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An Improved Photovoltaic Array Configuration for Photovoltaic System in the Presence of Maximum Power Point Tracking during Partial Shading Condition

K. Burhanudin*[1], N. A. Kamarzaman[2], A. A. A. Samat[3], A. I. Tajudin[4], S. S. Ramli[5], N. Hidayat[6]
[1,2,3,4,5] Faculty of Electrical Engineering, UiTM Permatang Pauh, 13500, Pulau Pinang, Malaysia
[6] Faculty of Electrical Engineering, UiTM Shah Alam, 40450, Selangor, Malaysia
*Corresponding author, e-mail: koiezy.kr@gmail.com

Abstract

Power-Voltage (P-V) curve and Current-Voltage (I-V) curve determine the performance of the PV system. In this work, the arrangements of the PV module were reconstructed by adding the number of PV module in 3 strings configuration from 5 to 45. This method enhance the performance of the PV system as it able to show the characteristic of the P-V and I-V curve during partial shading and maximum irradiance despite higher number of PV panel. This study focuses on improving the PV array configuration and simulation speed of the PV panel. The simulation of small size PV array is possible, but the problem lies when the number of string and PV module used increases. New PV array configuration is flexible and easy to add string and increase the number of PV module. PV array configuration was modeled using MATLAB/SIMULINK software.

Keywords*: I-V, P-V, MPPT, Photovoltaic*

1. Introduction

Renewable energy source (RES) is non-polluting indigenous resources which the source is recurring and non-depleting. Researches on photovoltaic (PV) system develop drastically due to increment of petroleum prices and the need to reducing greenhouse gasses [1]. PV panel was used to absorb solar energy from the sun and convert it to electrical energy; lots of researches have been made to improve the performance of PV module to achieve high output power. PV module consists of P-N junction fabricated in the form of thin film. The particle interaction cause electron to be produces at the other end of the PV panel. The electron flow will cause electricity to flow in the opposite direction. The process of the PV panel to produce electricity starts when PV module absorbs photon from sunlight. Photon absorption causes particle interaction on the PV module. PV module consists of P-N junction just like a diode and fabricate in thin layer of semiconductor.

PV module use for the simulation is of mono-crystalline cells based on NT R5E3E model. The mono-crystalline cells have the highest efficiency when compared to other cells [1]. Temperature and irradiance is inversely proportional to each other in term power production from PV module. The higher the irradiance causes the higher power of the PV module. In contrast, high temperature cause opposite power value. High temperature causes the air gaps between photon narrower while low temperature causes the air gaps between photon wider. The wider gaps of photon will cause the photon absorption to the PV module higher hence the current and power produces bigger [2]. By using Particle Swarm Optimization (PSO) for Maximum Power Point Tracking (MPPT), it is able to shorten the process of tracking maximum power. Each particle position represent the possibility of the solution for the optimization problem by finding the fitness value of each particle, where it is used to identify the personal best position [3]. This paper studies the combination of PV array and compares the output characteristic of series-parallel PV array under various irradiance values.

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2. Research Method
2.1. Photovoltaic (PV) Array Configuration

PV module used is single diode model. The model consists of 2 inputs and 2 outputs. For this PV array configuration, the PV voltage and irradiance is the input for PV system while PV current and PV power is on the output side. Figure 1 shows the characteristic of the single diode SIMULINK PV cell.

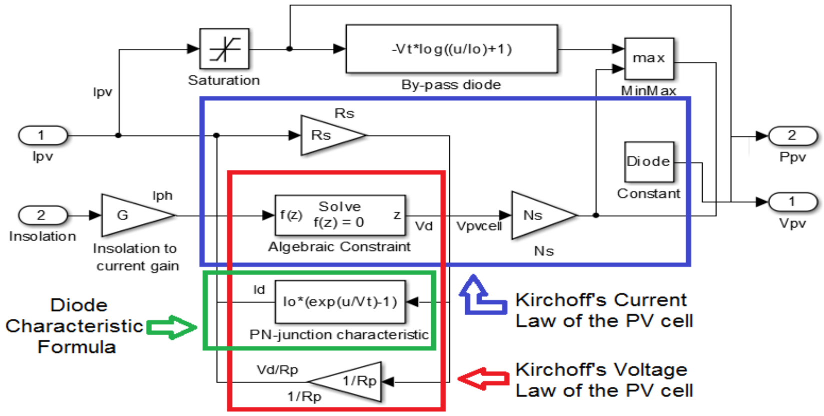

Figure 1. The SIMULINK Photovoltaic (PV) cell block

The equation below shows the characteristic of the SIMULINK PV module block shown from Figure 1. This equation shows how PV cell works and relationship of each block. The equation below is the equation from the real single diode model PV cell.

Photovoltaic (PV) cell equations:

Kirchhoff's Current Law of the PV cell,

$$I_{sc} - I_D - (V_d / R_P) - I_{PV} = 0 \quad [4]$$

Diode characteristic formula,

$$I_D = I_o (e^{VD/VT} - 1) \quad [5]$$

Kirchhoff's Voltage Law of the PV cell,

$$V_{PV\text{-}Cell} = V_D - R_s I_{PV} \quad [6]$$

Where,

V_D : Diode Voltage
V_T : Thermal Voltage
V_{PV} : PV cell Voltage
I_D : Diode Current
I_{PV} : Photovoltaic Current
I_o : Reverse Saturation Current
I_{SC} (I_{ph}) : Short Circuit Current
R_s : Series Resistance
R_P : Parallel Resistance

Data driven method of modelling eliminate the need of formulating and implementing mathematical formulae [7]. Simulink PV model used for the research is set from following SHARP NT R5E3E model. Table 1 shows the SHARP NT R5E3E PV module. This module is mono-crystalline PV module and weighting at 17 Kg per PV module.

The number of module used for PV connection is 12, which 6 PV module connected in series consisting of 2 strings. Parallel connection included for the PV array connection to minimise the space used for PV array connection. However if the string is too long, then the simulation for the PV array will be very slow. Figure 2 shows the series-parallel connection of the PV array in 2 strings while Figure 3 showsthe series-parallel connection in 3 strings.

Table 1. Parameters of SHARP NT R5E3E PV module (Irradiance of 1000W/m^2, AM1.5 Spectrum and cell temperature of 25 ^{0}C)

Nominal Rating	Value
Maximum Power (+10%-5%) (P max)	173.5W
Open Circuit Voltage	44.4V
Short Circuit Current	5.4A
Voltage at max	35.4V

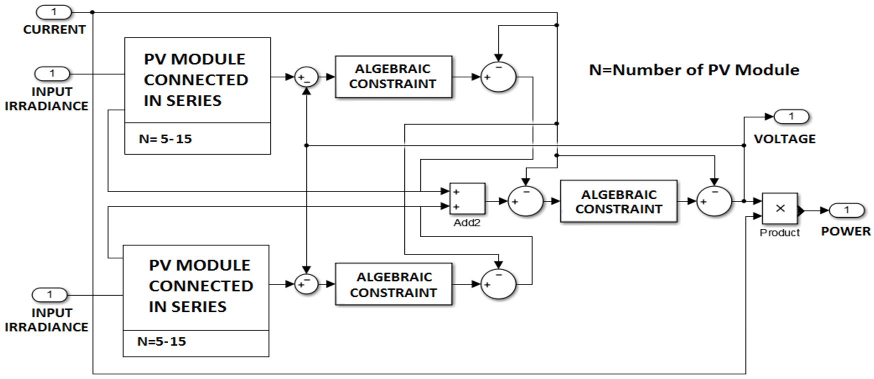

Figure 2. Parallel connection of PV array in 2 strings

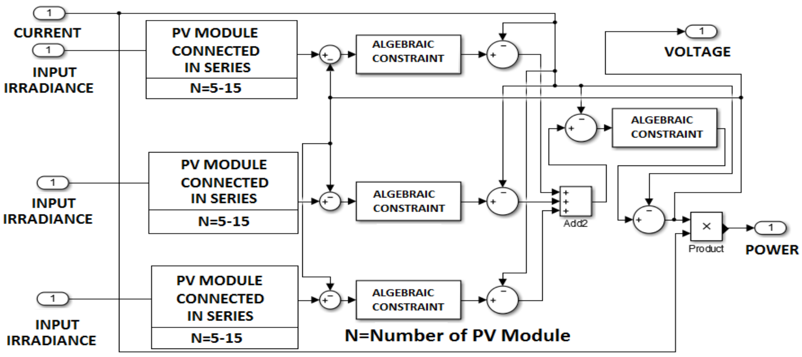

Figure 3. Parallel connection of PV array in 3 strings

2.2. Non Uniform Illumination (Partial Shading)

Non uniform irradiance is the situation where PV module unable to absorb full irradiance from the sun light. This situation is also known as partial shading. Non uniform irradiance is part of natural process that happen during power harvesting process. It is impossible to absorb full irradiance from the sunlight continuously. In order to justify the partial shading condition, the irradiance value is input to the PV module randomly. Partial shading is due to the shadow which blocks the PV panel from absorbing total power from sunlight. The shadow is cause by dust on the PV module, cloud blocking the sun, shadow from the tree, blocking from the building and many more. Table 2 shows the amount of irradiance as input to the PV module. If several cells in series PV module mismatched, this cell will limit the output current of normal cells. This may lead to decrease the output power, even present hot spot cause damage to the cells [8].

Table 2. Amount of Solar irradiance tested to the PV module

PV Module	Amount of solar irradiance 1st irradiance, W/m^2	2nd irradiance, W/m^2
1	1000	500
2	850	300
3	650	500
4	450	300
5	250	500
6	150	1000
7	1000	800
8	900	600
9	700	800
10	500	600
11	300	800
12	100	1000

Most of the PV module also have a by-pass diode and reverse blocking diode. The approach enables easy integration of PV modules of any type in series or parallel configurations to suite an end user application [9].

2.3. PV Array in the Presence of MPPT

MPPT technique used is based on Particle Swarm Optimization (PSO). PSO is based on swarm intelligent movement which is known as particle position update and velocity update. It simulated the movement of organisms of bird flocks or fish schools [10]. Based on the advance update method, PSO is able to track the PV power at a shorter time. The formula for PSO is given as:

Particle Swarm Optimization formula

Velocity update,

$$V_i^{k+1} = W\, V_i^{\ k} + c_1 r_{1i}^{\ k} (P_i^{\ k} - x_i^{\ k}) + c_2 r_{2i}^{\ k} (P_g^{\ k} - x_i^{\ k}) \qquad [11]$$

Position update,

$$X_i^{k+1} = X_i^{\ k} + V_i^{k+1} \qquad [12]$$

Based on the given formula, $V_i^{\ k+1}$ represent the velocity update, $V_i^{\ k}$ is the original velocity state, X_i^{k+1} is update position state, $X_i^{\ k}$ is the original position of particle, r_1 and r_2 is two randomly distributed, W is weight ratio, $P_i^{\ k}$ and $P_g^{\ k}$ is power value local and global, and c_1 and c_2 is influence of individual learning rate. Figure 4 and 5 shows the connection and MPPT block of PSO on PV system.

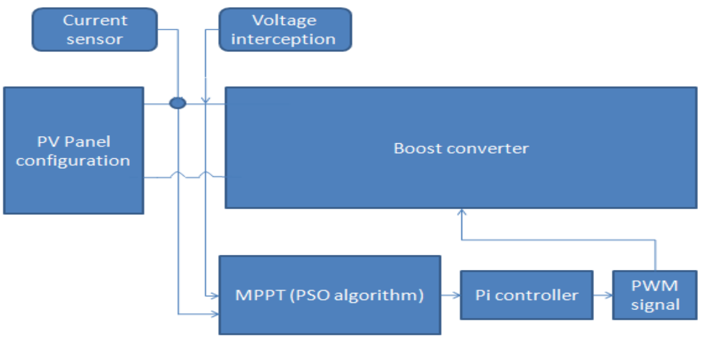

Figure 4. The Connection of PSO algorithms on PV system

The proposed PV array configuration design give lots of advantage to the user. PV array can be configured up to 45 PV module at the same time connected in 3 strings, means that in 1 string consisting of 15 PV module. Resistor value of the boost converter need to be the value of total voltage emitted from the PV array divided the total value of current produce by the PV array. The value of inductor and capacitor of the boost converter are changeable following the situation of the simulation. Manufacturer of photovoltaic modules, instead of the parameters that forms I-V equation, manufacturer only provide few experimental data about electrical and thermal characteristic at STC conditions [13]. Figure 6shows the boost converter used for the research.

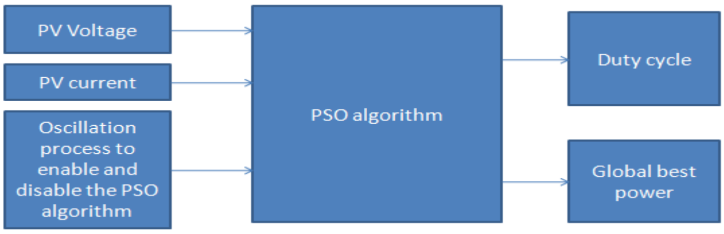

Figure 5. The MPPT block consisting of PSO algorithm

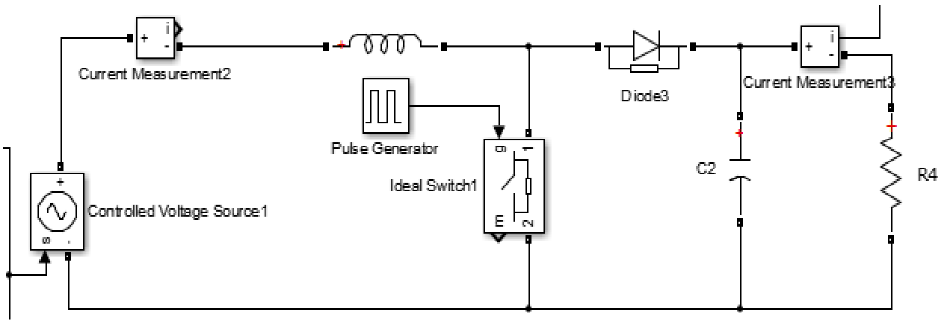

Figure 6. The Boost converter model used to test the PV array configuration

3. Results and Analysis

3.1. Tested PV Array Configuration with Uniform Irradiance using Particle Swarm Optimization (PSO) as MPPT

In order to test the new configuration of PV panel, the PV array is connected directly to boost converter. For this test, PV array consists of 12 PV panels whereas 6 PV panels connected in single string. Open circuit voltage 266.4V, short circuit current 10.8 A, PV voltage 212.4 V, PV current 9.9 A, load resistance of PV panel set to 280 ohm and overall equivalent resistance of the irradiance between 100 to 1000 W/m^2 is lower than 280 ohms which involving the impedance matching process. The formula involve in this test is $R_{eq} = (1\text{-}D)^{2} R_{load}$ [14]. By using this formula it is clear that R_{eq} depends on duty cycle and load resistance. If R_{load} is constant then R_{eq} depend only on duty cycle. The value of R_{eq} equals to V_{in}/I_{in}. The value of R_{eq} will affect the value of V_{in}, I_{in} and the extracted power from PV panel. Table 3 shows the output power changes depends on the irradiance of the absorbed by PV panel.

Table 3. Amount of PV Power collected due to uniform irradiance and the duty cycle required to converge at peak Power

Irradiance, W/m^2	PV Power, W	Duty Cycle, D
1000	2103	0.71
900	1894	0.69
800	1683	0.67
700	1469	0.648
600	1252	0.617
500	1033	0.578
400	812.7	0.525
300	591	0.448
200	369.6	0.318
100	152.4	0.036

The data of the duty cycle and PV power collected simultaneously and observe based on the graph simulated. Figure 7 to 9 shows the PV power collected based on irradiance from 100 to 1000W/m^2. This peak power is collected by implementing PSO as MPPT.

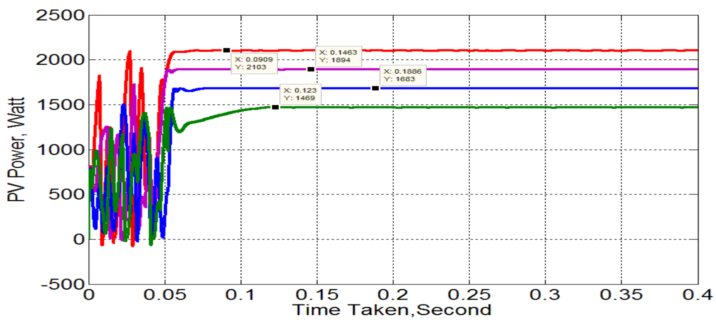

Figure 7. The PV powers irradiance from (700-1000) W/m^2

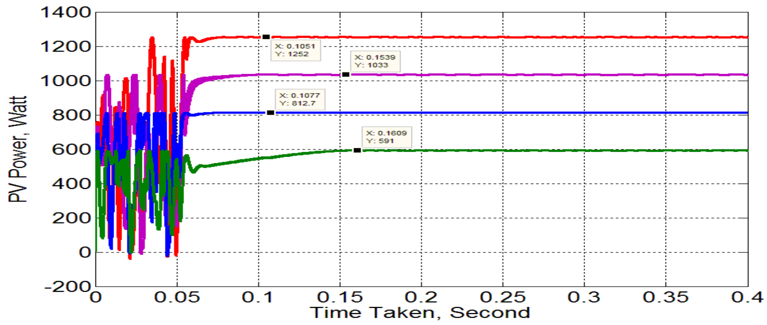

Figure 8. The PV powers irradiance from (300-600) W/m^2

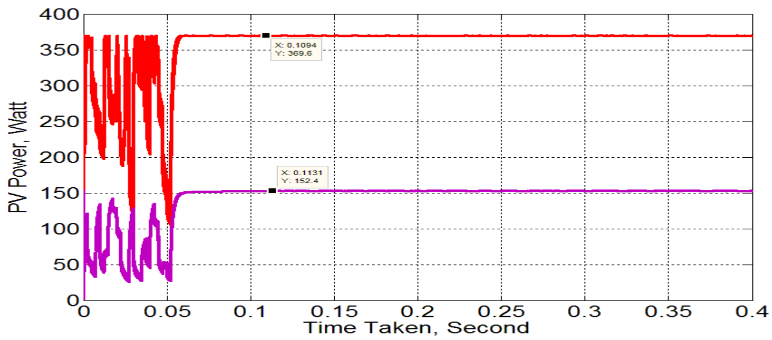

Figure 9. The PV powers irradiance from (100-200) W/m^2

3.2. Tested PV Array Configuration with Partial Shading Condition using Particle Swarm Optimization (PSO) as MPPT

Simulation result follows the irradiance value from Table 2 where the simulation is conducted to collect the reading of PV voltage, current and power. The graph of P-V curve, I-V curve and PV power is collected to observe the differences between uniform irradiance and partial shading. Table 4 shows the value of the PV voltage, current and power due to partial shading irradiance based on Table 2.

Table 4. The PV voltage, current and power collected during partial shading condition

Parameters	1st irradiance, W/m^2 value	2nd irradiance, W/m^2 value
PV Voltage (V)	112.4	221.5
PV Current (A)	6.74	4.6
PV Power (W)	757.2	1019
Duty Cycle (D)	0.7476	0.5525

After PV system simulated, the PV voltage and current is collected. The changes of irradiance and surrounding temperature are the main factors which influenced the value of PV voltage and current. From the parameters setup, the value of voltage is highest when the irradiance is high and the temperature is low. Meanwhile, the value of voltage is medium when both irradiance and temperature is high. The value of voltage is lowest when the irradiance is low and temperature is high. PV module used in MATLAB software is not temperature dependence, therefore the value of current, voltage and power totally depends on the value of irradiance. I-V and P-V characteristic curve of the PV module are shown in the Figure 10 to Figure 15. The P-V and I-V curve is not uniform and consisting multiple peak.

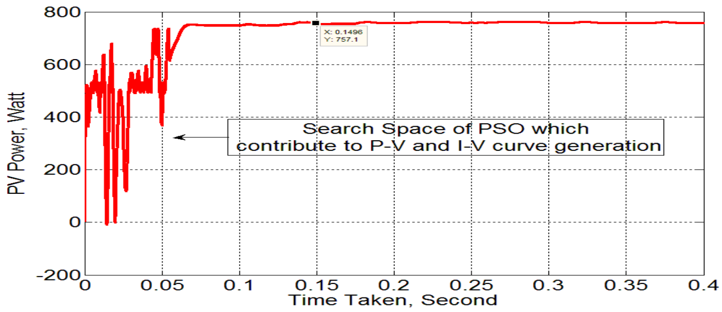

Figure 10. The PV power collected based on 1st irradiance value by using PSO as MPPT

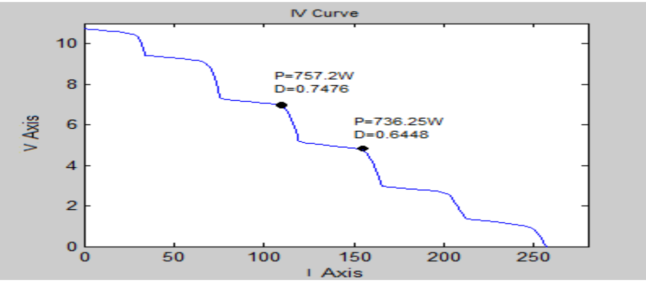

Figure 11. The I-V curve characteristic for 1st irradiance value by using PSO as MPPT

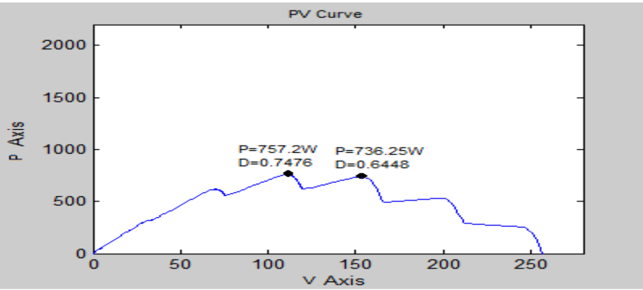

Figure 12. The P-V curve characteristic for 1st irradiance value by using PSO as MPPT

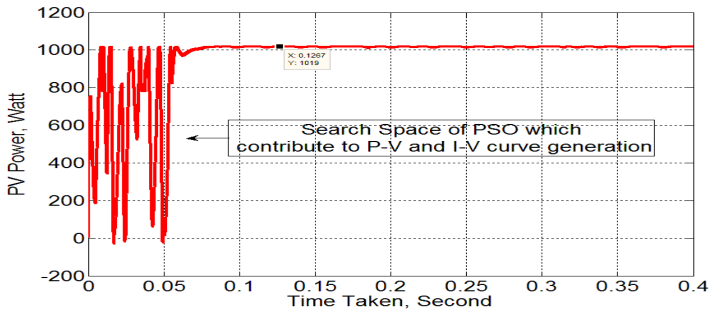

Figure 13. The PV power collected based on 2nd irradiance value by using PSO as MPPT

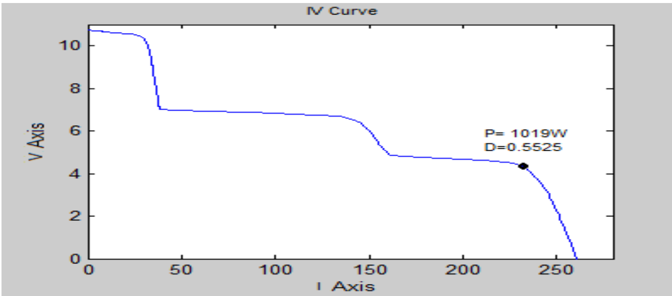

Figure 14. The I-V curve characteristic for 2nd irradiance value by using PSO as MPPT

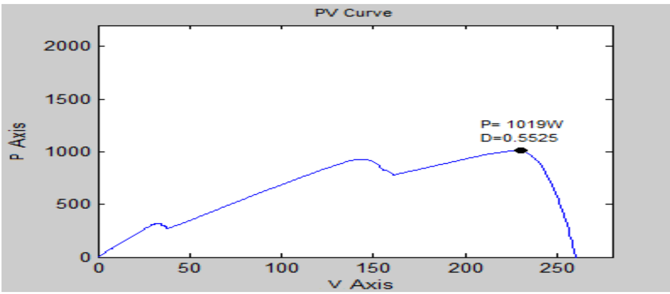

Figure 15. The P-V curve characteristic for 2nd irradiance value by using PSO as MPP

4. Conclusion

As a conclusion, simulation process of the PV module by using this PV array configuration is greatly improved by its capacity of handling 45 PV modules at one time. Simulation takes longer time for a big number of PV modules. However, the output I-V and P-V curve produce is accurate depending on the value of irradiance input to the system. The PV array configuration works well under difference irradiance value and generate graph simultaneously. The presence of boost converter is essential as it can give a preliminary picture of how the PV system will work. The present of bypass diode have a strong influence on the performance of the PV module under partial shading conditions. The presentation of PSO in the MPPT makes the process to track the optimum output power from the new configuration of PV module faster and accurate.

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