Hybrid Modified PSO – IC Methods Based MPPT to Overcome Partial Shading

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Abstract: Electrical energy can be generated by using solar panels to convert solar energy. However, it is highly influenced by weather conditions. This often affects the output power of the solar panels not in its optimum condition. During the day shadows could block the surface of the solar panels, a condition called partial shading, where several peak power points appear on the power-voltage (P-V) curve, namely the local maximum power point (LMPP). From several LMPPs, there is one point that produces the most power called the global maximum power point (GMPP). This condition causes the conventional MPPT method trapped in LMPP which hampers the output power optimization of the solar panels. In this paper, the proposed MPPT system combines conventional methods with artificial intelligence, the Modified Particle Swarm Optimization with the Incremental Conductance method, to avoid LMPP and produce maximum solar panel output power. The MPSO method has 98.36% accuracy with 0.5 seconds tracking time. The Incremental conductance has faster tracking time of 0.3 seconds but was trapped in LMPP with only 61.89% accuracy, while the proposed method has higher tracking accuracy average of 99.66% with 0.34 seconds tracking time in average to achieve GMPP.

Keywords: Maximum Power Point Tracking (MPPT), Partial Shading, Incremental Conductance, Modified Particle Swarm Optimization (MPSO).

1. Introduction

Renewable energy is very important at the moment because the increasing need for energy over time unproportionate superior to the availability of fossil which remains the main energy source. One of the renewable energies that are very abundant is solar energy [1]. It is a natural energy that is environmentally friendly, pollution-free and can be used throughout the day when the sun is shining. Electrical energy can be obtained by using solar panels that convert the solar energy [2].

Solar panels have a characteristic curve of power-voltage (P-V) and current-voltage (I-V). The solar panel's characteristic curve determines the optimal operating point, i.e. the point where the solar panel output power reaches maximum, also known as the maximum power point (MPP). However, the power generated by the solar panels is affected by weather conditions, temperature and solar irradiation that are prone to sudden change [3][4]. This causes output power to fluctuate and consequently hampers the maximization of photovoltaic modules. Therefore, a solution is needed so that the power generated from solar panels is still optimal in its utilization. The MPPT (Maximum Power Point Tracking) technique can be used to maximized the output power of solar panels by searches for its maximum power points [5].

However, when the solar panels work during the day, there is a possibility that its surface is partially blocked by shadows, leaves, and other objects so that the solar irradiation reception is not optimal and causing a decrease in output power [6]. This situation is called partial shading, which can result in the emergence of several peak points on the power-voltage curve (P-V), namely Local Maximum Power Point (LMPP) and Global Maximum Power Point (GMPP) [7].

Currently, there are a lot of developed methods used for MPPT, from conventional methods to artificial intelligence methods. Some conventional methods that are often used for MPPT are the Perturb and Observe (P&O) and the Incremental Conductance [8][9].

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Some of the artificial intelligence methods are Artificial Neural Network (ANN), Fuzzy Logic Control (FLC), Modified Particle Swarm Optimization (MPSO), Firefly Algorithm (FA), Flower Pollination Algorithm (FPA), and many more. Each method has its own advantages and disadvantages, both conventional and artificial intelligence methods [2].

The conventional methods for MPPT is widely use simply because it's easy to implement and able to produce high power efficiency [10]. However, it could potentially get stuck in LMPP and not be able to achieve GMPP during partial shading [11][12]. Therefore, MPPT using the artificial intelligence method or soft computing is employed to search for GMPP so that the solar panels output power remains optimal [7][13]. Nevertheless, this method has certain weaknesses, such as complexity in the coding process and, sometimes, a long tracking time due to computing process [11].

In this paper, a method that combines conventional with artificial intelligence methods, namely the hybrid Modified Particle Swarm Optimization - Incremental Conductance method, is proposed. This method is used to find GMPP with high accuracy and fast tracking time. The proposed method will be compared with each method alone, MPSO and incremental conductance, in the process of finding the GMPP in partial shading conditions. The optimization method for the proposed MPPT is implemented in a DC-DC converter.

2. Solar PV Module

A. Solar PV Module Modelling

Solar panels are power plants that use solar energy directly to produce a source of electrical energy. In solar panels, there are semiconductor elements that can generate electrical energy by converting solar energy. One of the renewable energies that has an abundant amount to be utilized is solar energy.

Figure.1 [14] shows the solar panel equivalent circuit which consists of a current source (I_{pv}), a diode (D), and a series resistor (R_{se}).

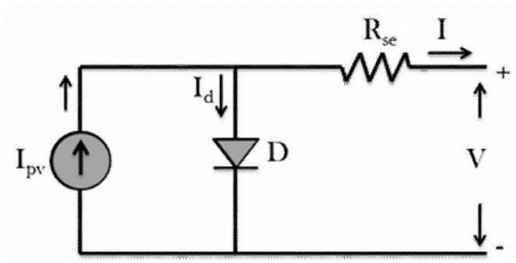


Figure 1. Solar Panel Equivalent Circuit [14]

The Kirchoff's law can be used in the solar panel equivalent circuit to obtained the value of the output current (I).

The equation for the output current (I) on a solar panel:

$$I = I_{pv} - I_d \tag{1}$$

Equation (2) can be rewritten as:

$$I = I_{pv} - I_s \left\{ \exp\left(\frac{q}{A_k T_c N_s} V + IR_{se}\right) - 1 \right\} \tag{2}$$

where

$$I_{pv} = [I_{sc} + K_1(T_c - T_r)] \cdot G \tag{3}$$

$$I_{pv} = I_{rs}\left(\frac{T_c}{T_r}\right) \exp\left[\frac{qE_g}{A_k}\left(\frac{1}{T_c} - \frac{1}{T_r}\right)\right] \tag{4}$$

$$I_{rs} = \frac{I_{sc}}{exp\left(\frac{q}{A_k T_{c(n)} N_s} V_{oc}\right) - 1} \tag{5}$$

The equivalent circuit modeling of solar panels generally has a parallel resistor (R_p) connected in parallel to the diode as shown in Figure.2 [15] below. Even so, the value of the parallel resistor (R_p) is extremely high. Subsequently, it is usually neglected in the solar panel equivalent circuits model.

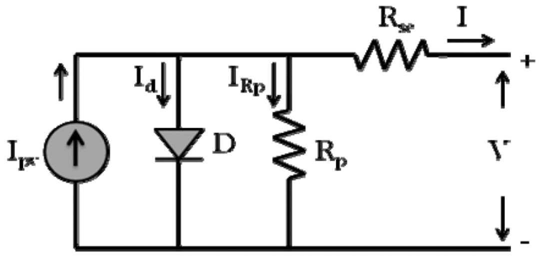


Figure 2. Solar Panel Equivalent Circuit with Parallel Resistor [15]

Solar panels have a power-voltage (P-V) characteristic curve with a maximum power point (MPP) influenced by weather conditions, such as irradiation, and temperature. Figure.3 [16] shows the solar panels power output with different irradiation.

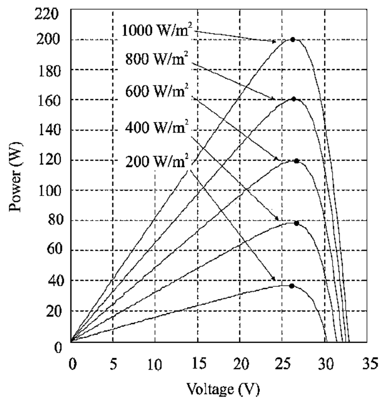


Figure 3. P-V for Different Irradiation [16]

Figure.3 shows that the solar panel operates optimally or at its maximum when the solar irradiation is a maximum value of 1000W/m^2. The maximum power generated by solar panels decreases with decreasing solar irradiation value.

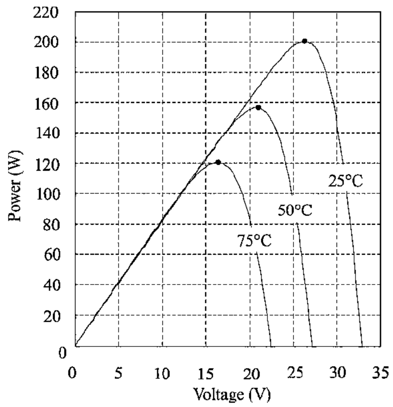


Figure 4. P-V for Different Temperature [16]

Shown in Figure.4 [16] is the power - voltage characteristic curve (P-V) of solar panels that are influenced by temperature. It is known from the characteristic curve above, that the maximum power of the solar panels is obtained at a temperature of 25°C. The solar panels power output will decrease as the temperature rises.

This research uses three solar modules with a total generated power of 300 Watts. Table 1 shows the proposed solar module specifications.

Table 1. Solar Module Specification

Polycrystalline	
Rated Maximum Power (Pmp)	100 W
Voltage at Pmp (Vmp)	17,8 V
Current at Pmp (Imp)	5,62 A
Open-circuit Voltage (Voc)	21,8 V
Short-circuit Current (Isc)	6,05 A
Maximum System Voltage	1000 V
Dimension	$1125 \times 670 \times 30\ mm$
Standart test condition	1000W/m^2, 25°C

B. Partial Shading Condition

Condition in which the surfaces of several solar panels connected in parallel or series are partially closed is called partial shading condition. Under this condition each solar panel has different irradiation and produces different amount of power. Figure.5 [17] shows the characteristic curve when partial shading occurs.

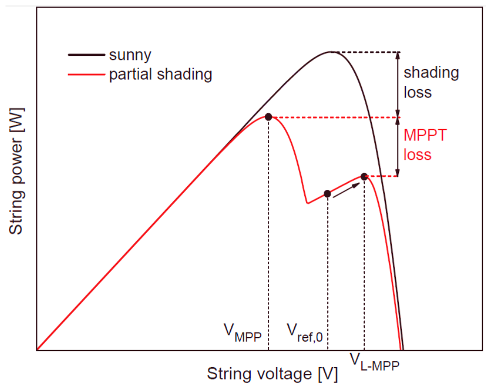


Figure 5. P-V curve during Partial Shading [17]

When partial shading occurs, there will be more than one peak point on the P-V curve, one of which is the actual peak point. Some of these peak points are called Local Maximum Power Points (LMPP) and from some LMPPs there is one peak point where the power at that point is the greatest value which is called the Global Maximum Power Point (GMPP).

3. Maximum Power Point Tracking (MPPT)

The maximum power point (MPP) of solar panels will change depending on the weather and irradiation conditions. It is, therefore, necessary to find the right work point. An MPPT technique can be used to get the optimal voltage and current value so optimal power from PV module can be achieved. MPPT work by changing the operating point on the P-V curve so that the maximum power value are obtained [16].

The purpose of using MPPT control system is to ensure that the solar panel is always operating at the MPP. MPPT consist of a DC-DC converter that connected in between solar panels and the load. The MPPT algorithm which calculates the best duty cycle value is applied to the DC-DC converter so solar panel maximum power can be generated in different irradiation and shading conditions.

The MPPT system working principle is shown in Figure.6 [18], which is by increasing and decreasing the solar panels working voltage. If the working voltage of the solar panel is at the left of V_{mp} (the working voltage is smaller than the V_{mp} voltage), the working voltage of the solar panels will be increased until it reaches V_{mp} and vice versa. After the maximum power point is reached, the output power of the solar panel will automatically be maximized.

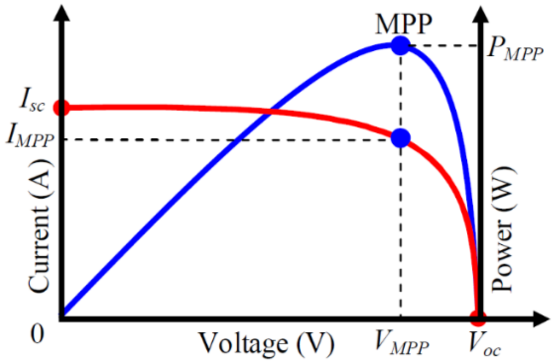


Figure 6. MPP in P-V and I-V Curve [18]

Accuracy and tracking speed is used to describe how well the MPPT is. The more accurate and faster in tracking the better the method. Accuracy indicates how close the MPPT tracking results to MPP at the P-V characteristic curve and can be defined as a percentage. Equation (6) is used to calculate the accuracy of the MPPT[19].

$$Accuracy = \frac{P_{PV}}{P_{MPP}} \times 100\% \qquad (6)$$

4. SEPIC Converter Modelling

SEPIC converter is a DC-DC converter that can acted to step up or step down the voltage so that the output voltage value is either greater or less than the input. The SEPIC converter has no polarity difference or, in other words, has the same polarity between the input voltage and the output voltage [20].

SEPIC converter is suitable for MPPT appliances because another feature of it, which has a lower input current ripple [21]. Figure.7 shows the circuit for SEPIC converter and using equation (6) to (8) the parameters can be determined.

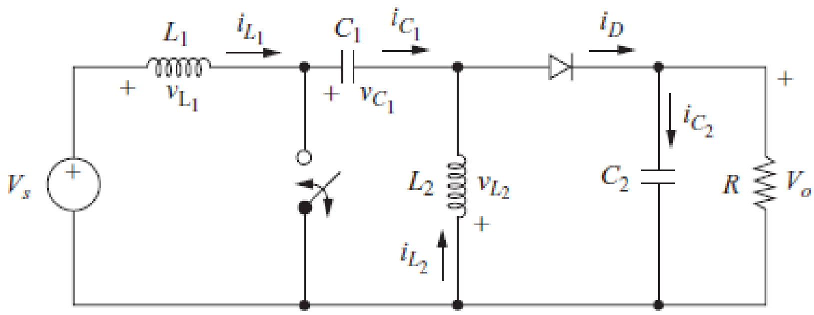


Figure 7. Circuit of SEPIC Converter [20]

$$V_o = V_s\left(\frac{D}{1-D}\right) \tag{7}$$

$$L_1 = L_2 = L = \frac{V_S D}{\Delta I_L f} \tag{8}$$

$$C_1 = C_2 = C = \frac{D}{R(\Delta V_O/V_O)f} \tag{9}$$

The frequency used for converter in this paper is 150 kHz. This classified as high frequency, which can decrease the value of inductance of L1 and L2 [22]. Using high frequency can also make the SEPIC converter output signal better and smoother because of the low ripple [23]. The calculation for SEPIC converter parameter is similar to Buck-Boost Converter [20]. Table 2 shows the proposed SEPIC converters parameters.

Table 2. Design Parameters of SEPIC Converter

Parameter	Value	Unit
Input Voltage (V_{in})	53.4	V
Switching Frequency (f_s)	150	kHz
Output Voltage (V_{out})	14.4	V
Current Ripple (ΔI_L)	20%	A
Voltage Ripple (ΔV_o)	0.1%	V
Inductor 1 (L_1)	67.15	µH
Inductor 2 (L_2)	67.15	µH
Capacitor 1 (C_1)	2048.3	µF
Capacitor 2 (C_2)	2048.3	µF

5. MPPT Algorithm

In this paper, three methods are compared for MPPT, namely Incremental conductance, MPSO, and MPSO-IC hybrid. The shading patterns used in this paper are shown in Figure 8.

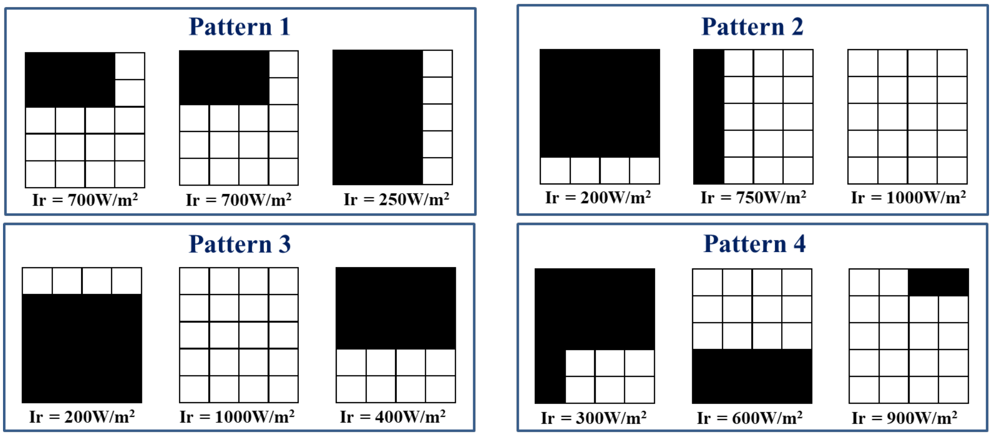


Figure 8. Shading Patterns of Solar PV Modules

In this paper, shading pattern are applied to the solar panels that connected in series. Shading pattern modeling is simulated by giving irradiation to each panel according to a predetermined pattern. This is done so that the P-V curve under the condition of partial shading can be obtained. In real conditions, a shading pattern can be applied by covering the surface of the solar panel with the shadow of an object positioned to the shading pattern.

A. Incremental Conductance

Conductance is a measure of how easily electricity flows in an object and the reciprocal of the resistance shown in the equation (9) below [24].

$$G = \frac{1}{R} = \frac{I}{V} \quad (10)$$

The MPPT design requires 2 parameters to determine the slope, namely the converter input voltage and the converter input current according to equation (10) below.

$$P_{in(n)} = V_{in(n)} \times I_{in(n)} \quad (11)$$

From these 2 parameters, the power $P_{in\,(n)}$ and voltage $V_{in\,(n)}$ is obtained, so it is compared with the previous data reading parameters $P_{in\,(n\text{-}1)}$ and $V_{in\,(n\text{-}1)}$. The results of the calculation are ΔP and ΔV.

$$\Delta V = V_{in(n)} - V_{in(n-1)} \quad (12)$$

$$\Delta P = P_{in(n)} - P_{in(n-1)} \quad (13)$$

From the results of dividing ΔP and ΔV, the slope is formulated as follows [25]:

$$Slope = \frac{P_{in(n)} - P_{in(n-1)}}{V_{in(n)} - V_{in(n-1)}} = \frac{\Delta P}{\Delta V} \quad (14)$$

One of the most used algorithm for MPPT appliances in photovoltaic systems because of its simplicity is the Incremental Conductance method [26]. The principle of the Incremental Conductance algorithm is the power derivative divided by the voltage derivative equal to zero in the MPP as shown in Figure.9 below.

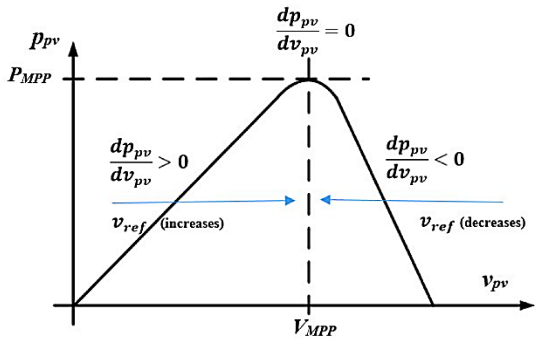


Figure 9. Basic State of the Incremental Conductance Algorithm [26]

In Figure.9 there are 3 types of points that are in these three following positions:

$$\frac{\Delta P}{\Delta V} = 0 \text{ , at the peak of the curve (MPP)} \quad (15)$$

$$\frac{\Delta P}{\Delta V} > 0 \text{ , at the left of the peak of the curve (MPP)} \quad (16)$$

$$\frac{\Delta P}{\Delta V} < 0 \text{ , at the right of the peak of the curve (MPP)} \quad (17)$$

If the solar panel is operating at the position to the left of the curve peak, the solar panel voltage must be increased by reducing the duty cycle. If the solar panel is operating at the peak position of the curve, the voltage solar panel voltage must be maintained constant by maintaining the duty cycle. If the solar panel is operating at the right position of the curve peak, the solar panel voltage must be lowered by increasing the duty cycle.

B. Modified Particle Swarm Optimization

A single organism's behavior is often insignificant, but collective behavior of a group is very important. Kennedy and Eberhart first proposed the Particle Swarm Optimization method as an optimization that use population based search process in 1915. Natural action of a group of birds or a pack of fish that shows when they are looking for a target / prey (food) is adapted for this method.

In the process of optimization using particle swarm, each individual is called a particle. Individual particles in a swarm are a potential solution to solving optimization problems through search space navigation. The purpose is to search the system's global optima by initially randomly scattered the particles in the search space. Each particle tracks its position and the best solution has been reached. This is what is known as Pbest ie individual best value and the Particle Swarm Optimization process also tracks the global best solution reached by a group of particles with its particle index known as Gbest.

During the process of finding the optimal point by particles in a predetermined iteration, each particle's velocity for the next iteration is calculated as a function of the best position of the swarm (Gbest), the best position of the particle (Pbest) and the velocity of the previous particle. The individual and social components of the particle swarm influence the subsequent position of the particles [27]. It is illustrated in Figure.10 [28] where particles move in the process of finding the optimum point in Particle Swarm Optimization.

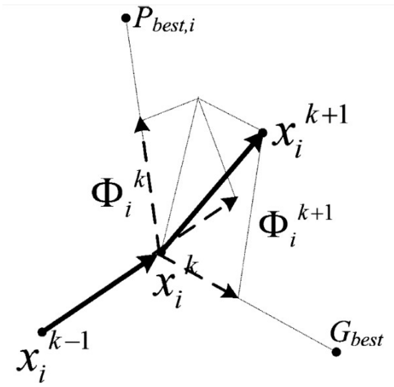


Figure 10. The Movement of Particles in the Optimization Process [28]

The formula for the Modified Particle Swarm Optimization method is written in equations (17) and (18) below [9]:

$$v_i(k+1) = wv_i(k) + c_1r_1\left(P_{best_i} - x_i(k)\right) + c_2r_2\left(G_{best} - x_i(k)\right) \quad (18)$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \quad (19)$$

$$i = 1,2,3,\dots,n$$

Where:
x_i : The position of the particles i
v_i : The speed of the particles i
k : Number of iterations
w : Moment of inertia, value (0-0.5)
r_1, r_2 : Variable random, value (0-1)
c_1, c_2 : Social coefficient, each value (0.8)
P_{best_i} : The variable used to save the best position already obtained from the particles i
G_{best} : The variable used to save the best position already obtained from all the particles

C. Hybrid MPSO – IC

Hybrid Modified Particle Swarm Optimization Method- *Incremental Conductance* here in after referred to as the hybrid MPSO - IC method is a type of computational algorithm that combines the Modified Particle Swarm Optimization method with Incremental Conductance. Hybrid MPSO – IC method can be applied to search the MPP under the condition of partial shading.

MPPT hybrid MPSO method- IC starts the algorithm by using the MPSO algorithm which is then followed by the IC algorithm. When the MPP search process uses the MPSO algorithm, the Gbest algorithm will begin to be initiated using the duty cycle of the MPSO algorithm. Figure.11 shows the flowchart of MPPT hybrid MPSO- IC.

Figure 11 describes the flowchart of the MPSO - IC hybrid method used in this paper. In the initial process, the search was carried out using the MPSO algorithm to avoid LMPP due to partial shading. After reaching the predetermined iteration, the search algorithm is changed to Incremental Conductance. The duty cycle value resulting from the MPSO process will be used for the initial value to start the Incremental Conductance algorithm. When the MPP has been achieved, the system will lock the duty cycle value until there is a change of irradiation or temperature resulting in change of the solar panel power output (Ppv).

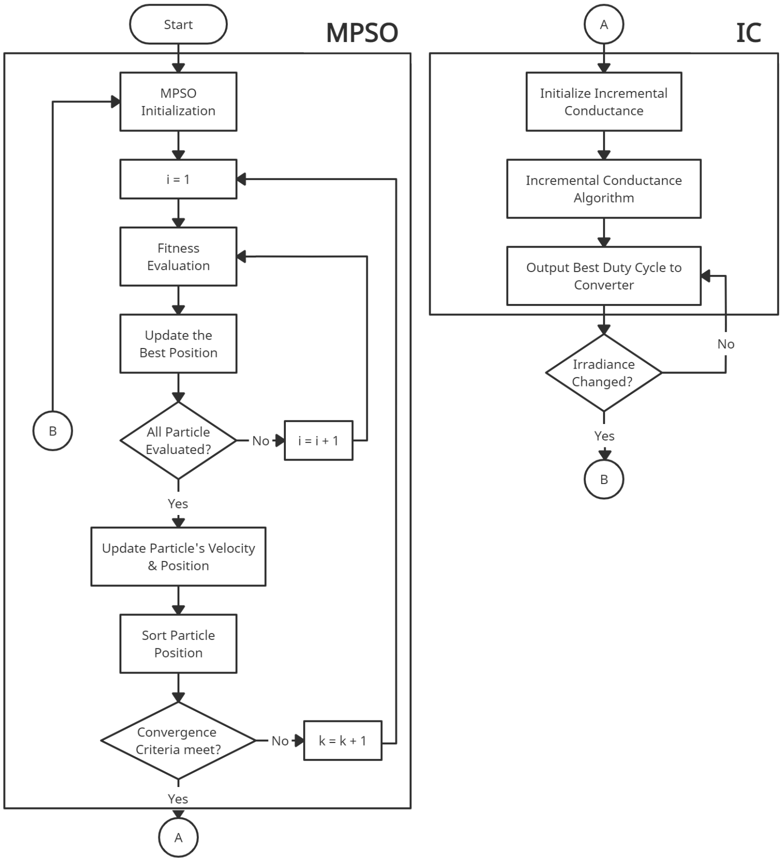


Figure 11. Hybrid MPSO-IC Algorithm Flowchart

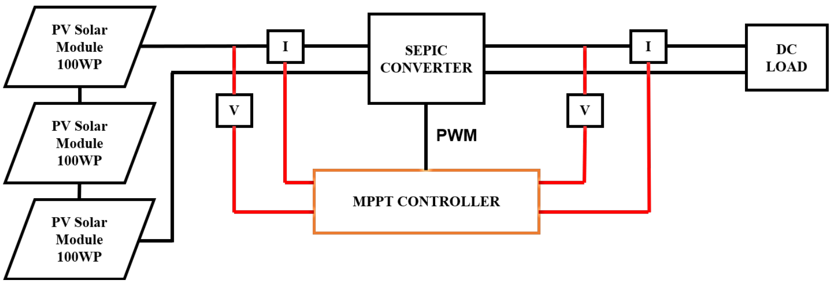


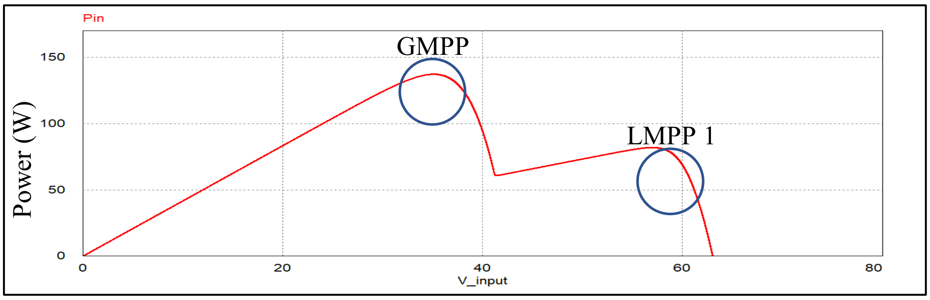
Figure 12. Block Diagram of the System

Figure.12 shows the block diagram of the system.

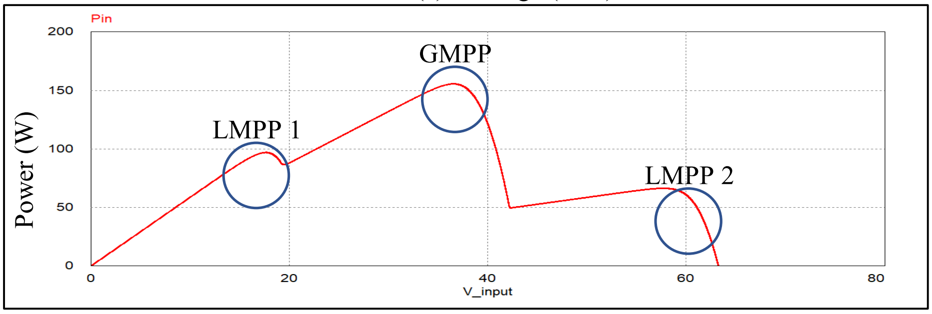
The solar PV module will be connected to SEPIC converter which connected to DC load by using simulation. The algorithm for MPPT will be applied in the control system and comparison of performance will be made between these methods: Incremental Conductance, MPSO, and

Hybrid MPSO-IC for MPPT applied under condition of partial shading. Tracking accuracy and tracking speed are the two variables that will be analyze.

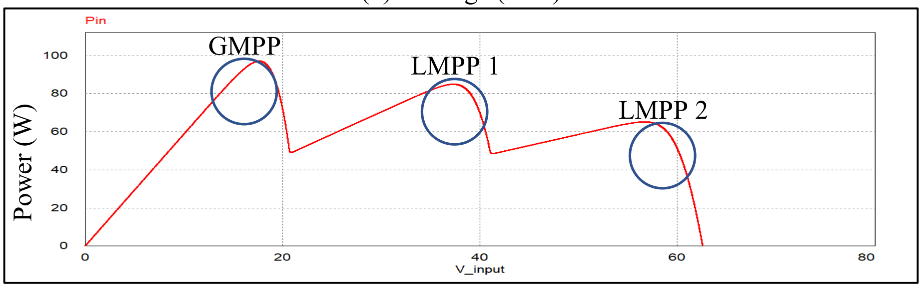
6. Results and Discussions



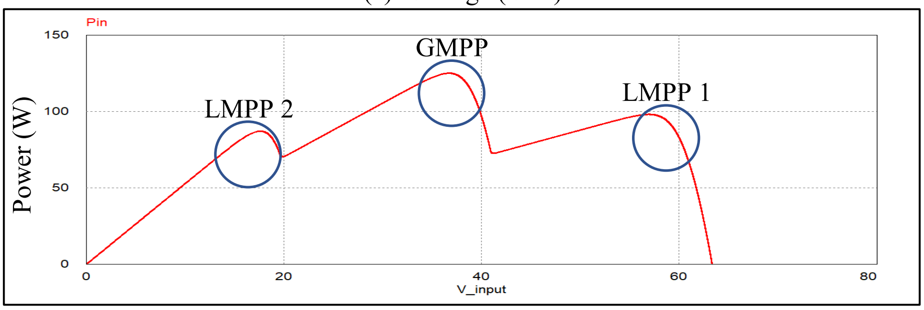
(a). Voltage (Volt)



(b). Voltage (Volt)



(c). Voltage (Volt)



(d)
Voltage (Volt)

Figure 13. P-V Curve during Partial Shading Condition (a) Pattern 1 (b) Pattern 2 (c) Pattern 3 (d) Pattern 4

In this discussion, a comparison between the Incremental Conductance, MPSO and Hybrid MPSO-IC algorithms will be made in application of MPPT process during partial shading conditions to determine which method has the better time and accuracy in tracking the MPP.

Partial shading curves are necessary to determine the GMPP value so that the accuracy of the MPPT algorithm can be determined. Using simulation, each PV modules were given different irradiance following predetermined shading pattern so the P-V curve can be obtained and the results are shown in Figure 13.

Figure.13 shows the four shading patterns that have been made, produce characteristic curves that have more than one peak power, namely GMPP and LMPP. GMPP is the peak value that must be achieved by the MPPT method, while the peak power with value below GMPP are called LMPP. In each P-V characteristic curve there is only one GMPP while LMPP can be more than one or more. The GMPP and LMPP values of each curve can be seen in Table.3.

The MPPT Partial Shading pattern 1 simulation result is shown in Figure 14.

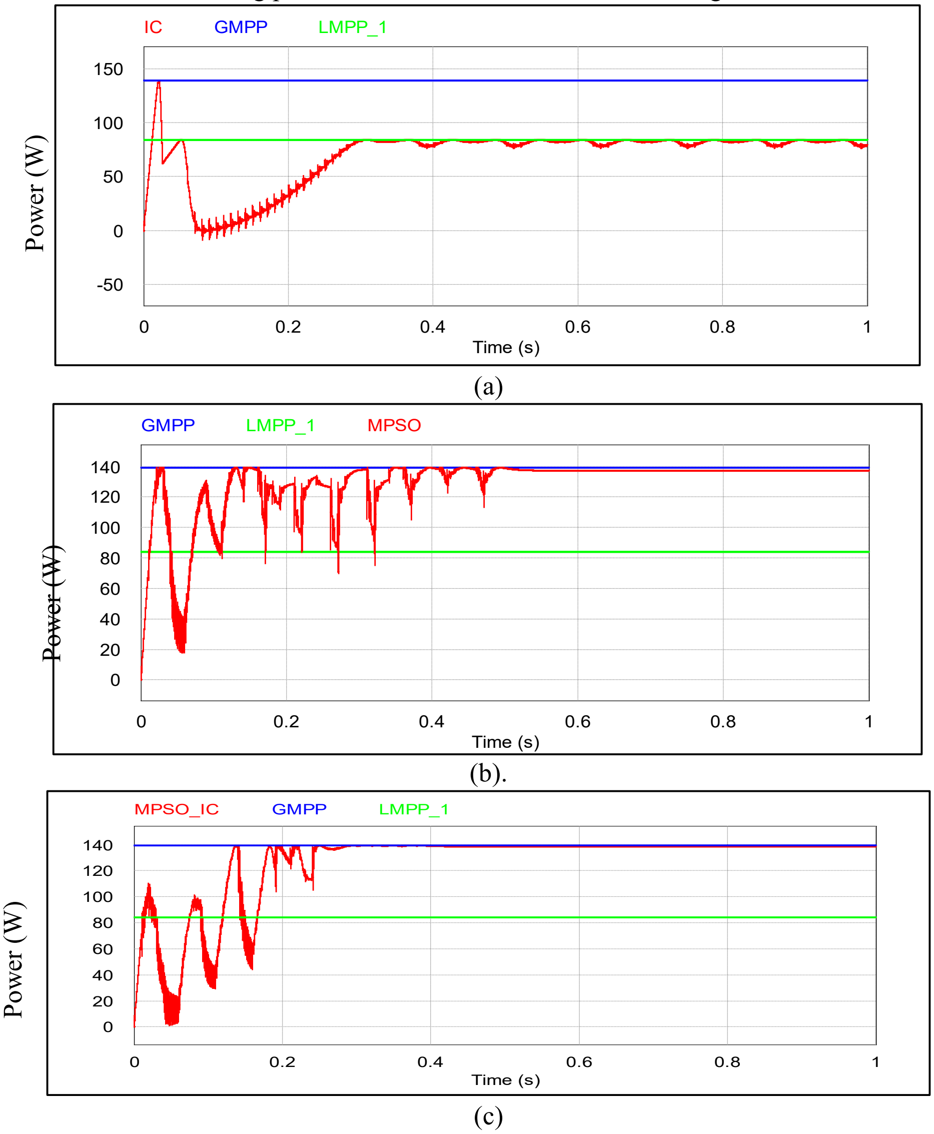
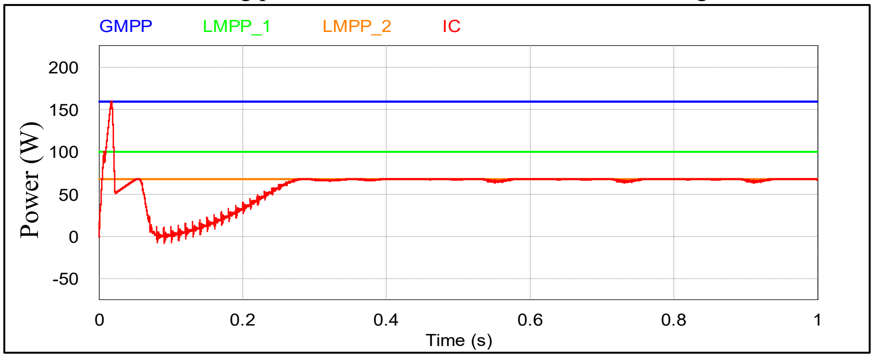


Figure 14. MPPT Simulation Result Pattern 1 (a) Incremental Conductance (b) MPSO (c) MPSO-IC

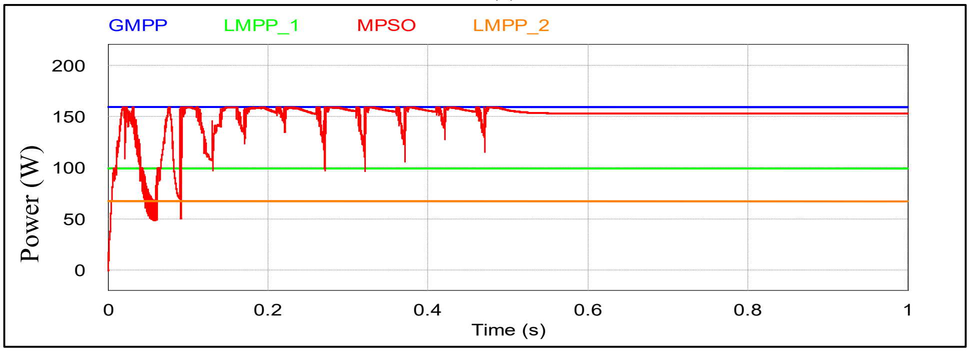
Table 3. The Value of GMPP and LMPP of each Shading Pattern

Pattern	Irradiance (W/m²)			GMPP (Watt)	LMPP 1 (Watt)	LMPP 2 (Watt)
	PV 1	PV 2	PV 3			
1	700	700	250	139.43	84.33	-
2	200	750	1000	159.57	99.99	68.37
3	200	1000	400	99.99	87.4	67.06
4	300	600	900	128.55	101.04	89.94

The MPPT Partial Shading pattern 2 simulation result is shown in Figure.15.



(a)



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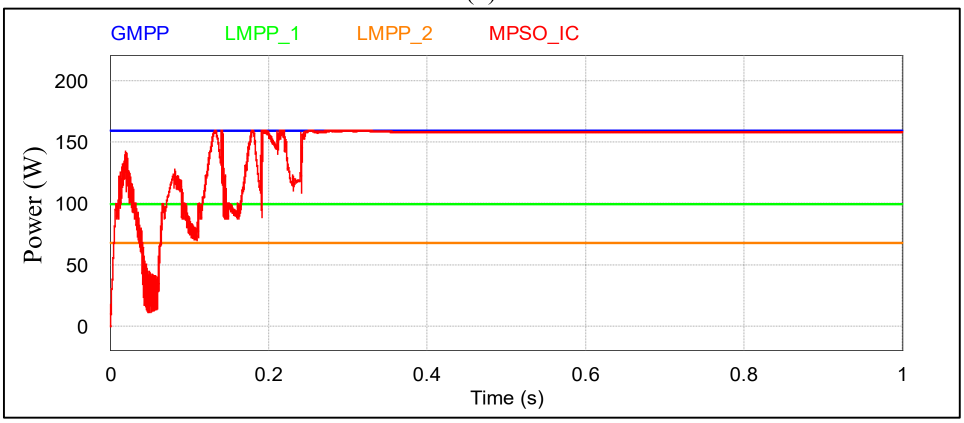


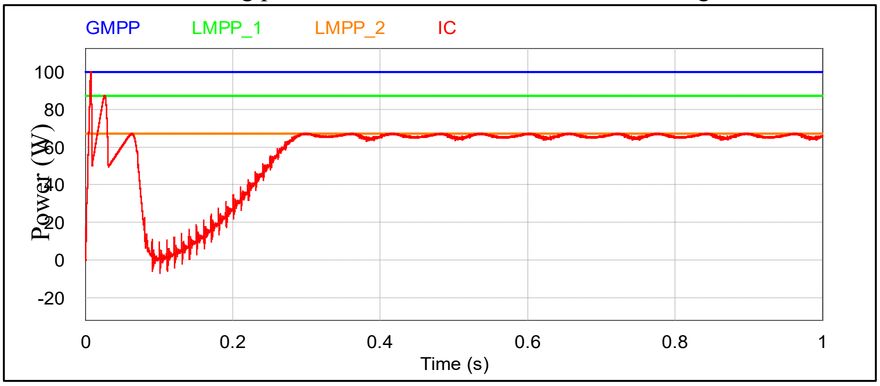
(c)

Figure 15. MPPT Simulation Result Pattern 2 (a) Incremental Conductance (b) MPSO (c) MPSO-IC

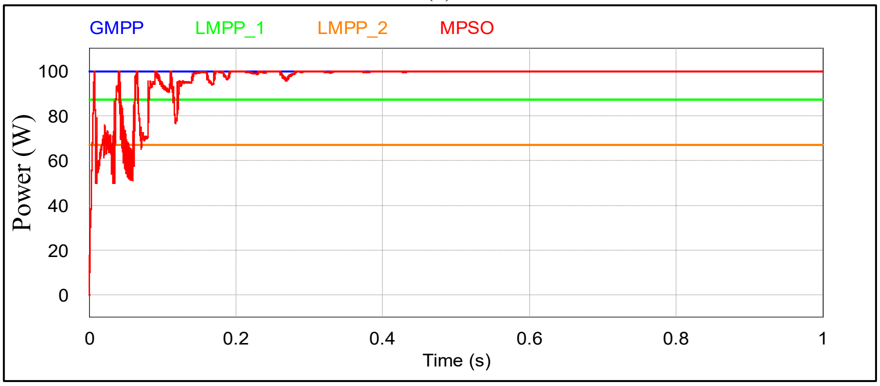
According to Table 3, it is known from shading pattern 1 that the P-V curve has two maximum power point, consist of GMPP and one LMPP. While P-V curve from shading pattern 2, 3, and 4 has three maximum power point that consist of GMPP and two LMPPs.

The maximum power obtained from shading pattern 1 is 139.43 Watt. Figure.14 shows the power tracking process of each method. From Figure.14(a), it can be inferred that power tracking using Incremental Conductance cannot reach GMPP and trapped in LMPP with a power of 82.89 Watt. Whereas the MPSO method in Figure.14(b) reached 136.55 Watt with an accuracy rate of 97.93%. The proposed method, the MPSO-IC method in Figure.14(c), has an even higher accuracy rate of 99.59% with 138.87 Watt.

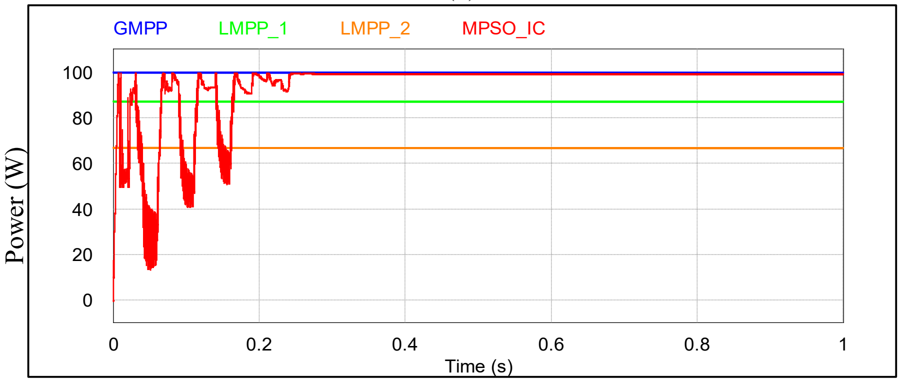
The MPPT Partial Shading pattern 3 simulation result is shown in Figure.16.



(a)



(b)



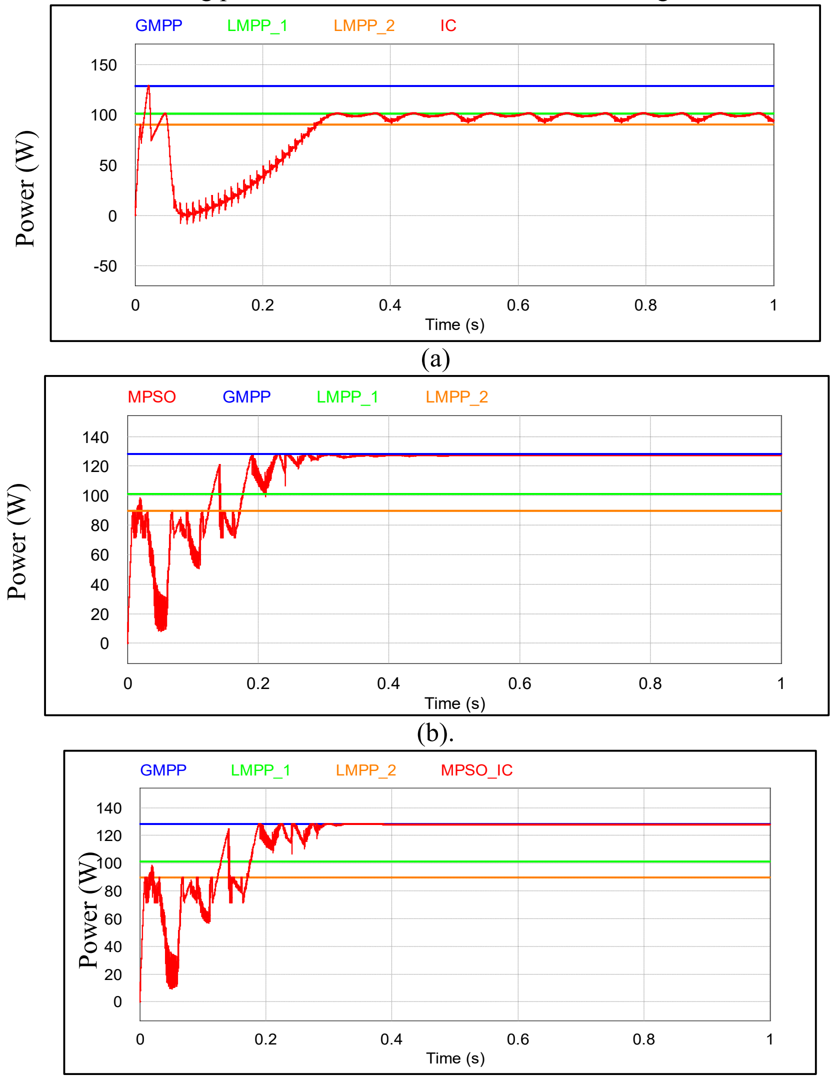
(c)

Figure 16. MPPT Simulation Result Pattern 3 (a) Incremental Conductance (b) MPSO (c) MPSO-IC

The maximum power obtained from shading pattern 2 is 159.57 Watt. Figure.15 shows the power tracking process of each method. From Figure.15(a), it can be seen that power tracking using Incremental Conductance cannot reach GMPP and trapped in LMPP with a power of 68.09 Watt. Whereas the MPSO method in Figure.15(b) reached 154.08 Watt with an accuracy rate of 96.55%. The proposed method, the MPSO-IC method in Figure.15(c), has a higher accuracy rate of 99.58% with 158.90 Watt.

The maximum power obtained from shading pattern 3 is 99.99 Watt. Figure.16 shows the power tracking process of each method. From Figure.16(a), it can be seen that power tracking using Incremental Conductance cannot reach GMPP and trapped in LMPP with a power of 66.93 Watt. Whereas the MPSO method in Figure 16(b) reached 99.89 Watt with an accuracy rate of 99.89%. The proposed method, the MPSO-IC method in Figure.16(c), has a lower accuracy rate of 99.65% with 158.90 Watt. However, it took 0.21 second faster in tracking process.

The MPPT Partial Shading pattern 4 simulation result is shown in Figure 17.



(c).

Figure 17. MPPT Simulation Result Pattern 4 (a) Incremental Conductance (b) MPSO (c) MPSO-IC

The maximum power obtained from shading pattern 4 is 128.55 Watt. Figure.17 shows the power tracking process of each method. From Figure.17(a), it can be seen that power tracking using Incremental Conductance cannot reach GMPP and trapped in LMPP with a power of 100.93 Watt. Whereas the MPSO method in Figure.17(b) reached 127.35 Watt with an accuracy rate of 99.07%. The proposed method, the MPSO-IC method in Figure.17(c), has a higher accuracy rate of 99.85% with 128.36 Watt.

Table 4 shows the result of the comparison made between each method. Tracking accuracy of each method is calculated using equation (6) from [19].

Table 4. Simulation Result of Incremental Conductance, MPSO, MPSO-IC Method

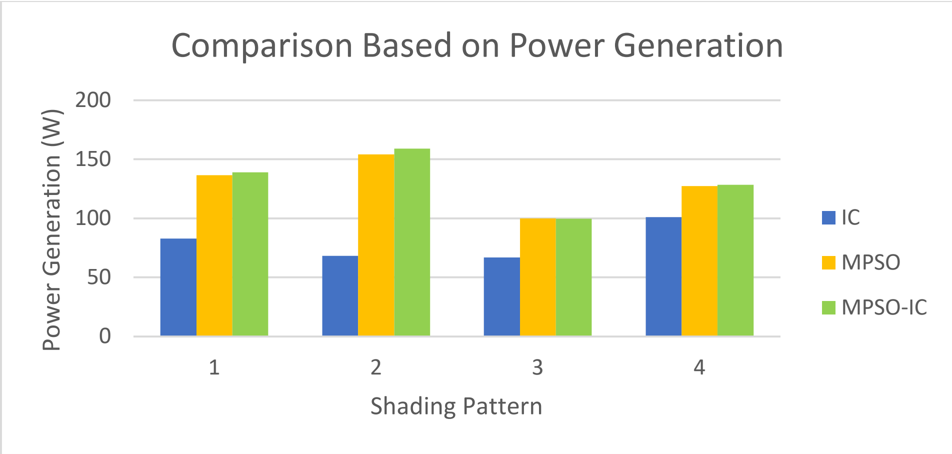
Pattern	Pmax (W)				Accuracy (%)			Convergence (s)		
	Target	IC	MPSO	MPSO-IC	IC	MPSO	MPSO-IC	IC	MPSO	MPSO-IC
1	139.43	82.89	136.55	138.87	59.45	97.93	99.59	0.30	0.52	0.42
2	159.57	68.09	154.08	158.90	42.67	96.55	99.58	0.33	0.53	0.33
3	99.99	66.93	99.89	99.65	66.94	99.89	99.65	0.29	0.48	0.27
4	128.55	100.93	127.35	128.36	78.51	99.07	99.85	0.31	0.49	0.36
Average					61.89	98.36	99.66	0.30	0.50	0.34

From the data in Table 4 above, simulation comparison of each method for every shading condition can be made using bar graphs, which presented in Figure.18, namely comparison based on power generation in Figure 18(a), based on tracking accuracy in Figure 18(b), and based on tracking speed in Figure 18(c).

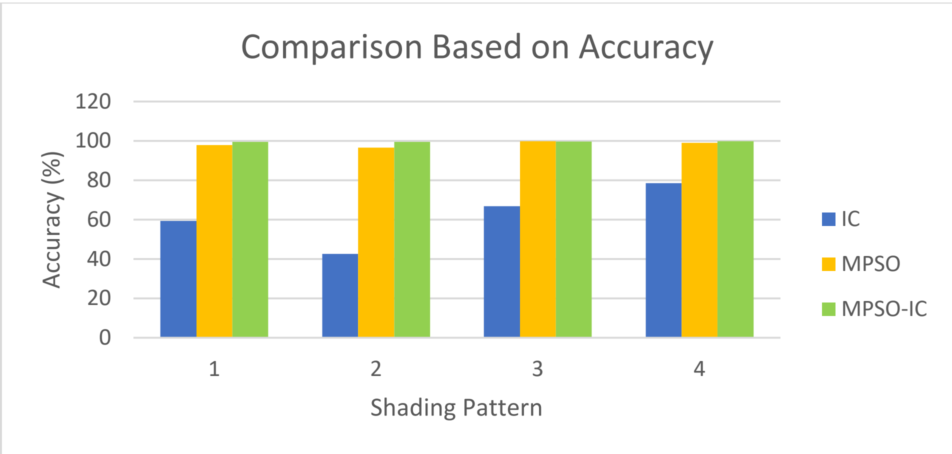
It can be seen in Figure 18(a) that MPPT using the IC method produces much lower power than the other two methods, so the tracking accuracy rate of this method is only 61.89% on average. This is because the IC method is stuck on the LMPP in every shading pattern. The method that produces the most power is MPSO-IC in three out of four shading patterns with an average accuracy of 99.66% which makes this method the most accurate method compared to the three methods discussed in this paper. Followed by the MPSO method with an average accuracy of 98.36%. By using the MPSO-IC method, the accuracy increases by 37.77% when compared to the IC method and increases by 1.3% when compared to the MPSO method.

The simulation comparison based on tracking speed in Figure 18(c) shows that the MPSO-IC method has a faster time in reaching convergence with an average time of 0.34 seconds, 0.16 seconds faster than the MPSO method which has an average time of 0.5 seconds. This is because the MPSO-IC method uses the MPSO algorithm to avoid LMPP with the aim of overcoming partial shading where in this method fewer iterations are used than the MPSO method which then switches to the IC method to continue tracking GMPP accurately when the iteration has been reached. This strategy makes the time required by the MPSO-IC method to perform tracking faster in achieving convergence compared to the MPSO method.

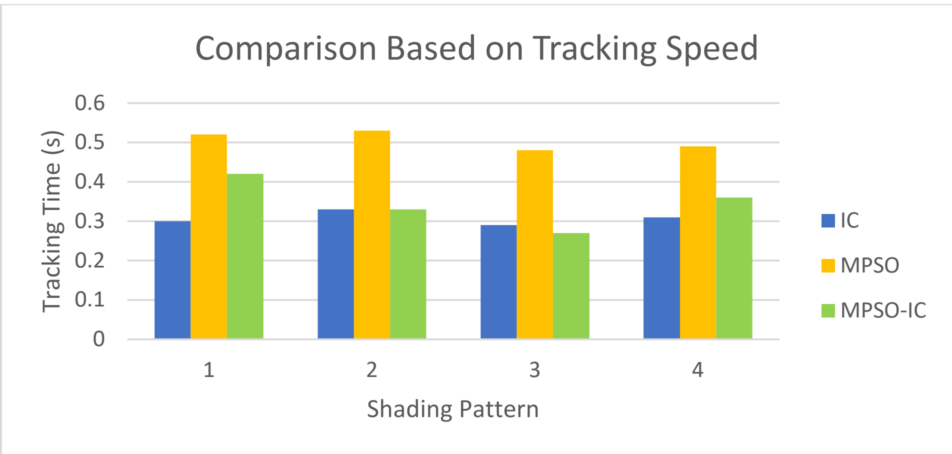
Similar results is discussed in [12] where the IC method is trapped in the LMPP and cannot achieve GMPP under partial shading conditions. The results of the method comparison analyzed in this paper show that the proposed method for MPPT application under partial shading conditions can avoid LMPP and can reach the GMPP with a greater accuracy result and faster tracking time. Thus, the MPSO-IC method has the best performance of all methods compared in this paper.



(a)



(b)



(c)

Figure 18. Simulation Result Comparison (a) Based on Power Generation (b) Based on Accuracy (c) Based on Tracking Time

7. Conclusion

The hybrid MPSO-IC method, a combination of conventional method with artificial intelligence method, used for MPPT application to track the GMPP from P-V curve during the condition of partial shading is proposed. This hybrid method is compared to each method in this paper and evaluated through simulation result using PSIM software. The simulation result shows that the MPSO method has 98.36% accuracy with over 0.5 seconds in tracking time and the incremental conductance method has only 61.89% accuracy with 0.3 seconds tracking time. Using the proposed method, the average tracking accuracy is higher with 99.66% and able to achieve the GMPP in 0.34 second in average. From the simulation results, it shows that the proposed method, hybrid MPSO-IC method, has better performance compared to each method alone in finding the GMPP during partial shading condition. It has more accurate tracking result and more faster tracking time compared to MPSO method, while the conventional MPPT method, Incremental Conductance, is trapped in LMPP and unable to reach the GMPP.

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