Maximum Power (Vmp) and Current Maximum Power (Imp). To maintain the system still work on MPP, the MPPT method has been widely developed, such as the Perturb and Observe Algorithm (P&O). Based on the characteristic curves of I-V and P-V it can be seen that the work of PV is not linear and dynamic according to changes in the value of sunlight intensity on the PV surface and temperature on the PV surface. Figure 4 explains the characteristic graph of the MPPT.

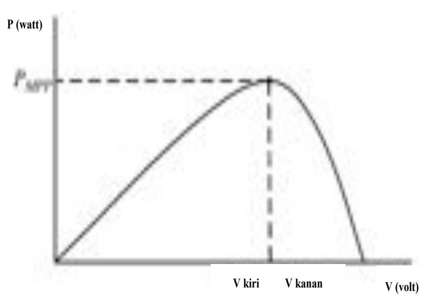


Fig. 4. P&O-based MPPT working principles

Figure 4 shows that the maximum P_{MPP} power point divides the V voltage region into two areas namely, the left V and right V areas. The P&O method obtains the PMPP value by shifting the value of the V voltage to the left and right. When the P&O algorithm works to shift the voltage V to the right and an increase in the value of the power then the next perturbation must remain the same i.e. shift the V towards the right to reach MPP. But if there is a decrease in power, perturbation must be reversed.

This study uses the P&O algorithm as an MPPT control algorithm because of fast and easy computation. This algorithm refers to the P-V characteristics of the PV used. There are three types of dots that are in three positions. The position of $\Delta P/\Delta V$ can be seen in Figure 5.

To the left of the peak is a mathematically formulated point $\Delta P/\Delta V > 0$, the peak point of the curve is $\Delta P/\Delta V = 0$ and to the right of the peak point $\Delta P/\Delta V < 0$.

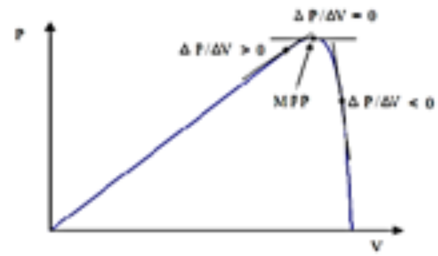


Fig. 5. Different Positions of ΔP / ΔV on the Curve PV power

Figure 5 shown one of the P-V panel curves that presents the basis of the P&O Algorithm method. MPP shows the area with the maximum value. And conversely, if the signal value (slope) is negative, the voltage of the solar panel will drop. The direction of the slope is determined by comparison of ΔP and ΔV. With the characteristics of the boost converter the direction of the duty cycle is obtained. If the result of the comparison (slope) is positive, then the voltage value is added. If it produces a negative value, the voltage value is reduced. If the duty cycle is reduced, the voltage will increase. And if the duty cycle is reduced, the voltage will decrease. By determining the slope, a new duty cycle reference is obtained.

D. Pulse Width Modulation

Pulse Width Modulation (PWM) is a way to manipulate the pulse width in a period. PWM is used to obtain a different average voltage with a fixed amplitude and frequency value. One pulse cycle is a high condition then it is in the transition zone to a low condition. The pulse width is directly proportional to the amplitude of the unmodified original signal and can be interpreted that the PWM has a fixed frequency value but varies duty cycle values. Duty cycle is a condition of high logic signal and low logic signal in a signal period expressed in the form (%) with a range of 0% to 100% [3]. The PWM signal can be seen in Figure 6.

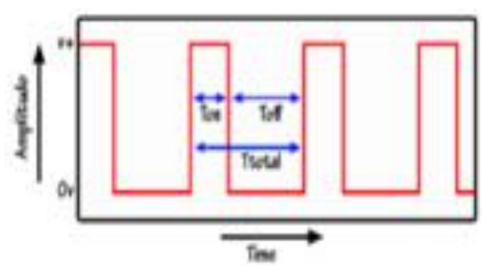


Fig. 6. PWM Signal

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III. RESULT AND DISCUSSIONS

A. System Design Diagram

Block diagram of the system design of this study can be seen in Figure 7. Figure 7 explains that the electricity generation from the PV array is measured through a voltage and current sensor. The measurement results will be input to the Boost Converter circuit. Boost Converter is used to keep the voltage on the output side high. The results of changes in voltage and current from the panel received by the voltage and current sensor are then sent for processing in the P&O Algorithm. Multiplication of changes in voltage and current is called a change in power. In order to keep the power change stable, the duty cycle in the P&O algorithm will work. The duty cycle will ignite the switch via PWM. The switch in the Boost Converter circuit works so that the output voltage obtained stays at the desired range.

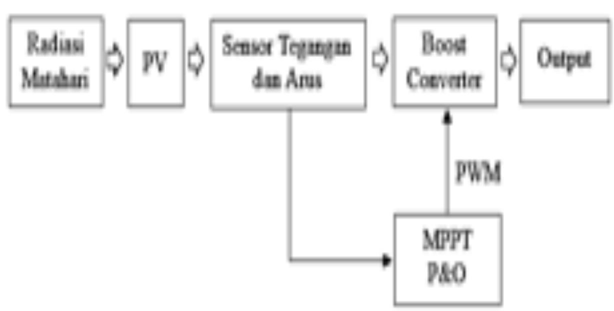


Fig. 7. System Design Diagram Blocks

B. Designing a 10 kWp Simulink PV Module

The solar panel specifications used are 250 Wp, with a peak output voltage of 35 Vdc and a peak output current of 7.15 A. Figure 8 shows the type of solar module to be used in the simulation.

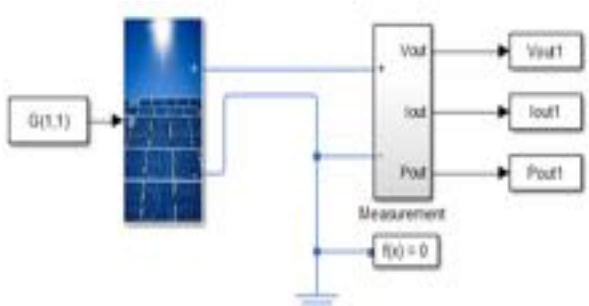
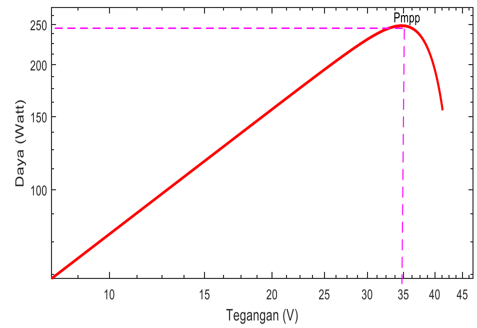


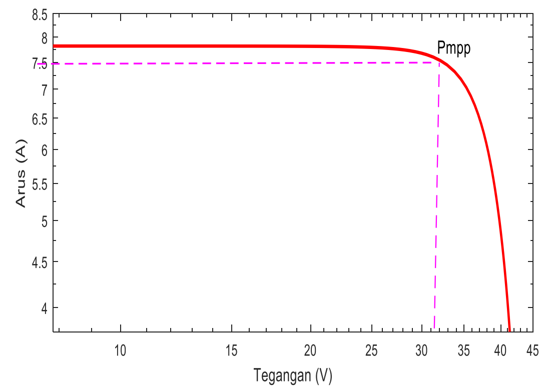
Fig. 8. Simulation PV Module

The PV module simulation results are shown in Figure 9.



a. Characteristic Curve P-V

b.



b. Characteristic Curve I-V

Fig. 9. Characteristic Curve Simulation PV Module

To achieve greater power, the PV modules can be arranged in parallel series. In accordance with Figure 10, PV modules are arranged in series as many as 10 pieces so as to produce a power of 2500 Wp. Based on the characteristic curve in Figure 11, the current value at the time of maximum power is 7 A with a threshold of 350 Volts.

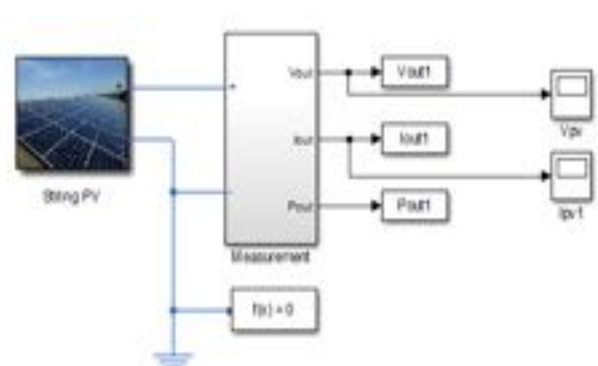


Fig. 10. Simulation PV string

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The PV String simulation results are shown in Figure 11.

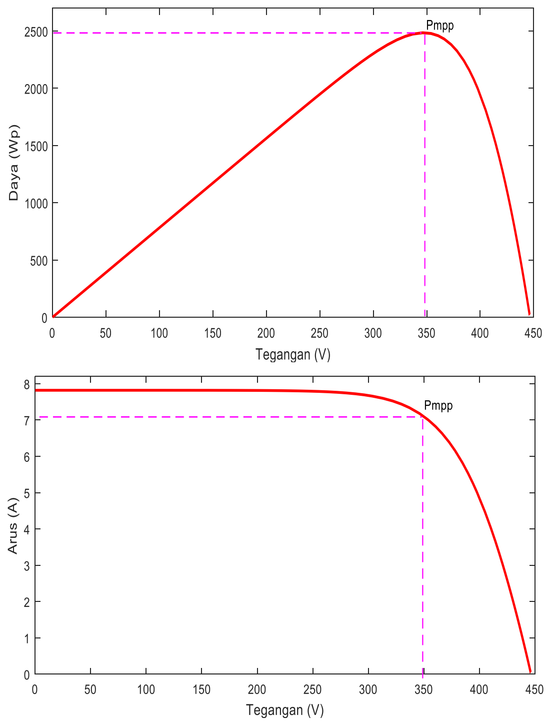

Fig. 11. Characteristic Curve Simulation PV string

To achieve 10 kWp power from PV Farm, the PV arranged in an array by combining panels in series and parallel. PV modules that have been arranged in a string are inserted into one subsystem to make it easier to do parallel links on each subsystem that contains a PV module string. Figure 12 is a modeling of solar panels with a capacity of 10 kWp. PV array model simulation produces characteristic curves. These characteristic curves will be discussed in the results and conclusions.

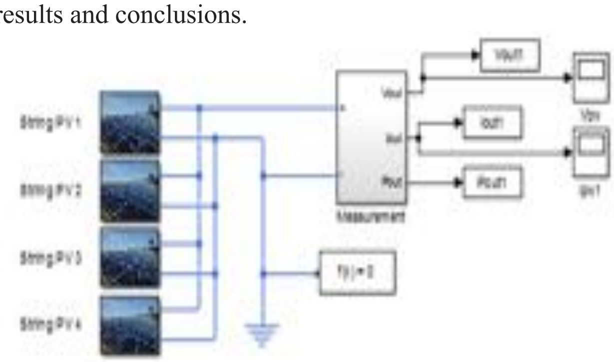

Fig. 12. PV Array 10 kWp

C. Design of Boost Converter

The design of the Converter is done to achieve a voltage of 380 - 400 Vdc. This Converter is designed to keep the voltage steady during the power tracking process. Therefore, Boost Converter is combined using the MPPT P&O Algorithm. The algorithm produces duty cycle as a switching controller in Boost Converter. Figure 13 shows the Boost Converter circuit modeling used in the simulation.

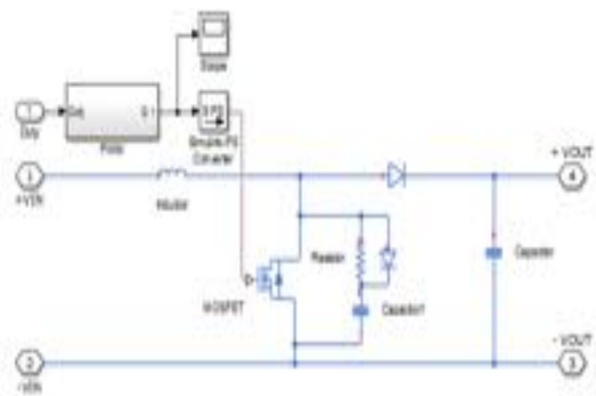

Fig. 13. Boost Converter on Simulink

In designing the Boost Converter circuit, the inductor and capacitor values are needed as follows:

a. Inductor Value Correspons Equation 5.

$$L_{min} = \frac{D(1-D)^2 R}{2f}$$

$$L_{min} = \frac{0.12(1-0.12)^2 16}{2 \times 20000}$$

$$L_{min} = 3.8281 \times 10^{-5} \text{ H}$$

b. Capacitor Value Correspond Equation 6.

$$C = \frac{V_o D}{R \Delta V_o f}$$

$$C = \frac{400 \times 0.12}{16 \times 0.01 \times 20000}$$

$$C = 0.015625 \text{ F}$$

D. P&O System

The P&O algorithm loaded in a subsystem on MATLAB as a duty cycle controller. The duty cycle ratio does not change. If there is an increase in power and voltage, the duty cycle ratio will be reduced. If there is an increase in power but the voltage is fixed or decreases, the duty cycle ratio is added. If the power and voltage of the solar panel drops, the duty cycle ratio is reduced. If the power decreases but the voltage rises, the duty cycle ratio is added.

Duty cycle functions as a switching controller signal generator in the Boost Converter circuit. Duty cycle requires a PWM control signal as a carrier signal. The duty cycle of the P&O algorithm is shown in Figure 15.

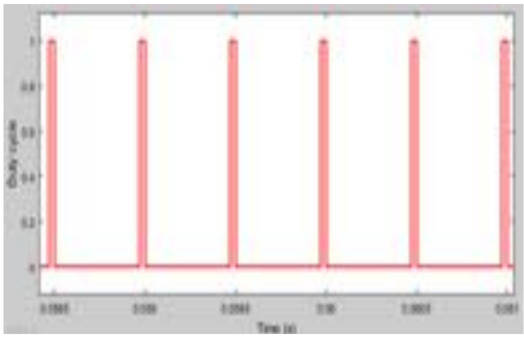

Fig. 15. Duty Cycle

The MPPT P&O algorithm was used in this study to optimize the output power of the designed PV Farm. The P&O Algorithm Program to be used is shown in Program 1.

```
D=d+dd;
 if D<0.01
   D=0.01;
   d=D;
else
   if D>0.99
       D=0.99;
       d=D;
    else
   end
```

Program 1 explains the reading of power delta or power difference. The program is inserted into the system block as shown in Figure 16.

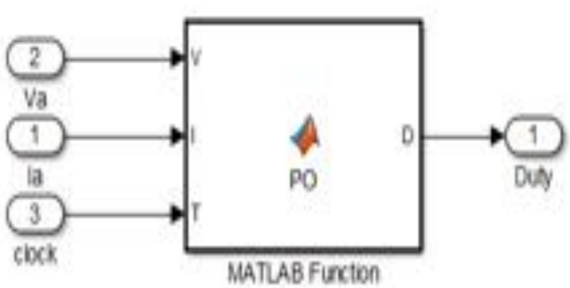

Fig. 16. Design of MPPT P&O Algorithm

E. System Design Diagram Blocks

In this study the parameters of the PV modules used are shown in Table 1. The parameters of the PV modules are adjusted based on the parameters of the PV modules contained in the market.

Table 1. Modul PV 250 Wp

Parameter	Value
Isc	7.82 A
Voc	0.6202 V
Rs	5.10E-03
Pout	250 Watt
Vout	35.86 V

Table 1 it can be seen that each PV module generates a voltage of 0.6202 Volts. And produces a current of 7.82 A during a short circuit. From these parameters the author can determine the number of modules used to achieve power of 10 kWp.

F. Parameter Boost Converter

In accordance with the calculations performed, the Boost Converter parameters can be seen in Table 2. With a frequency of 20 KHz, the inductor and capacitor values are respectively 3.1264e-5 H and 0.01771714 F.

Table 2. Parameter Boost Converter

Parameter	Value
Inductor	3.12624e-5 H
Capacitor	0.01771714F
Switching frequency	20000

G. PV Farm Model Simulation

Simulation tests are carried out using parameters by providing light intensity or known as radiation (G). The amount of radiation given in the simulation to get the characteristic curve of PV modules are 1000 W / m2, 800 W / m2, 600 W / m2, 400 W / m2 and 200 W / m2. The characteristic curves are shown in Figure 17 and Figure 18.

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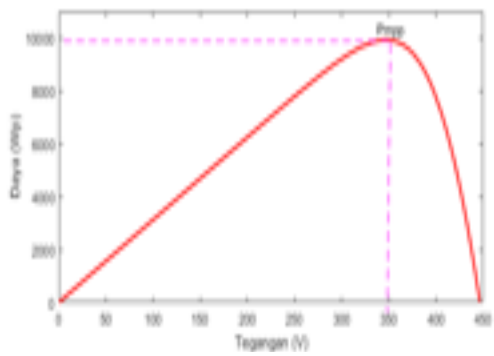

Fig. 17. Pmax Curve PV Farm

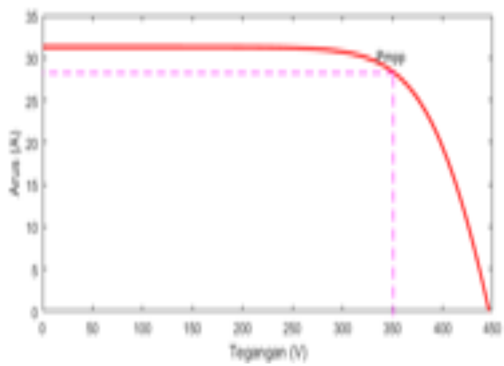

Fig. 18. I-V Curve PV Farm

From Figure 17 and 18 the power, current and voltage values are compared to the duty cycle. From the simulation test conducted, the results obtained are in accordance with Table 3.

Table 3. Data Characteristic PV

Irradiation	Iinput (A)	Vinput (V)	Pinput (Wp)
1000	28.5	350	9975
800	23.5	340	7990
600	18	335	6030
400	12	335	4020
200	5.8	335	1943

H. Test Result of The PV Array Model Using MPPT P&O

After testing with the values of each component that have been set, PV will produce a different output power when exposed to different amounts of solar radiation with a fixed temperature. The curves of the simulation results of the PV model simulation at 1000 W / m2 radiation are shown in Figure 19.

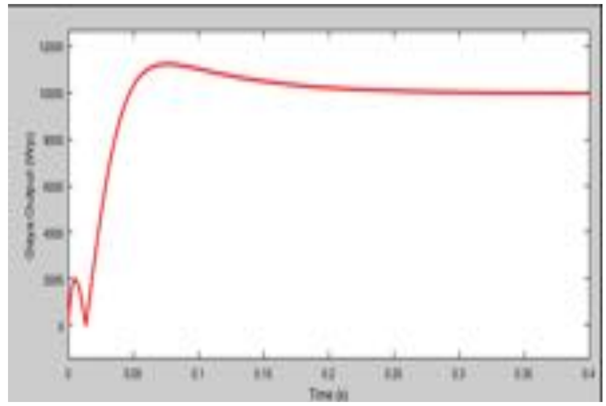

Fig. 19. Output Power on Radiance 1000 W/m^2

Table 5 shows the data of the PV design simulation test results using MPPT P&O and Boost Converter for each of the predetermined radiation. With the maximum amount of radiation, the PV Array produces a maximum power of 9962,385 Wp. The power is reduced if the PV Array receives different amounts of radiation.

Table 5. Simulation Result Using MPPT P&O and Boost Converter

Irradiation	Vout (V)	Iout (A)	Pout (Wp)
1000	397.7	25.05	9962.385
800	396.4	20	7928
600	394.3	15	5914.5
400	391.1	10.1	3950.11
200	388.7	4.9	1904.63

I. Efficiency Result on PV Farm Using MPPT P&O and Boost Converter

Table 6 shows the power efficiency obtained from the simulation results. The use of the MPPT P&O mechanism can determine the efficiency of a panel. PV Array can produce maximum power according to the input power received.

Table 6. Power Efficiency

Irridiation	Pinput (Wp)	Pout (Wp)	Efficiency (%)
1000	9975	9962.385	99.8
800	7990	7928	99.2
600	6030	5914.5	98.08
400	4020	3950.11	98.26
200	1943	1904.63	98.02

J. Result of PV Array Model Using Different Irradiance

To find out the MPPT work point, a PV array test is performed for different radiation as shown in Figure 20.

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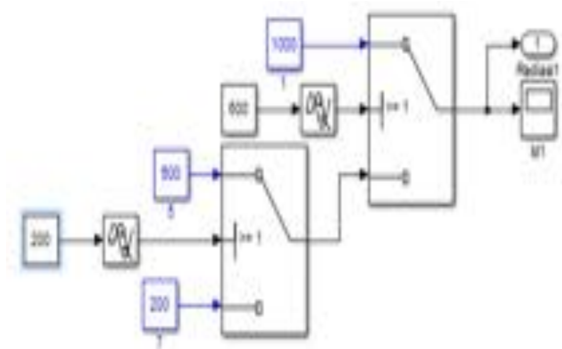

Fig. 20. Different Irradiance of PV Array

The intermittent radiation produces a characteristic curve like in Figure 21. According to the different amounts of radiation, the PV will produce different power.

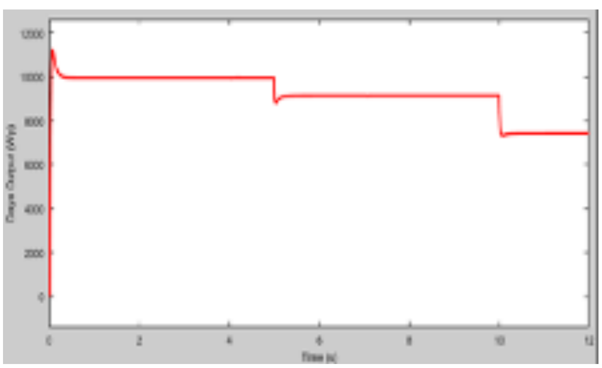

Fig. 21. Output Power Characteristics Curve

The irradiation given to the PV Array is 1000 W/m2, 800 W /m2, 600 W/m2. The power obtained each in the order of radiation that is equal to 10000 Wp, 9000 Wp, and 7900 Wp.

V. Conlusion

From the results of the tests that have been carried out, it can be concluded that the results of the study are as follows:

1. The amount of irradiation received affects the amount of output power from the PV Array.
2. With the MPPT P&O PV Array mechanism, it can reach a maximum power point of 9962,385 Wp with an efficiency of 99.8%.

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