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Fuzzy Maximum Power Point Tracking Using Cuk Converter Onphotovoltaic System

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Abstract: The Potential of solar energy in Indonesia can be used all day long, It's very profitable to generate electrical energy by using photovoltaic. The main problemson using photovoltaic are the generation of electrical energy which is low at low irradiance condition and the magnitude of generated electrical energy changes periodicas weather and temperature change. Maximum Power Point Tracking (MPPT) is the device used to increasethe power ratio of photovoltaic modules. It is used to track maximum point by increasing and decreasing voltage using cuk converter. In this research, fuzzy algorithm is used to adjust the value duty cycle of MPPT device, so that it can increase output power ratio of photovoltaic modules.Theresult showed that the highest power ratio of photovoltaic afterMPPT installation in variation of irradiance is 78.63% when irradiance 1000 W/m^2. At 1000 W/m^2 irradiance conditionincreases power ratio of 33.89%. The highest power ratio of photovoltaic after MPPT installationin variation of temperature is 80.09% when the temperature is 46°C. At 46°C temperature condition, occur increasing power ratio of 36.02%.. And the highest power ratio of photovoltaic after MPPT installation in variation of irradiance and temperature is 79.069% at1000 W/m^2 irradiance and 30°C temperature. At 1000 W/m^2 irradiance and 30°C temperature condition occur increasing power ratio of 34.609%. By installing MPPT device using fuzzy algorithm at photovoltaic module can increase power ratio with an average increase of 29.69% compared to condition before installationof MPPT device.

Keyword: Photovoltaic, MPPT, Duty cycle,Fuzzy Logic

I. Introduction

The potential of solar energy in Indonesia can be utilized all day. This potential is very profitable to generate electrical energy by using photovoltaic [Zeida Zeidane Bouna Ould,2006].

The main component of the photovoltaic system is the module. Photovoltaic modules have been widely used in Indonesia. The main problem with photovoltaic use is low electricity generation, especially under low irradiance. And the amount of electrical power generated is changing periodically as the weather changes [Marcelo Gradella Villava, Jonas Rafael Gazoli and Ernesto Ruppert Filho,2009].The power that can be generated based on the intensity of solar energy when it reaches the earth's surface is around 100 watts per m^2, at 10% photovoltaic efficiency [Eric Anderson, Chris Dohan, Aaron Sikora,2003].

Maximum Power Point Tracking (MPPT) is the device used to increase the photovoltaic power ratio. Maximum Power Point Tracking (MPPT) works by looking for the maximum point from the curve of the power to input voltage (P-V) and the curve of input to input voltage (V-I)on the solar module. With the MPPT method, it is expected that the output power will always be at maximum condition [Chung-Yuen Won, Duk-Hoen Kim, Sei-Chan Kim, Won-Sam Kim and Hack-sung Kim,2009].

There are several MPPT algorithms that have been found and written in international scientific journals such as perturb and observe, incremental conductance, dynamic approach, temperature methods, methods of measuring short circuit currents, artificial neural network, Fuzzy Logic, and others [Moubayed Nazih, El-Ali Ali, dan Outbib Rachid,2009]. All of these algorithms vary in several aspects including simplicity, speed, hardware implementation, sensors needed, cost, effectivity, and parameters needed.

The V-I characteristic curve on the photovoltaic has a non-linear equation and only has one photovoltaic operating point equation to get the maximum condition under certain condition [Marcelo Gradella Villava, Jonas Rafael Gazoli and Ernesto Ruppert Filho,2009].When the current decreases to near zero the use of boost converter cannot reduce the value of the output voltage so that the current value will continue to drop and the voltage value will continue to rise resulting in a small output power [M. G. Villalva, J. R. Gazoli, E. Ruppert F,2009].

To solve this problem, MPPT was developed with a cuk converter on photovoltaic modules using fuzzy logic. The development of MPPT technology with cuk converter uses fuzzy logic in order to increase and decrease the output voltage of the photovoltaic with the duty cycle setting using fuzzy logic. So it can increase the output power ratio of photovoltaic modules. To facilitate analysis, simulations are made using Matlab software.

II. Design and Method

2.1 System Design

Flowchart of the fuzzy logic MPPT design using cuk converter is shown in Figure 1.

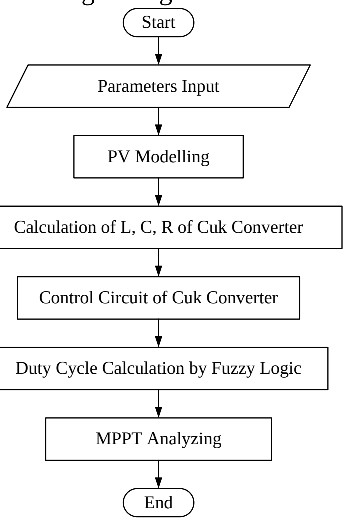

Figure1 System design flowchart

The simulation done by using Matlab 7.8 (R2009a).Table 1 shows PV data used in this simulation.

Table1 Photovoltaic Data

Performance Under Standard Test Conditions (*STC)	
Maximum Power (P_{max})	135 (±5%)
Maximum Voltage (V_{mpp})	17.7 V
Maximum Current (I_{mpp})	7.63 A
Open Circuit Voltage (V_{oc})	22.1 V
Short Circuit Current (I_{sc})	8.37 A
Maximum System Voltage	600 V
Temperature Coefficient (V_{oc})	$-8.0x10^{-2}$ V/^{o}C
Temperature Coefficient(I_{sc})	$5.02x10^{-3}$ A/^{o}C
Cell Per module	36

*STC : Irradiance 1000 W/m^2, AM1.5 spectrum, Cell Temperature 25^{o}C

The simulation design diagram block is shown in Figure 2.

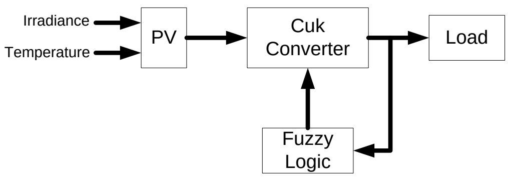

Figure 2 System Diagram Block

2.2 Photovoltaic Module Modeling

2.2.1 Cuk Converter Design

The specification of the cuk converter in this tesearchis shown in Table 2.

Table 2Cuk Converter Specification

Input Voltage (V_{in})*	22,1 V
Switching Frequency (f)	5000 Hz
Maximum Voltage Ripple	0,02 %
Duty Cycle	0,4-0,6
Resistance Load (R)	6
Output Current (I_{out})*	1,63 A

Output Voltage (V_{out})*	17,7 V
Maximum Power (P)*	135 W

** Based on specification data on table1 on STC condition*

a. Selection of Capacitor C_1

Based on equation 2.1, the minimum value of capacitor C1 is as follows [8]:

$$C_{1min} > \frac{D^2 T_s}{2R} \quad (2.1) \qquad C_{min} > \frac{0.6^2 2x10^{-4}}{2x6}$$

$$C_{min} > 6x10^{-6}\ \text{F}$$

SwitchingPeriod(*TS*) is 200µs, D at maximum is 0.6 and R equal to 6 ohm, then obtained*C1* > 6µF, then chosenC_1= 30µF.

b. Selection of Inductor L_1 and L_2

In order for the cuk converter working in CCM mode, the inductanceL_{1min} and L_{2min} and cukconverter circuit must fulfill the equations 2.2 and 2.3 which the valuesare as follows [8]:

$$L_{1min} = \frac{(1-D)^2 R}{2Df} \quad (2.2)$$

$$L_{1min} = \frac{(1-0{,}4)^2 6}{2.0{,}4.5000} = 540\mu\text{H}$$

While the valueL_{2min} as a follow :

$$L_{2min} = \frac{(1-D)R}{2f} \quad (2.\ 3)$$

$$L_{2min} = \frac{(1-0{,}4)6}{2.5000} = 360\ \mu\text{H}$$

Where D is the minimum duty cycle. Because converter is operated by continuous conduction mode (CCM) then

$L_1 > L_{1min}$ and$L_2 > L_{2min}$

then

$L_1 = L_2 = 2000\mu\text{H}$

c. Selection of Capacitor C_2

The value of C_2 can be determined based on approach of the converter ripple voltage value according to equation 2.4 which the value is [9]

$$\Delta V_{c0} = \frac{DV_s}{8C_2L_2f^2} \quad (2.4)$$

$$0{,}02 = \frac{1x\ 22{,}1}{8xC_2x2000x10^{-6}x5000^2}$$

$$C_2 = 2762{,}5\mu\text{F}$$

From the calculation of the values L_1, L_2, $C_1$and C_2, based on equations 2.1 to 2.4 the values of L_1, L_2, C_1 and C_2 are shown in Table 3.

Table 3Value L_1, L_2, $C_1$and C_2 specification data

Inductor L_1	2000µH
Inductor L_2	2000µH
Capacitor C_1	30µF
Capacitor C_1	2762,5 µF

The model of the cuk converter circuit is shown in Figure 3.

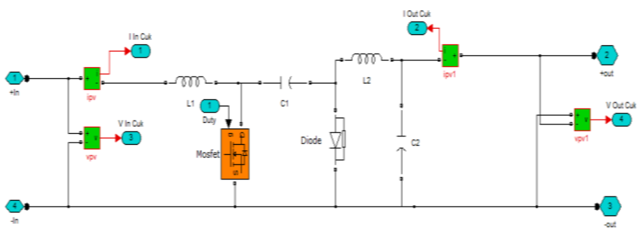

Figure 3Cuk converter circuit

Block modeling of the cuk converter control circuit is shown in Figure 4 [10, 11].

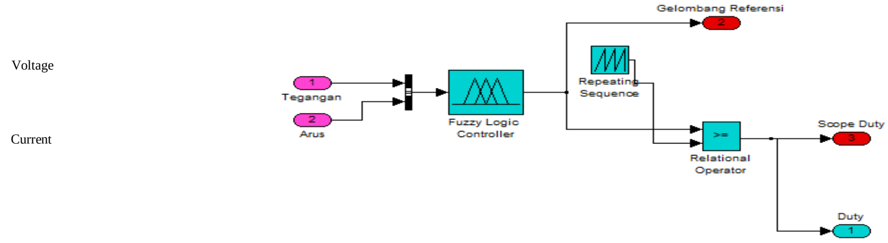

Figure4 Cuk converter control circuit modeling

2.2.2 Fuzzy Logic

The flowchart of fuzzy logic for determining the duty cycle in shown in Figure 5.

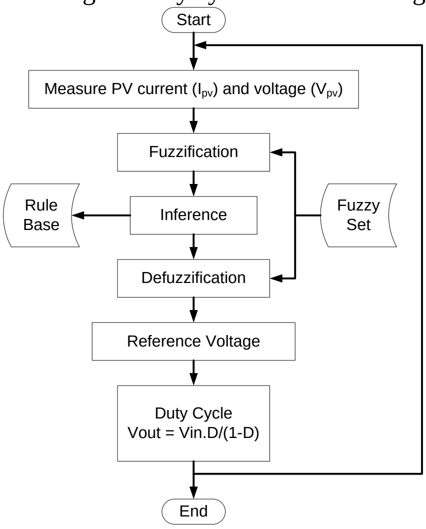

Figure 5Fuzzy logic control flowchart

Membership functions of voltage, current and duty cycle are shown in figures 6,7, and 8.

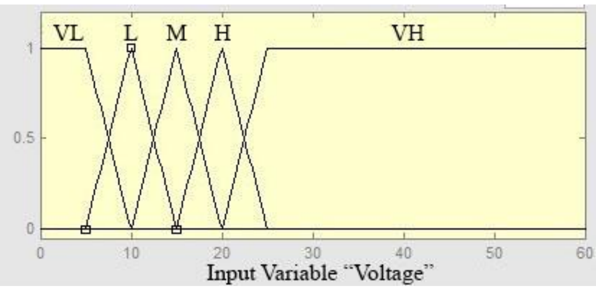

Figure 6 Membership function of voltage

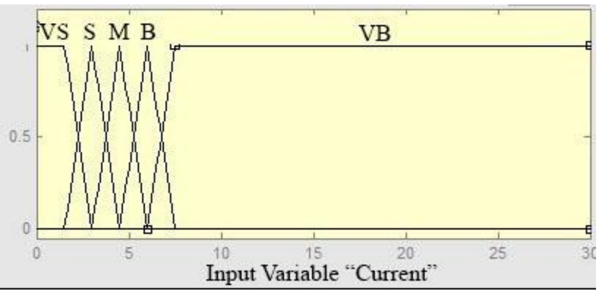

Figure7Membershipfunction of current

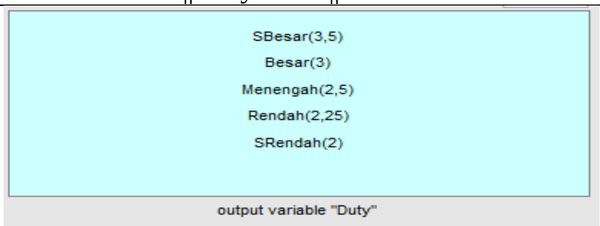

Figure8 MembershipFunction of duty cycle

The rules for determining the duty cycle is shown in Table 4.

Table 4 Rules for duty cycle determination

AND		VOLTAGE				
		VL	L	M	H	VH
CURRENT	VS	VL	VL	M	B	VB
	S	L	VL	L	B	VB
	M	VL	L	L	B	B
	B	L	L	M	B	B
	VB	VL	VL	M	M	B

2.2.3 System Modeling

Model of photovoltaic module with Maximum Power Point Tracking (MPPT) is shown in Figure 9.

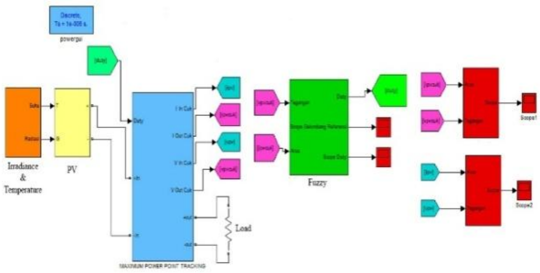

Figure 9 Photovoltaic system with MPPT modeling

III. Result and Analysis

3.1 Irradianceand Temperature Variation

The result of the photovoltaic module modeling test with irradiance and temperature variationis shown in Figure 10.

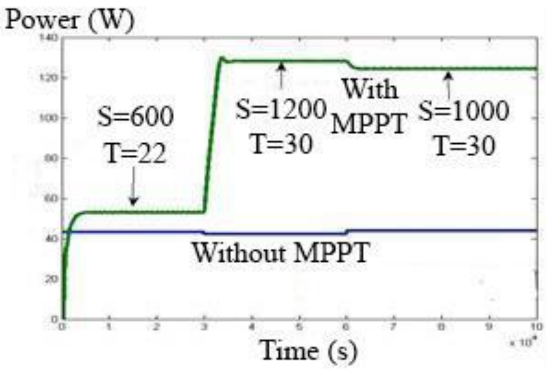

Figure 10Output power at 10 Ω resistance load with temperature (T) and irradiance(S) variation

In Figure 10, the modeling uses a load resistance at 10 Ω, and the value of output power of is obtained 43.32 W at the irradiance of 600 W/m^2 and the temperature of 22^{0}C. When the irradiance rise to 1200 W/m^{2}and the temperature of 38°C, the power is 42.18 W. When the irradiance decrease to 1000 W/m^2 and temperature 30°C, the power is 43.80 W.

The output power of photovoltaic after MPPT installation at the irradiance of 600 W/m^2 and the temperature of 22°C produced a power of 53.18 W with a duty cycle of 0.662. When the irradiance rise to 1200 W/m^{2}in a temperature of 38°C, the value of power result is 128.69 W with a duty cycle of 0.68. When the irradiance drops to 1000 W/m^2 and the temperature is 30°C, the value of power produced is 124.94 W with a duty cycle of 0.664.

The difference in increase power before and after the installation of MPPT at the same resistance is 17.49 W when the irradiance is 600 W/m^2 and the temperature is 22°C.It is 49.94 Watts when the irradiance is1000 W/m^2 and the temperature is 30°C, and 42.79 Watts when irradiance is1200 W/m^{2}in a temperature of 38^{0}C.

3.2 Effect of Load Resistance Changes

Data from the photovoltaic module modeling with irradiance and temperature variation is shown in Figure 11.

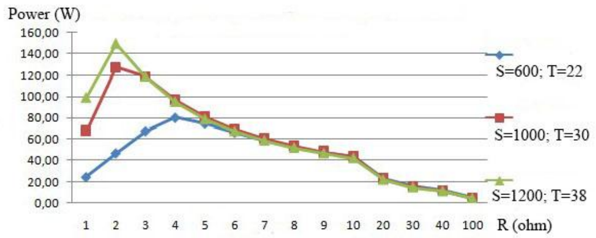

Figure 11Output power before MPPT installation with irradiance (S), temperature (T), and resistance load (R) variation

Based on Figure 11, the highest power that can be achieved from the modeling of photovoltaic modules before MPPT installation with variation in irradiance, temperature and load resistance is 149.68 W at 2Ω load resistance when irradiance is 1200 W/m^2 and temperature is 38°C. While the lowest power value is 4.47 W at 100Ω load resistance when irradiance is 1200 W/m^2 and temperature is 38°C.

Photovoltaic modeling data after MPPT installation with variations in irradiance, temperature and load resistance is shown in Figure 12.

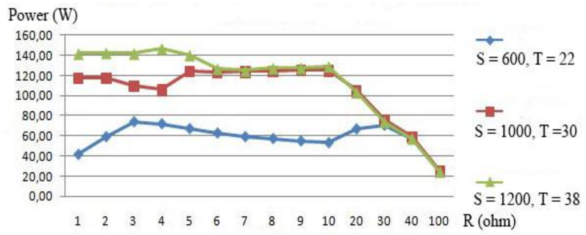

Figure 12 Output power after MPPT installation with irradiance (S), temperature (T) and load resistance (R) variation

Based on Figure 12 on each load resistance value, the graph of the duty cycle value can be seen in Figure 13 below

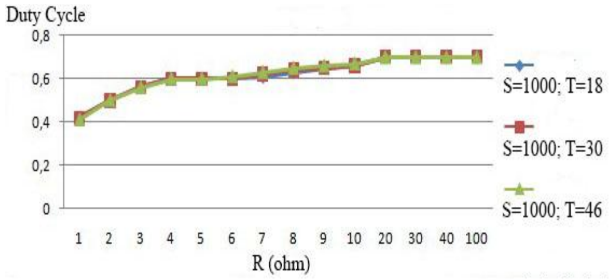

Figure 13Duty cycle after MPPT installation with irradiance (S), temperature (T), and load resistance(R) variation

In Figure 13, the highest power that can be achieved from PV after MPPT installation is 146.49 W at 5Ω load resistance when irradiance is 1200 W/m^2 and temperature is 38°C with a duty cycle of 0.6. While the lowest power is 24.21 W at 100 Ω load resistance when irradiance is 1200 W/m^2 and temperature is 38°C with a duty cycle of 0.70. In Figure 16, the duty cycle generated from the control circuit has a value that approaches each other for each change in irradiance.

3.3Analysis of PV Power Ratio

The photovoltaic power ratio before and after installation of MPPT is shown in Figure 14.

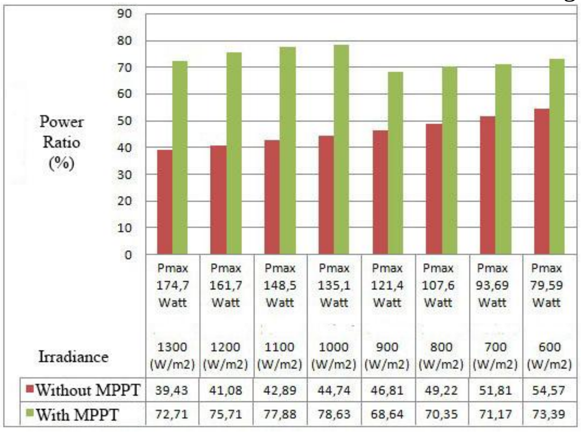

Figure 14Power ratio vsvariation in irradiance (S)

In Figure 14, it can be seen that after the installation of the Maximum Power Point Tracking (MPPT), the power ratio of the photovoltaic module increased from 18% to 35%. The highest power ratio 78.63%occurs when irradiance 1000 W/m^{2}is used, with a difference in power ratio of 33.89% compared to the output power of a photovoltaic module without MPPT. The power ratio produced by the addition of the MPPT device at each change in irradiance from interval 1300-600 W/m^2 is 73.56% with an increase in power ratio of 27.44% compared to the output power of photovoltaic module before installation of the MPPT device.

The power ratio for temperature changed from intervals of 18°C to 46°C. The photovoltaic power ratio before and after MPPT installation is shown in Figure 15.

From Figure 15 it can be seen that after the installation of the Maximum Power Point Tracking (MPPT) device the value of the power ratio of the photovoltaic module increased from 30% to 36%. The highest power ratio occurs at 46°C at 80.09% with a difference in power ratio of 36.02% compared to the output power of a photovoltaic module without MPPT at the same temperature. The power ratio produced by adding MPPT devices at each temperature change from the 18°C- 46°C interval is 79.18% with an increase in the power ratio of 32.09% compared to the output power of the photovoltaic module before installation of the MPPT device.

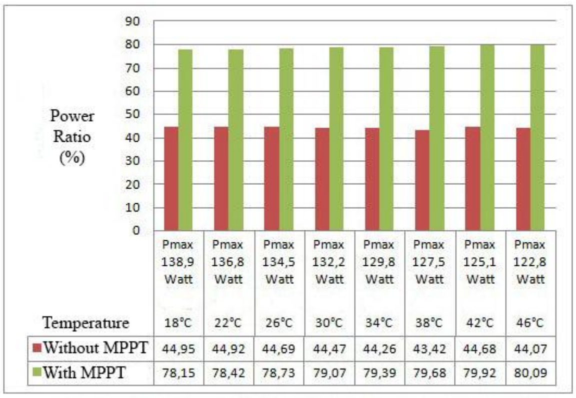

Figure 15Power ratio vsvariation in temperature (T)

If the irradiance and temperature change together then the value of the photovoltaic module modeling test before the installation of the MPPT and the photovoltaic module after this MPPT installation is shown in Figure 16.

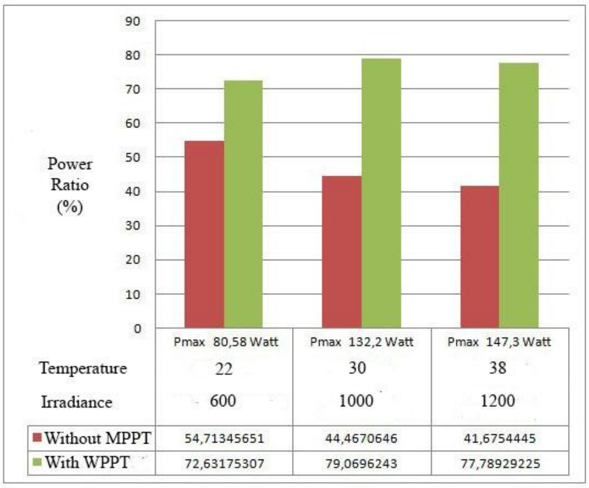

Figure 16Power ratio vs variation in irradiance (S) and temperature (T)

In Figure 16, it can be seen that with the addition of the Maximum Power Point Tracking (MPPT) device, the power ratio value of the photovoltaic module increased from 17.92% to 35%. The highest power ratio79.069% occurs at 1000 W/m^2 and the temperature of 30°C, with the difference in power ratio of 34.609% compared to the output power of the photovoltaic module without MPPT. The power ratio produced by the addition of the MPPT device at each change in solar irradiance and temperature is 76.49% with an increase in the power ratio of 29.54% compared to the output power of the photovoltaic module before installation of the MPPT device. The Maximum Power Point Tracking (MPPT) device is able to increase and maintain the output power of the photovoltaic module near its maximum point by adjusting the duty cycle using fuzzy logic.

IV. Conclusions

The Maximum Power Point Tracking (MPPT) with a cuk converter using fuzzy logic can be used to find the maximum operating point of a photovoltaic so that it can increase the ratio of output power of photovoltaic due to temperature and irradiance variation.

a. The highest power ratio of photovoltaic after installation of MPPT with variation of irradiance is 78.63% when irradiance is 1000 W/m^2 with an increase of 33.89% compared to photovoltaic without MPPT.
b. The highest power ratio of photovoltaic modules after installation of MPPT with temperature variation is 80.09% at a temperature of 46°C with an increase of 36.02% compared to photovoltaic without MPPT at the same temperature.
c. The highest power ratio of photovoltaic modules after installation of MPPT with irradiance and temperature variation is 79.069% at irradiance 1000 W/m^2 and temperature of 30°C with an increase of 34.609% compared to photovoltaic without MPPT at the same irradiance and temperature.

Installation of MPPT on photovoltaic system can increase the power ratio by an average increase of 29.69% compared to condition before the MPPT installation.

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