Performance of MPSO-MPPT on PV-Based DC Microgrid in Partial Shading Conditions

Haneef Nouval A.H.[1], M. Isnaeni B.S.[2], Sarjiya[3]

***Abstract*—Microgrid is a controllable decentralized group of energy resources and loads with the ability to operate both in grid-connected or island modes. Photovoltaic (PV) is one of the sources that are commonly used in microgrid. PV has a good ability to convert solar irradiation into electrical energy, especially under ideal condition, namely uniform irradiation or non-shading condition. However, PV often has some problems when facing partial shading condition. In this condition, PV does not produce optimal power because it stucks at the local maximum power point (MPP), thus it unables to track the global MPP. For this reason, it is necessary to implement a smart maximum power point tracker (MPPT) that can solve this problem. Furthermore, MPPT will be implemented in pulse width modulation (PWM) to control the buck converter. This study is focused on designing a laboratory scaled microgrid system with PV sources and controlled by modified particle swarm optimization (MPSO)-based MPPT. The 360 Wp PV array used consisted of two strings of three series modules Solarex MSX-60. The performance of the proposed method was compared with perturb and observe (P&O)-based MPPT, which was the commonly used method on MPPT. Furthermore, it was found that P&O and MPSO performed relatively similar accuracy (with difference of 0.04%) in non-shading condition. However, in partial shading condition, MPSO could perform better by producing greater output power so that it delivers better accuracy (98.74% to 99.11%) compared to P&O (57.95% to 71.87%). However, MPSO required a slightly longer time to converge because it had more complicated method and more computational load.**

***Keywords*—DC Microgrid, MPPT, P&O, MPSO, Partial Shading.**

I. Introduction

Modern society is critically dependent on the energy supply [1]. Based on Rio+20 conference, energy is one of the seven most critical issues to be discussed, besides employment, urban development, water, ocean, food, and natural disasters [2]. Indonesia has considerable solar energy potential. In view of solar radiation information gathered from eighteen areas in Indonesia, solar radiation in Indonesia can be classified as follows: western and eastern regions of Indonesia. The distribution of radiation in the western region of Indonesia is around 4.5 kWh/m2 per day with a month-to-month variation of around 10%; while in the eastern region of Indonesia is around 5.1 kWh/m2 per day with a month-to-month variation of around 9% [3]. Assuming the average irradiation is 4.8 kWh/m^2/day and the land area in Indonesia is 1,891,000 km^2, the total irradiation in Indonesia is approximately 9,100 TWh/day [4].

Sunlight is a renewable energy source. In photovoltaic (PV), sunlight is converted into electrical voltage. PV system consists of several parts, namely solar cells (or PV itself), maximum power point tracking (MPPT), and DC-DC converters with signal conditioning schemes [5]. The issue with the application of PV systems is efficiency [6]. The output power efficiency of PV module is highly dependent on solar irradiation and temperature. Each PV has a pressure-volume (P-V) and a current-voltage (I-V) curve to explain its characteristic. This study has used Solarex MSX-60. Fig. 1 shows P-V characteristic curve of 6 PV modules Solarex MSX-60 that ilustrates the relationship between solar irradiation changes to power output [7], [8]. The highest value of power, called the maximum power point (MPP), is found in this curve. A method for tracking this value is required to increase output power, resulting in improved PV system efficiency. This MPP tracking method is generally known as MPPT.

One of MPP tracking techniques is conventional techniques and intelligent techniques [9]. Among conventional tracking techniques are as perturb and observe (P&O), incremental conductance, and hill climb search. A higher output power produced by this conventional techniques when the PV is in uniform irradiation conditions. Among the types of intelligent techniques are fuzzy logic, evolutionary algorithms (EA) and artificial neural networks.

In partial shading conditions, conventional techniques failed to track global MPP (GMPP) because PV has more than one MPP in partial shading conditions as in Fig. 2. They often stuck on local MPP (LMPP). Therefore, an advanced MPPT technique is needed to solve this problem. EA is one of the MPP tracking techniques implementing artificial intelligence. There are many types of EA including particle swarm optimization (PSO), artificial ant colonies, differential algorithms, and genetic algorithms.

Several studies have observed MPPT using various methods. Some of them used the conventional method like hill climb search [10], P&O [11], [12], step size variable modified P&O [13], and combination of incremental conductance and P&O [14]. However, conventional methods are only effective when PVs have uniform irradiation input and fail to get GMPP in partial shading conditions. Furthermore, various researchers used EA to solve partial shading problems and get GMPP. Combinations of flower pollination algorithm and proportional-integral (PI) controller were used in [15] to control single-ended primary-inductor converter (sepic)-buck converter. Reference [10] showed the performance of an improved PSO during reduced steady-state oscillation.

[1,2,3] *Department of Electrical and Information Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jl. Grafika No. 2, Special Region of Yogyakarta 55281 INDONESIA (phone: 0274-552305; email: [1]haneefnouval@mail.ugm.ac.id, [2]isnaeni@ugm.ac.id, [3]sarjiya@ugm.ac.id)*

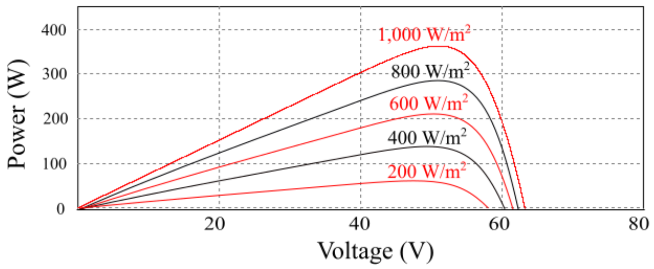
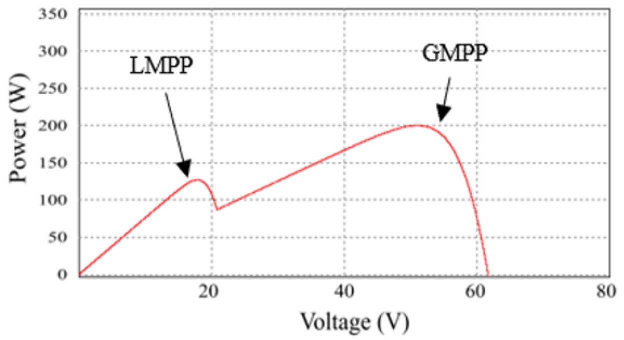
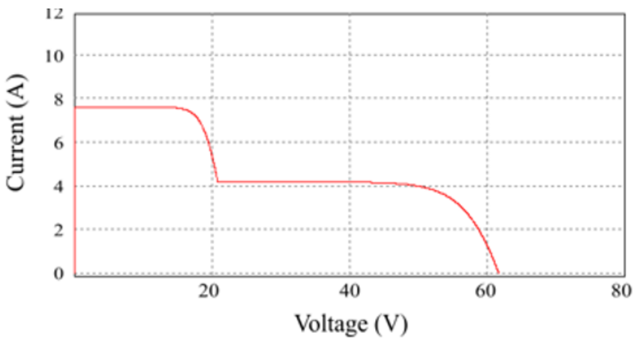


Fig. 1 P-V characteristic curve of Solarex MSX-60.



(a)



(b)

Fig. 2 Characteristic curve with two MPP, (a) P-V and (b) I-V.

Reference [16] employed gravitational search algorithm and compared its performance to the original PSO. Genetic Algorithm used in [17] and compared the performance to P&O.

When partial shading happened, more than one MPP would appear on the P-V characteristic curve in some conditions caused by the shadow of an object above the PV. This research problem aimed to solved this research. Conventional methods, such as P&O and incremental conductance, usually fails to track GMPP when P-V characteristic has more than one MPP and get stuck on LMPP. In this condition, PV produces lower power than GMPP. Therefore, advanced MPP tracking technique is needed. In this research, Modified PSO was proposed to solve the problem. Furthermore, the DC microgrid system with one type of source (PV) and battery-free was chosen to focus the discussion on the PSO algorithm performance in partial shading condition.

II. PV Module Modeling

In PV systems, sunlight is converted into electrical voltage. PV system consists of several parts including PV array, MPPT and DC-DC converters with signal conditioning schemes [18]. Fig. 3 shows the equivalent circuit of the PV module. Generally, a PV module comprises of 36 or 72 solar cells. Mathematical expressions of each cell are shown in (1) and (2).

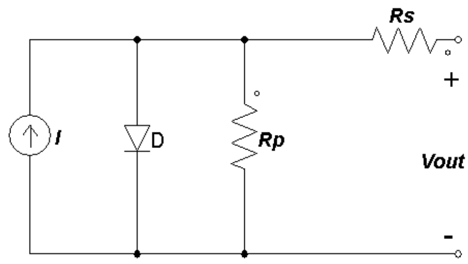


Fig. 3 Equivalent circuit of PV modules.

TABLE I
SOLAREX MSX-60 PV SPECIFICATION

Characteristic	Value
Maximum power (Pmax)	60 W
Current at Pmax (Imp)	3.5 A
Voltage at Pmax (Vmp)	17.1 V
Short-circuit current (Isc)	3.8 A
Open-circuit voltage (Voc)	21.1 V
Guaranteed minimum Pmax	58 W

$$I = I_{sc} - I_o\left(e^{\frac{q(V+IR_S)}{kT}} - 1\right) - \left(\frac{V+IR_S}{Rp}\right) \quad (1)$$

$$V_{oc} = \left(\frac{kT}{q}\right)\ln\left(\frac{I_{sc}}{I_o} + 1\right) \quad (2)$$

where:

I = cell's current (A),
Isc = cell short-circuit current (A),
Io = reverse saturation current (A),
V = cell's voltage (V),
V_{oc} = cell open-circuit voltage (V),
T = module temperature (K),
k = Boltzman constant,
q = electron charge (C),
Rp = parallel resistance,
Rs = series resistances.

The PV simulation circuit consists of a solar panel and a PV controller. The PV used in this study was Solarex MSX-60 with the specifications listed in Table I, also obtained from measurements on a solar simulator with standard test condition (STC) as follows.

- The irradiation value is 1,000 W/m^2 in the spectral distribution of 1.5.
- PV temperature at 25^{0}C.

This study used 360Wp PV array consisting of two strings of three series PV modules. Fig. 4 shows PV system diagram used in this study. This research employed three irradiation schemes to observe the system performance; they are

1. uniform radiation at 1,000W/m^2 as an illustration of an ideal PV system,
2. partial shading using pattern 1, shown in Fig. 5, and
3. partial shading using pattern 2, shown in Fig. 5.

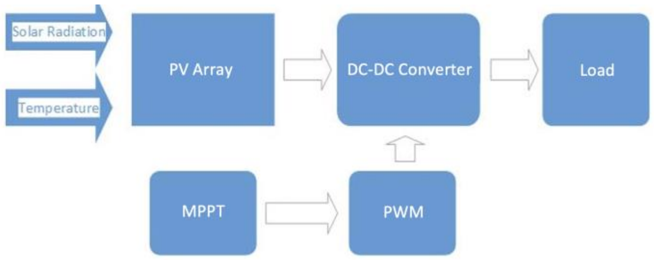


Fig. 4 PV system diagram.

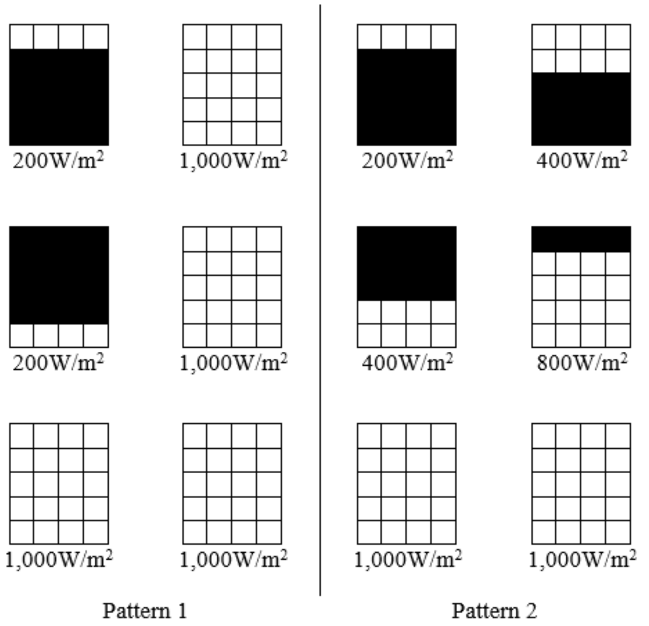


Fig. 5 Partial shading pattern.

Partial shading pattern 1 was used to produce a clear double peak P-V characteristic curve and pattern 2 was used to produce a clear triple peak P-V characteristic curve. An ideal condition of irradiation will deliver an ideal P-V and I-V characteristic which has one peak or MPP as shown in Fig. 6.

Partial shading with both patterns (pattern 1 and 2) resulted in multiple P-V and I-V characteristics, as shown in Fig. 7. MPPTs' main task is tracking the GMPP and avoiding getting trapped at LMPP.

III. DC-DC Converter Modelling

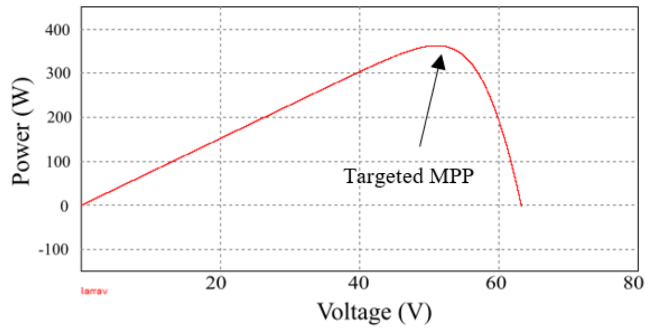
Buck converter is a non-isolated DC-DC converter that functions to lower the output voltage. MPPT controls the buck converter through pulse width modulation (PWM) injected into the switch. Fig. 8 shows the circuit of the buck converter. Its parameter found by using (3) and (4).

$$L = \frac{(V_{in} - V_{out})D}{f_s \, \Delta I_L} \quad (3)$$

$$C = \frac{\Delta I_L}{8 \, f_s \, \Delta V_{out}} \quad (4)$$

where:

L = inductance (H),
V_{in} = input voltage (V),
D = duty cycle,



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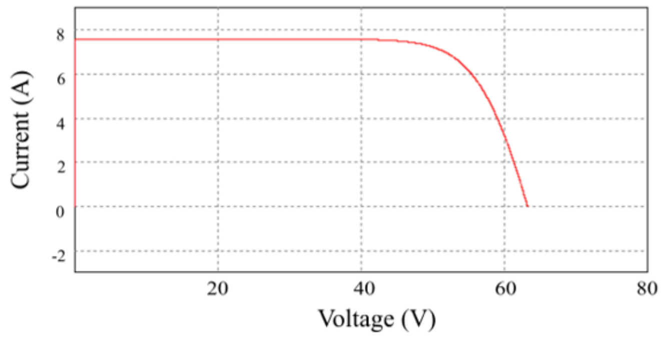


(b)

Fig. 6 Characteristic curve under uniform irradiation of 1,000W/m^2, (a) P-V, (b) I-V.

f_s = switching frequency (Hz),
C = capacitance (F),
V_{out} = output voltage (V),
ΔI_L = current ripple (A).

IV. MPSO-Based MPPT

MPPT is a system used to track the maximum output power in solar power plants [19]. The most common strategy used in the MPPT system is the hill climb search (HCS) strategy which is also used in the P&O MPPT type system [20]. In Fig. 1, the maximum power point is tracked using a modified PSO scheme. This MPPT system was implemented in duty cycle (D), which was then used to switch transistors on the DC-DC converter to produce maximum value of power from the PV array.

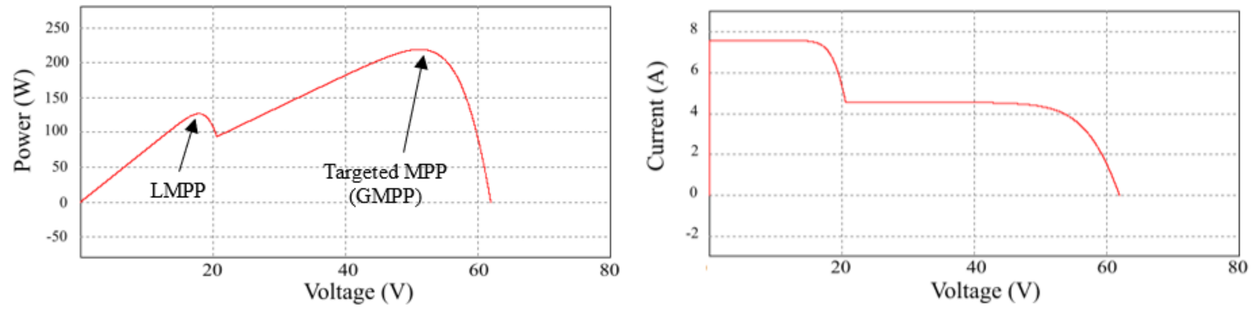
PSO is a nature-inspired algorithm, especially from flocks of birds in search of foods. PSO algorithm keeps a multitude of individuals, generally called particles, where each particle performs a candidate solution [21]. Each particle has a velocity and position component that will change to its best condition in each iteration. The best particle influences the position of a particle in a neighbourhood P_{best}, as well as its velocity. Modified PSO formula is expressed in (5) and (6). Fig. 9 shows the flowchart of MPSO method.

$$v_i^{k+1} = \omega v_i^k + c_1 r_1 \left(p_{best} - x_i^k\right) + c_2 r_2 \left(g_{best} - x_i^k\right) \quad (5)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (6)$$

where:

v_i = velocity of particle i,
x_i = position of particle i,



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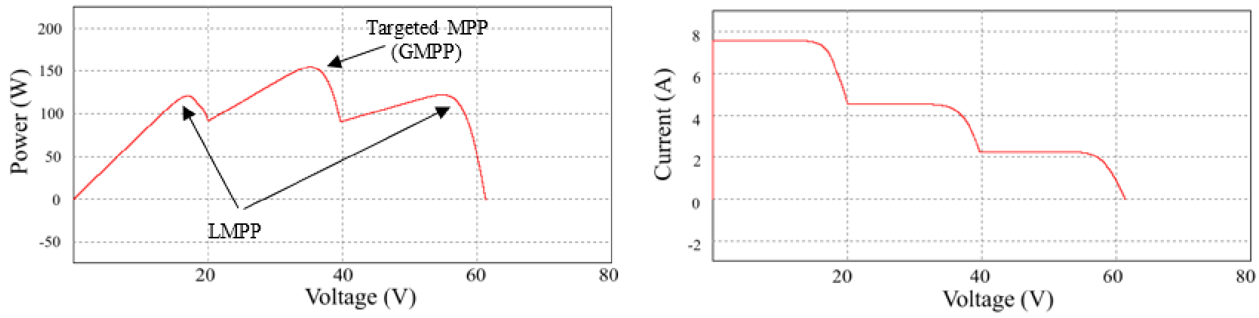

(b)

Fig. 7 P-V and I-V characteristic curve at partial shading condition, (a) pattern 1, (b) pattern 2.

k = repetition number,
ω = inertia weight,
P_{best} = best position in each particle,
G_{best} = best position of all particles,
r_1, r_2 = random variables, 0-1,
c_1, c_2 = cognitive and social coefficient.

Step of MPSO implementation is explained as follows.

1. Step 1: Define particle positions as duty cycle (d) and velocity as a perturbation in the present duty cycle (Φ) as in (7) and (8) [10].

$$\Phi_i^{k+1} = \omega\Phi_i^k + c_1r_1\left(p_{best} - d_i^k\right) + c_2r_2\left(g_{best} - d_i^k\right) \quad (7)$$

$$d_i^{k+1} = d_i^k + \Phi_i^{k+1}. \quad (8)$$

Define the objective function/fitness value as in (9).

$$P^k > P^{k-1} \quad (9)$$

where d denotes duty cycle and P denotes power produced (W).

2. Step 2: Define the number of particles used and initialization MPSO method by spreading the duty cycle randomly.
3. Step 3: Fitness evaluation for every particle.
4. Step 4: Renew the P_{best} of each particle and G_{best}.
5. Step 5: Renew the duty cycle and its perturbation.

V. Simulation Result

In the proposed system, the observation was initiated by testing the system at uniform irradiation of 1,000W/m^2 (non-shading condition) to show the performance of PV-based DC microgrid at the ideal condition. P&O and MPSO performance comparison in the non-shading condition is shown in Table A1

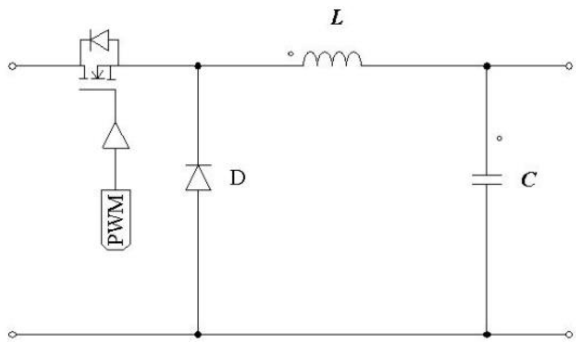

Fig. 8 Buck converter circuit.

and Fig. A1. The simulation result showed that P&O and MPSO had relatively the same accuracy in non-shading condition (with difference of 0.04%). In this condition, P&O had higher convergence speed. MPSO had lower convergence speed as it was more complicated and had more computational load.

Furthermore, the proposed system was tested under partial shading conditions. P&O and MPSO performance comparison in partial shading condition for pattern 1 is shown in Table A2, while for pattern 2 is shown in Fig. A2 and Table A3 and Fig. A3. In partial shading condition, P&O converged faster but had a lower output power and accuracy because it was trapped in the LMPP. According to GMPP, MPSO took longer to converge as it had more computational load and was more complicated, yet obtained maximum output power.

VI. Conclusion

This paper compares two MPPT methods for tracking GMPP, namely P&O, and the proposed method, namely MPSO. The

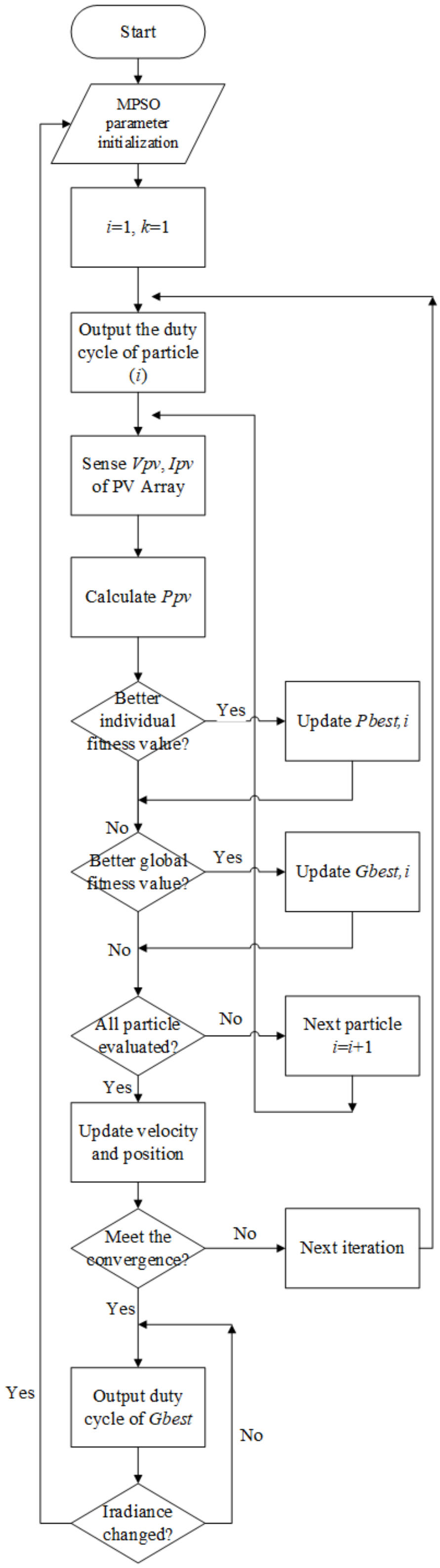

Fig. 9 MPSO flowchart.

result suggested that P&O and MPSO have relatively the same accuracy and output power under uniform irradiation of 1,000W/m^2 conditions. However, in partial shading conditions, P&O was unsuccessfuyl tracking GMPP and was trapped in LMPP, resulting in low accuracy (57.95% to 71.87%). The proposed method showed better performance with output power closer to targeted *P*, producing higher accuracy (98.74% to 99.11%). However, the proposed method took longer to converge because it had more computational load than the P&O method.

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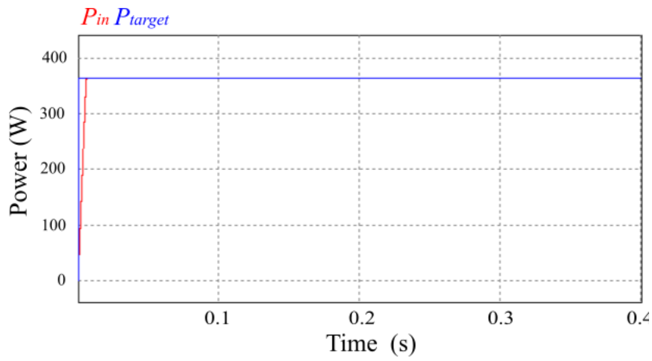
APPENDICES

TABLE A1
P&O AND MPSO COMPARISON IN NON-SHADING

	Targeted	P&O	MPSO
P_{in}	363.2 W	363.18 W	363.04 W
Accuracy	100%	99.99%	99.95%
Convergence speed	-	0.006 s	0.151 s



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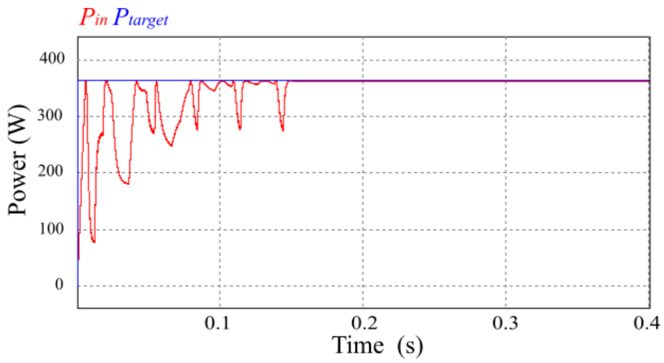
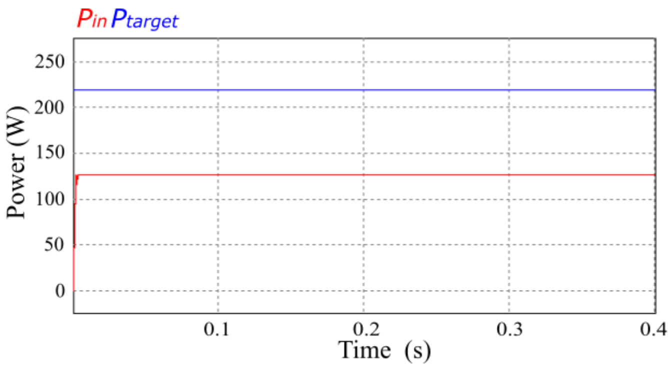


(b)

Fig. A1 Tracking process of GMPP in uniform irradiaton of 1,000W/m^2, (a) P&O, (b) MPSO.

TABLE A2
P&O AND MPSO COMPARISON IN PARTIAL SHADING PATTERN 1

	Targeted	P&O	MPSO
P_{in}	219.24 W	127.05 W	217.29 W
Accuracy	100%	57.95%	99.11%
Convergence speed	-	0.006 s	0.108 s



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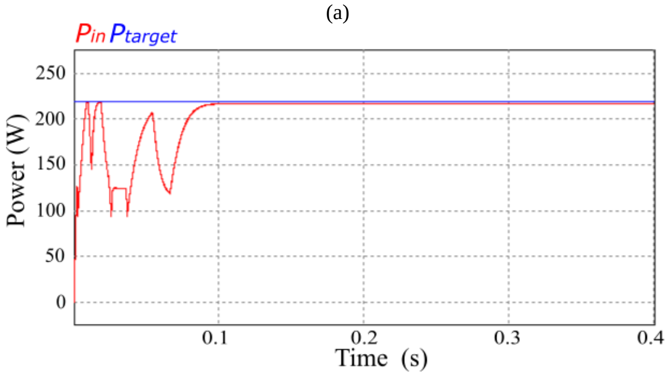
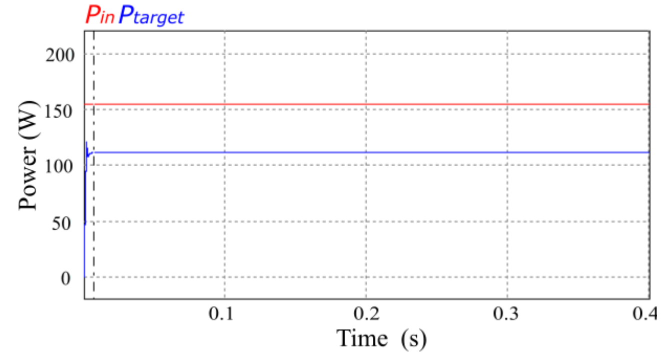


(b)

Fig. A2 Performance of GMPP tracking at partial shading condition pattern 1, (a) P&O, (b) MPSO.

TABLE A3
P&O AND MPSO COMPARISON IN PARTIAL SHADING PATTERN 2

	Targeted	**P&O**	**MPSO**
P_{in}	154.89 W	111.33 W	152.94 W
Accuracy	100%	71.87%	98.74%
Convergence speed	-	0.006 s	0.161 s



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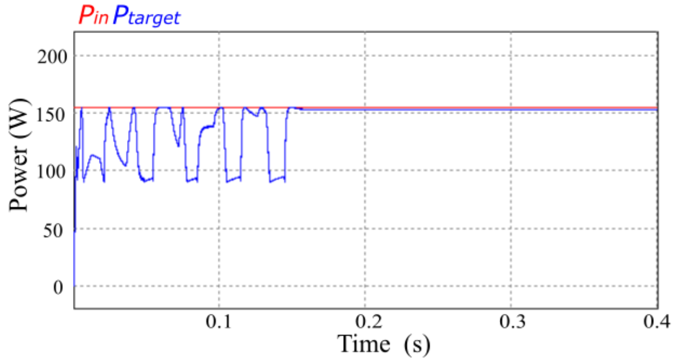

(b)

Fig. A3 Performance of GMPP tracking at partial shading condition pattern 2, (a) P&O, (b) MPSO.