Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. **67**, *3*, pp. 349–354, Bucarest, 2022

A NEW COMBINED METHOD FOR TRACKING THE GLOBAL MAXIMUM POWER POINT OF PHOTOVOLTAIC SYSTEMS

NORA KACIMI [1], ABDELHAKIM IDIR[2,3], SAID GROUNI[3], MOHAMED SEGHIR BOUCHERIT[1]

Keywords: Global maximum power point tracking; Grasshopper optimization algorithm; Model predictive control; Photovoltaic system; Partial shading conditions.

The power-voltage characteristic of photovoltaic (PV) systems operating under partial shading conditions (PSCs) exhibits multiple local maximum power points (MPPs). Conventional maximum power point tracking (MPPT) methods are effective under uniform solar irradiance conditions. Moreover, the power of PV systems may be decreased by the random fluctuation, oscillation, and slow speed of their power tracking. To overcome these problems, a new combined method based on the metaheuristic Grasshopper Optimization Algorithm (GOA) and Model Predictive Controller (MPC) is proposed. A series of experimental simulations were carried out on various cases to evaluate the performance of the proposed method and to better clarify our contribution, a comparative study with the traditional perturb and observe (P&O) method, PSO-based MPC (PSO-MPC), particle swarm optimization (PSO) method, and grasshopper optimization algorithm (GOA) was carried out. The results show that the proposed method significantly outperforms the competing methods such as PSO, PSO-MPC, and GOA regarding tracking time, power conversion efficiency, and oscillations in PV output power.

1. INTRODUCTION

In the past few years, solar energy has emerged as one of the most exploited renewable energy resources and the prime source of producing electricity [1]. Especially with integrating the photovoltaic (PV) system into the production of hybrid electricity systems, it has strengthened its position as an alternative source. However, PV systems under varying weather conditions encounter many challenges to maximizing output power, especially in low irradiance levels, in which it is challenging to deliver the maximum output, which results in low efficiency [1, 2].

To improve the PV system efficiency, the MPP tracker is an essential controller required for enhancing the available power from a PV system. Several MPP techniques for better extraction of maximum power have been proposed in the literature, and they are broadly classified into two categories: conventional [2] and soft computing methods [3]. In uniform irradiance, the conventional MPPT like perturb and observe (P & O), Fuzzy Logic Control (FLC), Neural Network (NN) control, and incremental conductance (IL) [3–8] can track the MPP quite efficiently, with considerable loss of power caused by oscillations around the MPP. GMPPT is a technique that extracts the possible maximum amount of power from the installed photovoltaic system under PSCs [9–14]. The paper [12] proposed a PSO for PV systems to locate the GMPP under PSCs. Several works on an alternative method known as the grasshopper optimization algorithm (GOA) are gaining traction compared to other optimization techniques [16, 17].

In this paper, a new combined method based on the recent meta-heuristic GOA-based MPC (GOA-MPC) to track the global maximum power point (GMPP) under partially shaded conditions (PSCs) is proposed. The main contribution of this work is to improve the GOA algorithm for optimal current extraction. Then the MPC is employed to tune the dc converter and maximize the output power. The output power maximization of the PV system is proposed as a goal function for GOA; this action is done via the setting of the optimal current using predictive control for the step-up converter. The effectiveness of the proposed control technique is compared with PSO, PSO-MPC, and GOA methods. The results confirmed the superiority of the proposed GOA-MPC algorithm in extracting the global maximum power from the partially shaded PV array.

The remainder of this paper is divided into the following sections: In section 2, a description and modeling of the PV system under different conditions are presented. Section 3 describes the proposed GOA-MPC algorithm. The simulation results under MATLAB/Simulink are presented in section 4, and the technique's performance is discussed. Finally, in section 5, appropriate conclusions are drawn.

2. PV SYSTEM MODELING UNDER PSC

A Photovoltaic cell is an electrical device that converts the energy solar directly into electricity by the photovoltaic effect. Figure 1 shows the most current modeling approach used consisting of a current source with one diode and resistors [18].

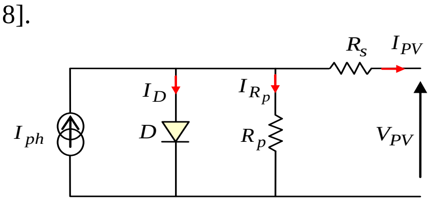


Fig. 1 – The equivalent electrical circuit of one diode.

The relation between the I_{pv} current and the V_{PV} voltage is given as follows [5]:

$$I_{PV} = I_{ph} - I_0\left(e^{\frac{V_{PV}+R_s I_{PV}}{V_t A}} - 1\right) - \frac{V_{PV}+R_s I_{PV}}{R_p}, \quad (1)$$

where the thermal potential (V_t) is given by:

$$V_t = \frac{N_s T K}{q}, \quad (2)$$

with: I_0, I_{PV} – saturation current of the diode and current supplied by the cell (A), respectively; K, q – Boltzmann

[1]Process Control Laboratory, National Polytechnic School, Algiers, Algeria, Email: nora.kacimi@g.enp.edu.dz, ms_boucherit@yahoo.fr
[2]Department of Electrical Engineering, University Mohamed Boudiaf of M'sila, Algeria, Email: abdelhakim.idir@univ-msila.dz
[3]University M'Hamed Bougara of Boumerdes, LAA Laboratory, Boumerdes, Algeria, Email: said.grouni@yahoo.fr

constant and electron charge, respectively; A, T – ideality coefficient of the PV cell and cell temperature in Kelvin, respectively; I_{ph} – photo-generated current in solar cells; R_p, R_s – are parallel and series resistance of the cell (Ω), and field N_p, N_s – cells number in parallel and series.

Several connected photovoltaic panels formed by solar cells connected in series and in parallel constitute a PV array. Equation (3) represents a PV array [18].

$$I_{PV} = N_{pp} I_{ph} - N_{pp} I_0 \left(e^{\frac{N_{ss} V_{PV} + R_s I_{PV} \left(N_{ss} / N_{pp} \right)}{V_t A}} - 1 \right) - \frac{N_{ss} V_{PV} + R_s I_{PV} \left(N_{ss} / N_{pp} \right)}{R_p \left(N_{ss} / N_{pp} \right)}, \quad (3)$$

where: N_{pp}, N_{ss} are the PV panels number connected in parallel and series, respectively.

A simplified block diagram of the PV system is depicted in Fig. 2. The electrical specifications of the PV panel at standard test conditions (STC) are summarized in Table 1. Its characteristics at 25°C are plotted in Fig. 3.

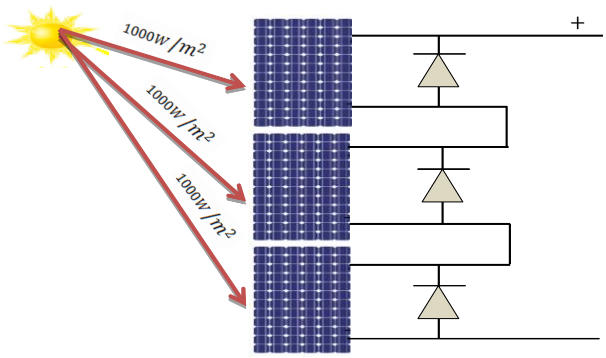


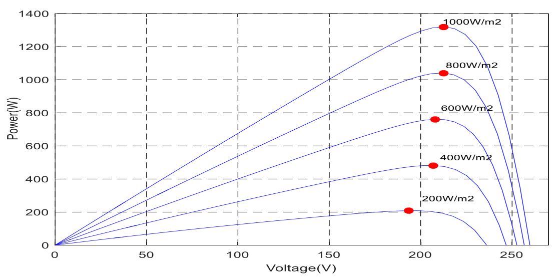
Fig. 2 – Schematic diagram of the PV system.

Table 1

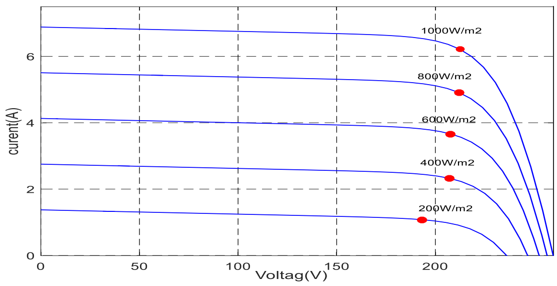
Electrical parameters of the PV

Maximum power (P_{mpp})	110 W
Open circuit voltage (V_{oc})	43.5 V
Short circuit current (I_{sc})	3.45 A
PV output voltage at MPP (V_{mpp})	35 V
PV output current at MPP (I_{mpp})	3.15 A
Number of cells connected in series (N_s)	72

Partial shading can occur at any time during the day. PSCs refers to the phenomenon that some parts of the solar panel are shaded by shade or dust. Under PSCs, the PV panels produce multiple peaks in power.



a)



b)

Fig. 3 – Characteristics of the used PV panel at 25°C for different levels of irradiance (graphs plotted with the step of 100 W/m^2): a) power-voltage (*P-V*) curves; b) current-voltage (*I-V*) curves.

The output characteristic (*P-V*) is shown in Fig. 4. The red circles represent the maximum power point positions at the corresponding irradiance. There is only one MPP for each irradiance level.

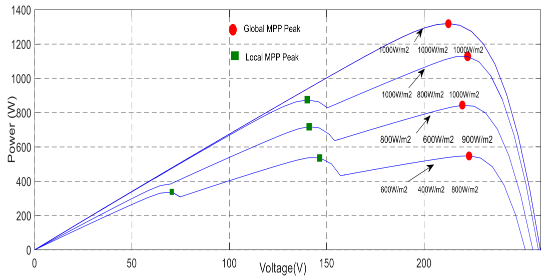


Fig. 4 – P-V curves under partial shading conditions.

The *P-V* curves are plotted under three different PSCs (Fig. 4):

1. The irradiance on three panels connected in series are 1000 W/m^2, 800 W/m^2, and 1000 W/m^2, respectively.
2. The irradiance on three panels connected in series are 800 W/m^2, 600 W/m^2, and 900 W/m^2, respectively.
3. The irradiance on three panels connected in series are 600 W/m^2, 400 W/m^2, and 800 W/m^2, respectively.

As seen from Fig. 4 under the PSCs, the characteristic curve of solar panel output is a multi-peaks curve. There is always a unique maximum power point, and the others are the local maximum points.

3. PROPOSED GOA-MPC ALGORITHM-BASED GMPPT TECHNIQUE UNDER PARTIAL SHADING

The GOA is one of the most recent populations to adopt a heuristic that copies the behavior of grasshopper swarms in wildlife. The algorithm is inspired by two characteristics, which are attraction and repulsion. To reach the target, the grasshoppers continue in their movement alongside the target direction to strike a balance between global search and local search during the iterative steps. The grasshopper locations are renewed, so the comfort zone is decreased adaptively until the best solution is achieved. Finally, Grasshopper finds the best solution. The grasshopper swarming behavior can be written as follows:

$$X_i(t+1) = c\left(\sum_{\substack{i=1 \\ j \neq 1}}^{N} c \frac{ub_d lb_d}{2} s\left(\left| X_j(t) - X_i(t) \right| \right) \frac{X_j(t) - X_i(t)}{d_{ij}} \right) + \hat{T}_d . \quad (4)$$

The *s* function, which defines the social forces, is calculated as follows:

$$s(r) = f \exp\left(\frac{-r}{l_s} \right) - \exp(-r), \quad (5)$$

where X_i is the i_{th} Grasshopper's position at iteration, s is a function represents the strength of the social forces, f is the attraction strength, r is a distance, l_s is the length attraction, ub_d and lb_d are the upper and lower bounds, d_{ij} is the distance between i_{th} and j_{th} grasshoppers, T_d is the d-dimensional position target, and c is the factor of shrinking represents the comfort zone decreasing. The equation of c is as follows:

$$c(t) = c_{\max} - t\,\frac{c_{\max} - c_{\min}}{t_{\max}}\,, \tag{6}$$

where $c_{\min}$ and $c_{\max}$ are the minimum and maximum of c values, $t_{\max}$ are the iterations maximum number.

PS can happen at any time during the day. The object of this research is to find the maximum value of the output power of the PV system under the PSCs, which produce several peaks of power in characteristic (*P-V*) to maximize the output power of PV and run it at GMPP.

The proposed method's main idea is to combine GOA and MPC algorithms to take advantage of each algorithm's capabilities. At GMPP, GOA tracks the current, but MPC is used because of its quick convergence and steady-state stability. Three particles of the PV current are randomly selected to find GMPP for the first time, and then the value of the fitness function of the three particles is evaluated. The maximum power supplied by the corresponding current is the best current sample. The flow chart of the proposed GMPPT method is given in Fig.5.

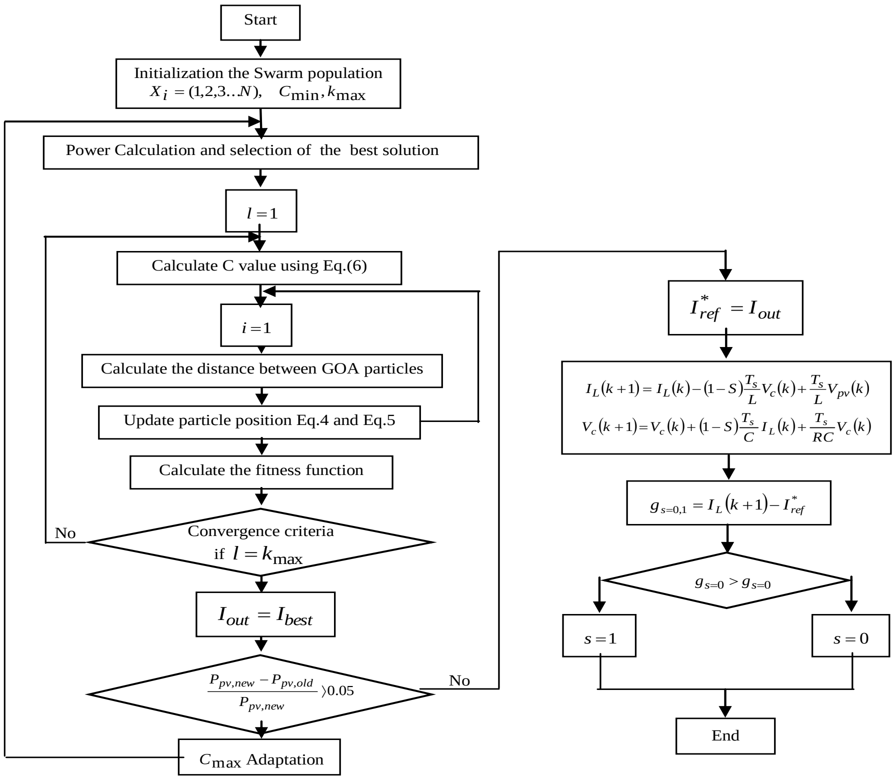


Fig. 5 – The flowchart of proposed GHO-MPC-based GMPPT.

Parameters are very important constants in GOA, which act on the search precision and speed of convergence of GOA. Initially, the value is high and in the search space. As the number of iterations increases, the population changes, this depends on maximum iteration and the initial parameter becoming low. It is clear from the preceding discussion that this can be used to determine the global peak region. In this paper, the parameters are changed to balance the GMPP exploration. The advantage of MPC is faster convergence with fewer power oscillations around GMPP.

The tracking of GMP is continued until the detection of an irradiance change. The change in irradiance results in GMPP shifting from the precedent value. GOA is reset when a significant difference in weather conditions is detected as a change in power. Equation 7 is used to identify changes in weather conditions and reset parametric GOA.

$$\frac{P_{pv,new} - P_{pv,old}}{P_{pv,new}} > \Delta P\,[\%]\,, \tag{7}$$

Therefore, the GOA algorithm is reinitialized to find the new GMPP.

In this article, the new GMPPT algorithm is proposed in which GOA is reinitialized with one parameter. With only one parameter of tuning, it helps to achieve faster GMPP tracking. In the first iteration, the parameters are adapted using eq. 8. After the change in irradiance is detected, the process of identifying a global region for new irradiance conditions remains the same as discussed above:

$$C_{\max}(k+1) = C_{\max}(k) \mp \Delta\,, \tag{8}$$

where Δ is a small constant.

The block of GOA gives the optimal current reference, compared to the instantaneous measured current for the minimization of the MPC cost function, and then delivers the dc/dc converter switching signals. The block diagram of a standard GMPPT controller utilized in the PV system is shown in Fig. 6.

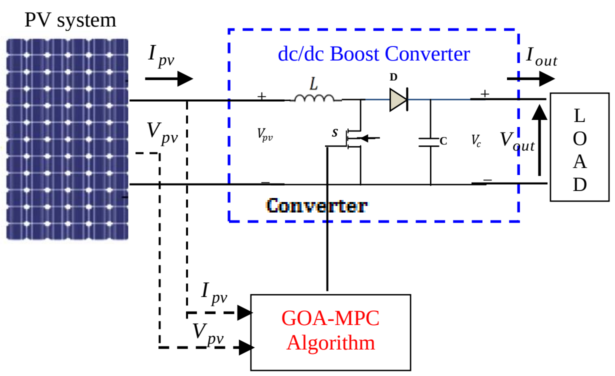


Fig. 6 – Block diagram of a typical PV system with GMPPT control

The predicted current and voltage in discrete time are given by:

$$I_L(k+1) = I_L(k) - (1-S)\frac{T_s}{L}V_c(k) + \frac{T_s}{L}V_{pv}(k), \quad (9)$$

$$V_c(k+1) = V_c(k) + (1-S)\frac{T_s}{C}I_L(k) + \frac{T_s}{RC}V_c(k), \quad (10)$$

where L, C, R represents: the inductance, capacitance, and resistance load, respectively, T_s is sample time, S is switching state, which can be presented by '1' or '0'. The variables I_L and V_c can now be predicted for a step horizon, which is used then to obtain control actions.

In this paper, the MPC used is based on a discrete time of the current system. In one-step horizon MPC, the variables I_{pv}, V_{pv}, and V_c are measured in time k and taken to estimate the future comportment in time $(k+1)$. The switching state is determined by optimizing a cost function g_s, which is chosen as follows:

$$g_{s=0,1} = I_L(k+1) - I_{ref}^{*} . \quad (11)$$

4. SIMULATION RESULTS AND DISCUSSION

To evaluate the performance of the proposed technique, a block diagram for tracking GMPP under PSCs is composed of a photovoltaic system that includes three PVs solar panels, a boost converter, and load. The parameters of boost are fixed as $C = 1100\ \mu\text{F}$, $L = 45\ \text{mH}$, and a resistive load of $R = 80\ \Omega$ was utilized. During the operation of a PV system, the MPPT controller calculates the best reference current under variable conditions and compares it with the current value to generate the switch signal and control the boost circuit. The datasheet parameters of the photovoltaic model at STC are listed in Table 1.

The performance of GOA-MPC is compared with that of P & O, PSO, PSO-MPC, and GOA in terms of tracking time and tracking efficiency. The iteration maximum number and same population size for PSO and GOA were consistent enough to have a fair comparison. The initial parameters for the algorithm are shown in Table 2. All three algorithms are subjected to the same test conditions. Three PV curves with different GMPPs have been generated in this paper to validate the proposed method. Each curve has one GMPP with varying locations. To test the effectiveness of the proposed controller, we will consider different shading scenarios.

Table 2

Controlling parameters of GOA, PSO

Parameters	PSO	GOA
No. of search agents	3	3
Maximum iteration	100	100
C_{min}	-	0.19
Inertia weight	0.9	-

4.1. TESTS UNDER PARTIAL SHADING

Three cases are considered in this section:

Test 1. The temperature of the three PVs was all 25 °C, and the irradiance was set at 1000 W/m^2 for PV1, 800 W/m^2 for PV2, and 600 W/m^2 for PV3. In this condition, the theoretical maximum power value was 846.67 W, the GMPP on the right side.

Test 2. The three PV systems' irradiance were 1000 W/m^2, 500 W/m^{2,} and 300 W/m^{2,} respectively, and the theoretical maximum power was 454.66 W.

Test 3. The three PV systems' irradiance were 1000 W/m^2, 800 W/m^{2,} and 1000 W/m^2, respectively, and the theoretical maximum power was 1128 W.

Three PV curves with different GMPPs have been generated in this paper to validate the proposed method. Each curve has one GMPP with varying locations.

Figure 7 shows the entire PV characteristic under study.

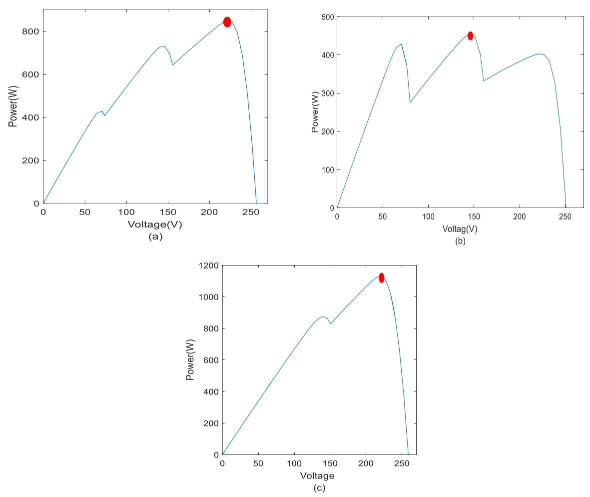


Fig. 7 – (*P*-*V*) characteristic under validation study: a) Test 1, b) Test 2, c) Test 3.

By using the maximum theoretical power, the efficiency is calculated, and the instantaneous extracted power is defined as:

$$E[\%] = \left(\frac{P_{MPPT}}{P_{\max}}\right) \times 100 , \quad (13)$$

where: P_{MPPT} is the output power of the PV array, and $P_{\max}$ is its theoretical maximum power.

In this section, four tests representing four conditions of operation are discussed. These tests are chosen for the comprehensive formulation, and the proposed GOA-MPC performance is compared with that of GOA-PI, PSO-MPC, PSO-PI, and P&O. Performance details are presented in Table 3. The results are examined regarding tracking time, tracking efficiency, and oscillation at MPP (W).

Figures 8, 9, and 10 compare the power obtained by GOA-MPC, GOA-PI, PSO-MPC, PSO-PI, and P&O for cases 1, 2, and 3, respectively.

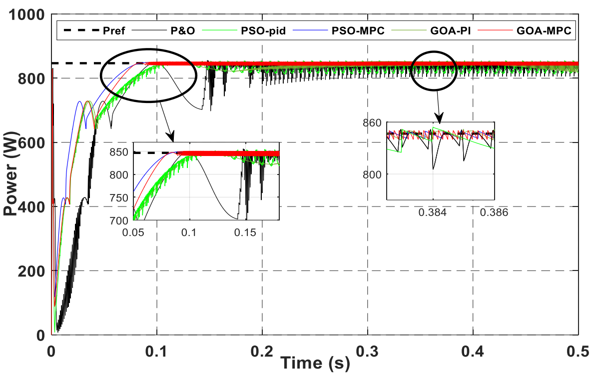


Fig .8 – PV output power waveforms for different GMPPT algorithms in Test 1.

In Fig. 8, zoomed-in, detailed transients of the power are given. The power and efficiency are measured against the location of GMPP at 846.67 W in Test 1. GOA-MPC, GOA-PI, PSO-MPC, PSO-PI, and P&O obtain 98.9%, 97.9%, 94.0%, 93.0%, and 89%, respectively, with GOA-MPC being the most efficient technique.

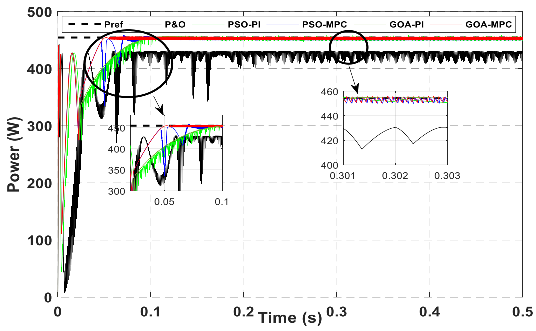


Fig. 9 – PV output power waveforms for different MPPT algorithms in Test 2.

Any MPPT technique's robustness is exhibited by GM fast tracking and the efficiency of their settling time at GM.

In our study, the experimental simulations show that it takes GOA-MPC 0.09 s, GOA-PI 0.11 s, PSO-PI 0.13 s, PSO-MPC 0.19 s, and P&O 0.152 s, respectively. As stated by their performance, these techniques can be ranked GOA-MPC > GOA-PI > PSO-PI > PSO-MPC > P&O.

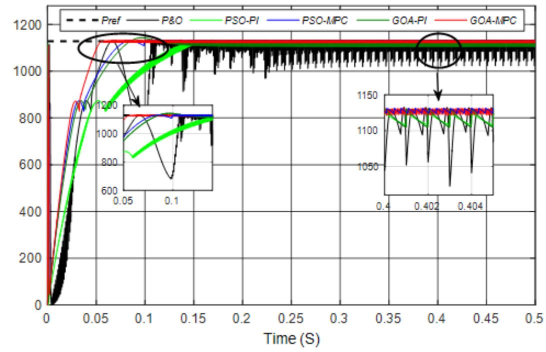


Fig. 10 – PV output power waveforms for different MPPT algorithms in Test 3.

Figures 9 and 10 show the simulation results in Test 2 and Test 3. The maximum power in *tests 2* and 3 was about 454.66 W and 1128 W, respectively. As we can see, the PSO has slow convergence, and the P&O method cannot track the MPP. However, the GOA method can successfully track the GMPP. The tracking time was very short in the proposed technique, needing just 0.05 s to achieve GMPP.

The proposed GOA-MPC not only helps to reduce the overshoot but also helps to save power loss caused by undesired oscillations. P&O converges to GM but does not settle at GM due to oscillations produced by continuous perturbation and observation. The oscillations produced by P & O are 80 W in magnitude, oscillating between 750 W and 850 W in the first test as shown in Fig. 8, and a detailed zooming-in of Fig. 8 shows the oscillations. GOA-MPC successfully reduces the oscillations' magnitude to 10 W, attaining a 96 % tracking efficiency.

Tests 2 and Test 3, again, demonstrate the superior performance of the proposed GOA-MPC algorithm.

Table 3 summarizes the main differences in performance between the tracking algorithms in three cases. As can be seen, the proposed algorithm has the highest efficiency.

Table 3

The quantitative comparison of proposed algorithm (GOA-MPC), P&O, PSO-PI, PSO-MPC, and GOA-PI of tests 1, 2 and 3

Parameter	Tests	P&O	PSO –PI	PSO-MPC	GOA-PI	Proposed method
Tracking time(s)	Test 1	0.152	0.13	0.19	0.11	**0.09**
	Test 2	-	0.9	0.16	0.07	**0.05**
	Test 3	0.107	0.096	0.12	0.1	**0.058**
Tracking efficiency (%)	Test 1	93 %	94 %	93 %	94 %	**96 %**
	Test 2	89 %	94 %	93 %	97 %	**98 %**
	Test 3	92 %	95 %	95 %	96 %	**98 %**
Oscillations at MPP(W)	Test 1	[770 850]	[820 852]	[838 848]	[825 835]	[840 850]
	Test 2	[280 430]	[432 436]	[435 443]	[447 458]	[451 456]
	Test 3	[920 1132]	[1110 1120]	[1116 1126]	[1120 1137]	[1123 1131]

4.2. STEP CHANGES IN IRRADIANCE WITH CONSTANT TEMPERATURE (TEST 4)

To evaluate the performance of the proposed technique to track GMPP under such conditions, the PV system was investigated in two steps (Test 1 and Test 3). In the time range of [0, 0.5 s], the three solar panels' irradiance was 1000 W/m^2, 800 W/m^{2,} and 600 W/m^{2,} respectively, and the PV system's theoretical maximum power value was 846.67 W. In the time range of [0.5 s, 1 s], the third solar panel irradiance was changed to 1000 W/m^{2,} and the PV system's theoretical maximum power value was 1128 W.

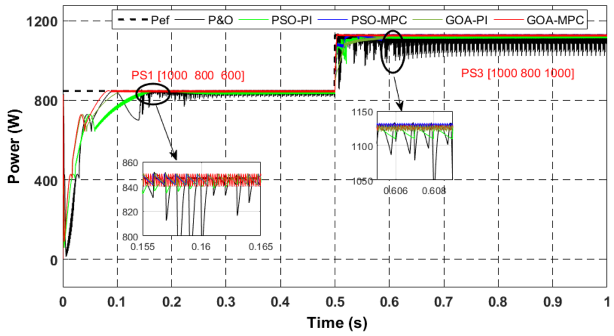


Fig. 11 – PV output power waveforms for different MPPT algorithms in Test 4.

In the time range of [2, 3s], all PV arrays receive the same conditions 1000 W/m^2. The results are shown in Fig. 11.

Table 4 summarizes the main differences in performance between the tracking algorithms in case (4). The overall tracking efficiency achieved by GOA-MPC, PSO-MPC, GOA-PI, PSO-PI, and P&O, measured by the average power over the maximum, is 98.7 %, 98.4 %, 97 %, 96 %, and 95 %. Therefore, the concerned techniques can be ranked GOA-MPC > PSO-MPC > GOA-PI > PSO-PI > P&O.

Table 4

The quantitative comparison of proposed algorithm, P&O, PSO-PI, PSO-MPC, and GOA-PI of test 4

Parameter	Interva time (s	P&O	PSO-PI	PSO-MPC	GOA-PI	Proposed GOA-MPC
Tracking time(s)	[0-0.5]	0.16	0.16	0.1	0.12	**0.09**
	[0.5-1]	0.15	0.07	0.09	0.1	**0.04**
Tracking efficiency (%)	[0-1]	95%	96%	98.4%	97%	**98.7%**
Oscillations at MPP(W)	[0.5-1]	[1020-1130]	[1110-1131]	[1125-1133]	[1120-1130]	[1124-1131]

5. **CONCLUSIONS**

This paper presents a novel combined GOA-MPC-based GMPPT technique for PV systems under partial shading conditions. The GOA-MPC technique has been evaluated according to criteria such as speed of their power tracking, efficiency, and oscillations at MPP. A series of experimental simulations on various cases have demonstrated that the proposed GOA-MPC technique is very effective.

The proposed method significantly outperforms the competing methods such as PSO, PSO-MPC, and GOA in terms of tracking time, power conversion efficiency, and oscillations in PV output power. The integration of the MPC controller with the GOA technique not only helped in reducing the steady state oscillations in output power considerably but also reduced the overall MPPT time compared to the GOA technique, the PSO-MPC, and as well as the conventional PSO. We can conclude that the new proposed GOA-MPC-based GMPPT is an effective technique to improve the PV system efficiency under PSCs.

Received on 10 December 2020

REFERENCES

1. A.A. F Mirza, Q Ling, M.Y Javed, M Mansoor, *Novel MPPT techniques for photovoltaic systems under uniform irradiance and Partial shading*, Solar Energy journal, **184**, pp. 628–648 (2019).
2. A. Attou, A. Massoum, M. Chadli, *Comparison study of two tracking methods for photovoltaic systems*, Rev. Roum. Sci. Techn. – Electrotechn. et Energ., **60**, *2*, pp. 205–214 (2015).
3. B. Bendib, H. Belmili, F. Krim, *A survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovoltaic system*, Renewable and Sustainable Energy Reviews Journal, **45**, pp. 637–648 (2015).
4. U Yilmaz, A. Kircayand, S. Borekci, *PV system fuzzy logic MPPT method and PI control as a charge controller*, Renewable and Sustainable Energy Reviews, **81**, pp. 994–1001 (2018).
5. N. Kacimi, S.Grouni, A. Idir, M.S. Boucherit, *New improved hybrid MPPT based on neural network-model predictive control-Kalman-filter for photovoltaic system*, Indonesian Journal of Electrical Engineering and Computer Science, **20**, *3*, pp. 1230–1241 (2020).
6. H. Deboucha, S.L. Belaid, *Improved incremental conductance maximum power point tracking algorithm using fuzzy logic controller for photovoltaic system*, Rev. Roum. Sci. Techn. – Electrotechn. et Energ., **62**, *4*, pp. 381–387 (2017).
7. S.P. Bihari, P.K. Sadhu, S. Das, P. Arvind, A. Gupta, *Design and implementation of a photovoltaic wind hybrid system with the assessment of fuzzy logic maximum power point technique*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **64**, *3*, pp. 235–240, (2019).
8. H.A. Azzeddine, M. Tioursi, D.-E. Chaouch, B. Khiari, *An offline trained artificial neural network to predict a photovoltaic panel maximum power point*, Rev. Roum. Sci. Techn. – Electrotechn. et Energ., **61**, *3*, pp. 255–257 (2017).
9. S Veerapen, H. Wen, X. Li,Y. Du, Y. Yang, Y. Wang, W. Xiao, *A novel global maximum power point tracking algorithm for photovoltaic system with variable perturbation frequency and zero oscillation*, Solar Energy Journal, **181**, pp. 345–356 (2019).
10. T. Guan et al., *Global maximum power point tracking algorithm for solar power system*, Pan JS., Li J., Tsai PW., Jain L. (eds.), *Advances in Intelligent Information Hiding and Multimedia Signal Processing*, Smart Innovation, Systems, and Technologies, Springer, Singapore, **157** (2020).
11. H.D. Liu et al., *A GMPPT algorithm for preventing the LMPP problems based on trend line transformation technique*, Solar Energy, **198**, pp. 53–67 (2020).
12. K Sundareswaran, V. Vigneshkumar, S Palani, *Application of a combined particle swarm optimization and perturb and observe method for MPPT in PV systems under partial shading conditions*, Renewable Energy Journal, **75**, pp. 308–317 (2015).
13. A. Al-Gizi, A. Craciunescu, M.A. Fadel, M. Louzazni, *A new hybrid algorithm for photovoltaic maximum power point tracking under partial shading conditions*, Rev. Roum. Sci. Techn. – Electrotechn. et Energ., **63**, *1*, pp. 52–57 (2018).
14. Z. Amokrane, M. Haddadi, N.O. Cherchali, *A new method of tracing the characteristic of photovoltaic generators under real operating conditions*, Rev. Roum. Sci. Techn. – Electrotechn. et Energ., **62**, *3*, pp. 276–281 (2017).
15. C. Ahmed, M. Cherkaoui, M. Mokhlis, *PSO-SMC controller based GMPPT technique for photovoltaic panel under partial shading effect*, International Journal of Intelligent Engineering and Systems, **13**, *2*, pp. 307–316 (2020).
16. A. Fathy, O. El-baksawi, *Grasshopper optimization algorithm for extracting maximum power from wind turbine installed in Al-Jouf region*, J. Renewable Sustainable Energy, **11**, *033303* (2019).
17. N.M. Amin, A.M. Soliman, H.M Hasanien, A.Y. Abdelaziz, *Grasshopper optimization algorithm-based PI controller scheme for performance enhancement of a grid-connected wind generator*, J. of Control, Automation and Electrical Systems, **31**, pp. 393–401 (2020).
18. S.A. Tadjer, A. Idir, F. Chekired, *Comparative performance evaluation of four photovoltaic technologies in Saharian climates of Algeria: ghardaïa pilot station*, Indonesian Journal of Electrical Engineering and Computer Science, **18**, *2*, pp. 586–598 (2020).