Proc. of the 2nd International Conference on Electrical, Communication and Computer Engineering (ICECCE)
12-13 June 2020, Istanbul, Turkey

Comparison of Two Hybrid Global Maximum Power Point Algorithms for Photovoltaic Module Under Both Uniform and Partial Shading Condition

Dalila Fares
Signals and Systems Laboratory
Institute of Electrical and Electronic Engineering,
University M'Hamed BOUGARA of Boumerdes, Avenue of Independence,
Boumerdes, 35000, Algeria.
d.fares@univ-boumerdes.dz

Mohamed Fathi
Unité de Développement des Equipements Solaires, UDES
Centre de Développement des Energies Renouvelables, CDER
Tipaza, 42415, Algeria.
dr_fathimohamed@yahoo.fr

Saad Mekhilef
Power Electronics and Renewable Energy Research Laboratory (PEARL),
Department of Electrical Engineering,
University of Malaya,
Kuala Lumpur, 50603, Malaysia
saad@um.edu.my

***Abstract*— Power vs. Voltage (P-V) characteristics of a photovoltaic module (PV) show multiple peaks under partial shading conditions (PSCs). Most conventional maximum power point tracking (MPPT) techniques can accurately locate the single point under uniform conditions but fail under PSCs. Intelligent algorithms can locate the global point (GMPP) among the local ones (LP) but incur more computational cost. Combining both types as hybrid GMPPT provides more effective performance under different environmental conditions. This paper aims to analyze and compare the performance of two hybrid GMPP techniques under both uniform conditions and partial shading. In the proposed approach, the genetic algorithm (GA) and particle swarm optimization (PSO) are integrated with the perturb and observe algorithm (P&O). The simulation results in Matlab/Simulink confirm that both hybrid algorithms can track the GMPP. Furthermore, they show the ability to differentiate between different environment changes occurrences.**

Keywords*— *Photovoltaic module, global maximum power point, hybrid algorithm, partial shading.

I. Introduction

Solar energy is the cleanest and most inexhaustible renewable energy resource. This made the use of the photovoltaic systems grow significantly over the past years. Solar photovoltaic systems are among the most promising technologies for energy production. However, the drawback of PV systems is the dependency on weather conditions. The varying temperatures and solar irradiation cause a changing performance for the PV module; the P-V characteristics curve shows inconsistent maximum power point (MPP) [1]. Thus, tracking techniques (MPPTs) should be applied to track the maximum power point and make the PV module operates at its maximum power. MPPT methods are classified according to their tracking techniques and they are reviewed in [2]. Among all the MPPT techniques; the commonly utilized are the perturb and observe (P&O) [3-5] and the incremental conductance (InC) [6], [7] due to their simple implementations. Modified versions of these techniques were proposed to enhance the tracking performance under rapid irradiance variation [8] and load variation [9].

The PV module performance is also affected by partial shading. The partial shading condition occurs when some portions of the PV module receive diverse levels of solar irradiance. This phenomenon is commonly caused by the shadows of trees, accumulated dust, and moving clouds. Under partial shading conditions, the P-V curve shows several maxima in where only one is the global point. The MPPT algorithms should appropriately track the global MPP and avoid dropping in local points [10]. The conventional MPPT algorithms are less efficient and inadequate to track the GMPP since they mostly drop in local peaks. Several intelligent optimization algorithms for tracking the real GMPP were introduced in the literature, e.g the particle swarm optimization (PSO) [11-13] and genetic algorithm (GA) [14-15]. The accuracy and fast-tracking are the most desired traits in MPPT algorithms under PSCs. Some MPPT techniques may fail to track the GMPP, while others prove the ability to determine the global point but with less accuracy or slower convergence [16]. Hence, hybrid MPPTs are introduced which are a combination of two techniques [17], [18]. The hybridization aims to combine the features of individual MPPT techniques and overcome their drawbacks when used alone.

This work objective is to analyze and compare the performance of two hybrid GMPPT algorithms, the P&O based Genetic and P&O based PSO, under two environmental conditions; uniform irradiance and partial shading. The proposed algorithms are simulated within the PV system model which is implemented using Matlab/Simulink. The tracking performances of the algorithms are compared considering three different solar irradiance profiles exhibiting partial shading conditions. The reminder sections of this paper are organized as follows: Section II describes the P-V characteristics of the PV module under partial shading. In section III, the well-known MPPT techniques P&O, Genetic, and PSO are discussed. Then, the proposed hybrid algorithms are discussed in

978-1-7281-7116-6/20/$31.00 ©2020 IEEE

Authorized licensed use limited to: Consortium - Algeria (CERIST). Downloaded on December 28,2020 at 07:54:53 UTC from IEEE Xplore. Restrictions apply.

section IV. The simulation results are provided in section V and the conclusion is in section VI.

II. PV MODULE CHARACTERISTICS UNDER PARTIAL SHADING CONDITIONS

Photovoltaic modules usually contain many bypass diodes that connect the same number of photovoltaic cells. Fig.1 shows a PV module with several cells bypassed by diodes; n denotes the number of these diodes. Each bypass diode protects the same number m of solar cells [19].

During a uniform solar irradiance condition, the power vs. voltage (P-V) curve of a PV module shows one single peak (Fig.1). This peak is considered the global peak and it represents the maximum power point in the P-V curve.

When partial shading occurs, the cells of the PV module receive distinct solar irradiance levels (Fig.3), and multiple peaks display on the P-V characteristics curve (Fig.2). The multi-peak curve is generated due to the bypass diodes existence in the module. As can be noticed in Fig.2, only the highest peak GP is the global maximum power point and the other peaks are local points. The number of the different solar irradiance levels stroking the PV module determines how many peaks will be generated in the curve.

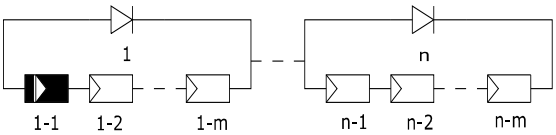

Fig. 1. PV module diagram containing bypass diodes and a shaded cell

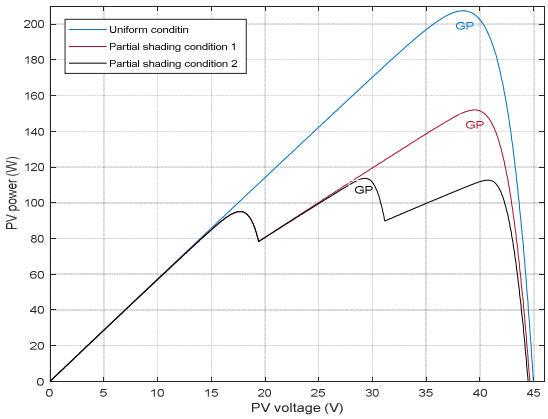

Fig. 2. P-V characteristics under different irradiance conditions

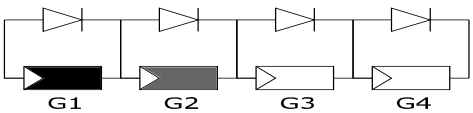

Fig. 3. Diagram of a PV module containing four cell groups with different shading levels

III. MPPT ALGORITHMS

A. P&O ALGORITHM

The perturb and observe (P&O) is a widely used algorithm in MPP tracking due to its simple structure and implementation. This method uses the trial and error process for finding the MPP where the duty cycle d(k) sent to the converter is disturbed to get a change in the power P(k). The values of the voltage V(k) and the current I(k) are measured at each cycle to calculate the corresponding power P(k) to be compared with the previous value P(k-1). In case the power has increased, the duty cycle is changed with a small perturbation value Δd (step size) in the same direction as the previous cycle. Otherwise, the duty cycle is varied in the opposite direction. The process of perturbing the duty cycle and observing the power level is repeated until the level of the power P(k) starts oscillating around the peak power. Hence, the maximum power point MPP is obtained. The steps of the P&O method are presented in Fig.4.

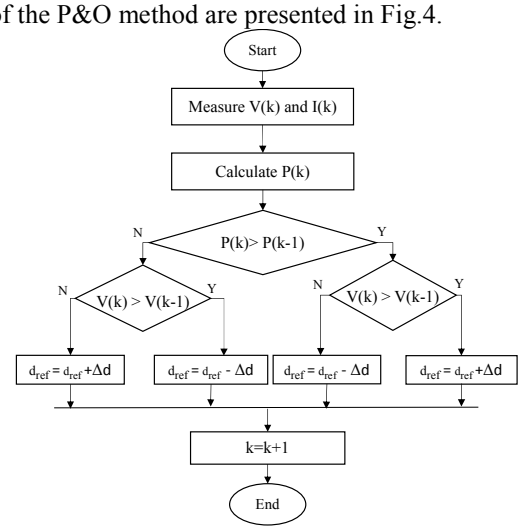

Fig. 4. The steps of the Perturb and Observe (P&O) method

B. GENETIC ALGORITHM

The genetic algorithm (GA) is a heuristic optimization method that mimics the natural evolution of genetics. The genetic algorithm was developed by David Goldberg, while the first idea for this search technique was proposed by John Holland in the early 1970s [20].

The genetic algorithm starts by initializing candidate solutions called the initial generation (population). Each candidate solution is a set of numerical values represented by a chromosome. At each generation, three fundamental operations will be applied; selection, crossover, and mutation. The fitness function is applied for each solution, and then a selection process is performed to include solutions to the next generation according to their fitness values [21]. The closer the solution gets to the optimal one, the highest chance it has to be selected. The selected solutions randomly split into separate offsprings. Then, the crossover operator combines two offsprings to produce a new solution. The mutation process aims to keep diversity and variability between generations. The new solutions are incorporated in the next generation and the overall evolution continues until the end condition is satisfied [22].

GA is a widely used algorithm for MPP tracking. A set of duty cycles can be selected as the initial population

Authorized licensed use limited to: Consortium - Algeria (CERIST). Downloaded on December 28,2020 at 07:54:53 UTC from IEEE Xplore. Restrictions apply.

(chromosomes). Through the process of evolution, they converge to the best duty cycle harvesting the maximum power and reach the MPP.

The entire process of the GA is given in the flowchart of Fig.5.

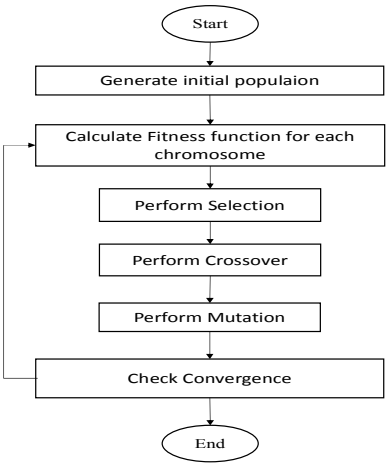

Fig. 5. Genetic algorithm process

C. PSO ALGORITHM

Particle swarm optimization (PSO) is a search optimization technique proposed in 1995 by Kennedy and Eberhart. It is an evolutionary method inspired by swarm intelligence in searching for food. A PSO algorithm initializes a set of particles (initial population) randomly distributed in the search space. Each particle in the population represents a candidate solution defined by its position and velocity. In each iteration, particles update themselves following their best position experience P_{best} and the best position experience of the whole particles swarm G_{best}. The particles use P_{best} and G_{best} to continuously adjust their direction and velocity, which leads to fast converging toward the optimal position. In applying PSO for MPP tracking, the duty cycles are taken as particles which update their position based on the following equation [1], [23]:

$$d_i^{k+1} = d_i^k + v_i^{k+1} \tag{1}$$

Where d_i is the ith particle position, k represents the current iteration. The variable v_i is the particle velocity (the step size) and it is calculated as follow:

$$v_i^{k+1} = \omega\, v_i^k + ar_1(P_{best} - d_i^k) + br_2(G_{best} - d_i^k) \tag{2}$$

Where the factor ω represents the inertia weight, a and b are the acceleration factors, r_1 and r_2 are values randomly chosen from the range [0, 1].

IV. PROPOSED ALGORITHM

Two algorithms are proposed in our work to be compared, P&O based PSO and P&O based Genetic. Both algorithms have the same overall structure as illustrated in the flowchart in Fig.6.

In the proposed approach, the hybrid algorithm works in two modes. Under uniform environmental cases, the P&O starts tracking the single MPP. When partial shading occurrence is detected, the heuristic algorithm subroutine is called to track the global MPP.

The hybrid algorithm should be able to distinguish between uniform conditions and PS conditions. Hence the following inequalities should be checked [24]:

$$\frac{I_{d3} - I_{d1}}{I_{d3}} \geq 0.1 \tag{3}$$

$$\frac{V_{d2} - V_{d1}}{V_{d2}} \geq 0.2 \tag{4}$$

Where the values (I_{d1}, I_{d2}, I_{d3}) and (V_{d1}, V_{d2}, V_{d3}) are the PV currents and voltages measured when sending the duty cycles (d_1, d_2, d_3) respectively to the converter connected to the PV module. The values 0.1 and 0.2 are selected based upon observation on the values of the current Impp and voltage Vmpp at the maximum power point. It is found that in a single current-voltage (I–V) curve, Impp is about 90% of *I*sc and Vmpp is about 80% of *V*oc [24].

The main steps of the proposed algorithm are described in the following:

- In the main code, three duty cycles d_1, d_2, and d_3 are sent to the boost converter. The corresponding voltages and currents V(k) and I(k) (k=1.2.3) are measured to check for partial shading occurrence using (3) and (4). The duty cycle that harvested the maximum power is saved as d_{max}.
- In the case of normal conditions, the perturb and observe (P&O) subroutine is called to search for the single peak MPP. The P&O performs the perturbations starting from d_{max}.
- In case partial shading is detected, a heuristic technique subroutine is called (GA or PSO). The intelligent algorithm takes a set of initial solutions ($d_i = [d_1, d_2, d_3, \ldots, d_9]$) and start the process of optimization. When the best solution is reached, it proceeds to the P&O subroutine to extract the exact GMPP.

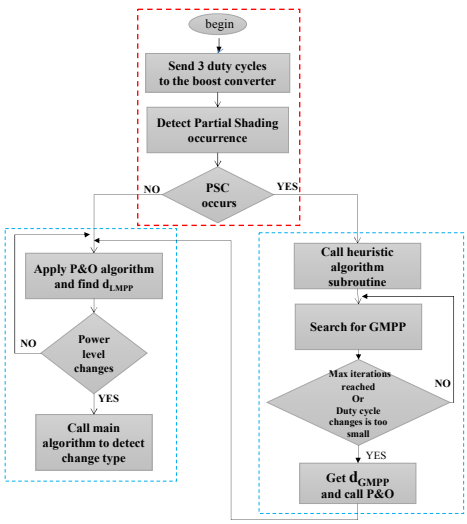

Fig. 6. Proposed algorithm

Authorized licensed use limited to: Consortium - Algeria (CERIST). Downloaded on December 28,2020 at 07:54:53 UTC from IEEE Xplore. Restrictions apply.

V. SIMULATION RESULTS

The SIMULINK environment in MATLAB software is used to perform simulations and verify the performance of the suggested algorithms. The PV system model used contains a PV module, a boost converter, and a resistive load. The module contains four groups of series-connected cells and its V_{OC} and I_{SC} are 45V and 5.75A, respectively. The converter is implemented with a 10 kHz switching frequency, and the sampling time is set to 0.01s.

The PV module model has been simulated with different solar irradiance profiles to examine the local MPPs and the GMPP. The P−V curves are shown in Fig.7.

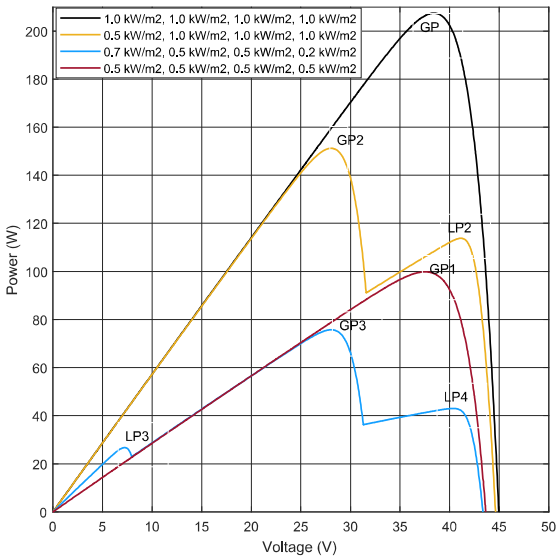

Fig. 7. P−V curves for different tested irradiance profiles

The solar irradiance profiles selected are used to create three different patterns exhibiting uniform conditions and partial shading conditions. These patterns are used to analyze the tracking performance of the algorithms. The output PV power, output PV voltage, and the converter duty cycle for both algorithms are shown in Fig.8 to Fig.10.

In the first case, all module cells are receiving uniform irradiance level 1kW/m^2. Under this case, there is just one peak GP of 208W as can be noticed in Fig.7. At t=0.2s the irradiance level suddenly changes and all parts now are receiving 0.5kW/m^2. As shown in Fig.8, both algorithms detected the uniform change and applied the P&O subroutine to locate the single maximum point GP1 of 99.82W (Fig.7).

For the second case; the whole module is receiving a solar irradiance of 1kW/m^2. At t=0.2s, the irradiance stroking one of the four parts of the module suddenly decreases and the new irradiance profile is 0.5kW/m^2, 1kW/m^2, 1kW/m^2, 1kW/m^2. As can be seen in Fig.7, two peaks exist; LP2 as local MPP and GP2 as the GMPP with 151W. Based on Fig.9, both algorithms detected the partial shading PS occurrence. Starting from t=0.24s, the heuristic algorithm subroutine started the tracking process ignoring the local peak. The GMPP is tracked by the P&O based Genetic after 0.44s while the P&O based PSO completed the tracking after 0.45s.

The solar irradiances are 0.7 kW/m^2, 0.5kW/m^2, 0.5kW/m^2, 0.2kW/m^2 in the third case. Fig.7 shows that three peaks exist; LP3 and LP4 as local MPPs and GP3 is the GMPP with 79W. The response of the two proposed algorithms is illustrated in Fig.10. As can be noted, both algorithms detected the partial shading occurrence and started tracking the GMPP at t=0.3s. Ignoring the local peaks, the P&O based Genetic spent 0.99s to reach the GMPP and The P&O based PSO took 0.93s.

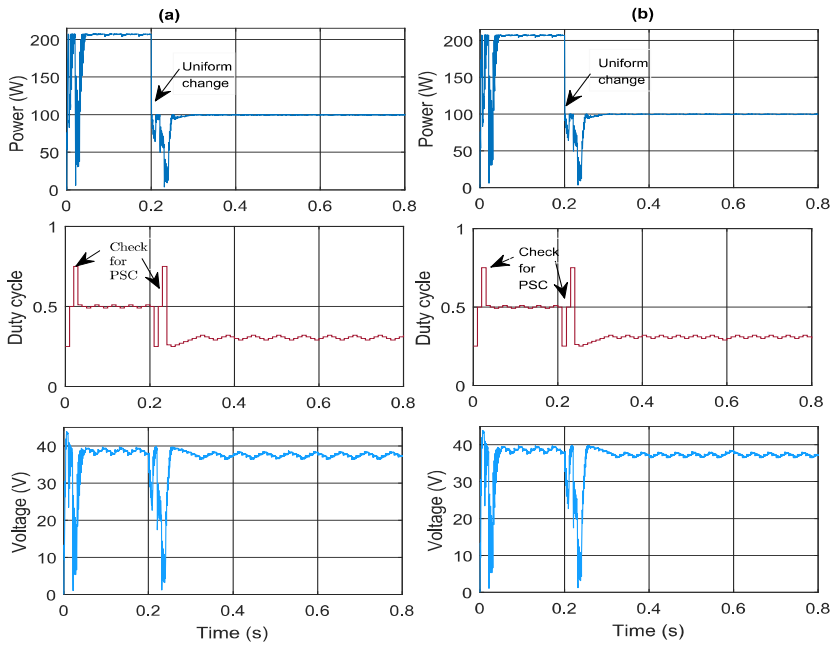

Fig.8. Global maximum power tracking under the first irradiance pattern [(1kW/m^2, 1kW/m^2, 1kW/m^2, 1kW/m^2) (0.5kW/m^2, 0.5kW/m^2, 0.5kW/m^2, 0.5kW/m^2)]; (a) P&O based Genetic (b) P&O based PSO.

Authorized licensed use limited to: Consortium - Algeria (CERIST). Downloaded on December 28,2020 at 07:54:53 UTC from IEEE Xplore. Restrictions apply.

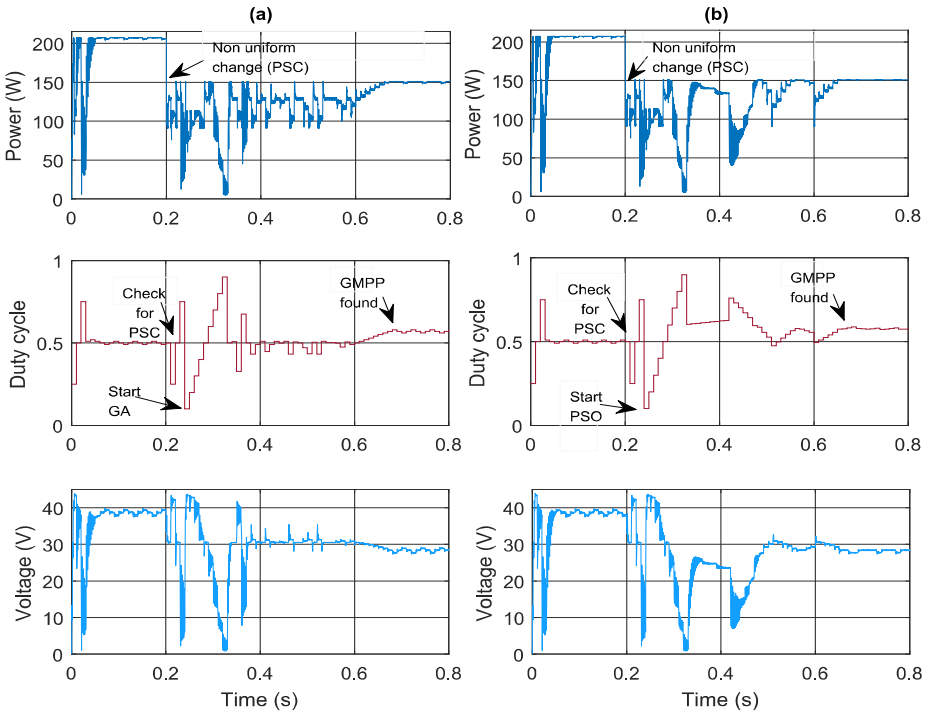

Fig.9. Global maximum power tracking under the second irradiance pattern [(1kW/m^2, 1kW/m^2, 1kW/m^2, 1kW/m^2) (0.5kW/m^2,1kW/m^2, 1kW/m^2, 1kW/m^2)]; (a) P&O based Genetic (b) P&O based PSO.

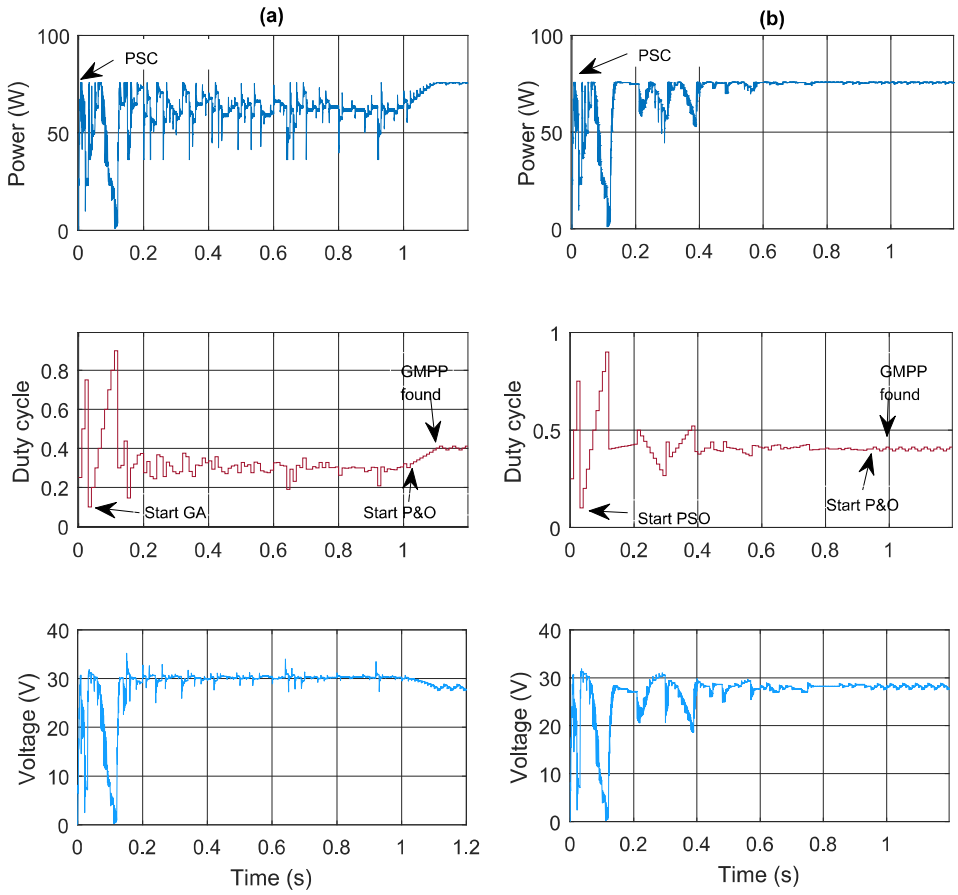

Fig.10. Global maximum power tracking under the third irradiance pattern [0.7kW/m^2, 0.5kW/m^2, 0.5kW/m^2, 0.2kW/m^2]; (a) P&O based Genetic (b) P&O based PSO.

Authorized licensed use limited to: Consortium - Algeria (CERIST). Downloaded on December 28,2020 at 07:54:53 UTC from IEEE Xplore. Restrictions apply.

VI. CONCLUSION

In this paper, two hybrid GMPPT algorithms are proposed for comparison; P&O based Genetic and P&O based PSO. The algorithms are implemented with the PV system model in Matlab/Simulink. Three solar irradiance profiles are used for the simulation. The simulation results show that both algorithms can detect the environmental changes and locate the GMPP when partial shading occurs. Furthermore, both algorithms show identical good performance in terms of speed. In the case of PSCs, the P&O based PSO shows a faster response and reduced transient compared with the P&O based GA; particularly in case the power-voltage curve contains more than two peaks.

REFERENCES

[1] K. Ishaque, Z. Salam, M. Amjad, and S. Mekhilef, "An Improved Particle Swarm Optimization (PSO)-Based MPPT for PV With Reduced Steady-State Oscillation," Ieee Transactions on Power Electronics, vol. 27, pp. 3627-3638, Aug 2012, doi: 10.1109/TPEL.2012.2185713.

[2] N. Karami, N. Moubayed, and R. Outbib, "General review and classification of different MPPT Techniques," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 1–18, Feb. 2017, doi: 10.1016/j.rser.2016.09.132.

[3] G. Dileep and S. N. Singh, "Maximum power point tracking of solar photovoltaic system using modified perturbation and observation method," *Renewable and Sustainable Energy Reviews*, vol. 50, pp. 109–129, Oct. 2015, doi: 10.1016/j.rser.2015.04.072.

[4] A. Bin Jusoh, O. J. E. Ibrahim Mohammed, and T. Sutikno, "Variable Step Size Perturb and Observe MPPT for PV Solar Applications," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 13, no. 1, pp. 1–12, Mar. 2015, doi: 10.12928/telkomnika.v13i1.1180.

[5] K. J. Singh and S. K. Sarkar, "Maximum power point tracking controller using P and O algorithm for solar PV array on FPGA," in *2016 International Conference on Communication and Signal Processing (ICCSP)*, Melmaruvathur, Tamilnadu, India, 2016, pp. 1878–1883, doi: 10.1109/ICCSP.2016.7754496.

[6] Fangrui Liu, Shanxu Duan, Fei Liu, Bangyin Liu, and Yong Kang, "A Variable Step Size INC MPPT Method for PV Systems," *IEEE Transactions on Industrial Electronics*, vol. 55, no. 7, pp. 2622–2628, Jul. 2008, doi: 10.1109/TIE.2008.920550.

[7] A. Safari and S. Mekhilef, "Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter," Ieee Transactions on Industrial Electronics, vol. 58, pp. 1154-1161, Apr 2011, doi:10.1109/ TIE.2010.2048834.

[8] K. S. Tey and S. Mekhilef, "Modified incremental conductance MPPT algorithm to mitigate inaccurate responses under fast-changing solar irradiation level," Solar Energy, vol. 101, pp. 333-342, Mar 2014, doi: 10.1016/j.solener.2014.01.003.

[9] K. S. Tey and S. Mekhilef, "Modified Incremental Conductance Algorithm for Photovoltaic System Under Partial Shading Conditions and Load Variation," Ieee Transactions on Industrial Electronics, vol. 61, pp. 5384-5392, Oct 2014, doi: 10.1109/ TIE.2014.2304921.

[10] Rezk, A. Fathy, and A. Y. Abdelaziz, "A comparison of different global MPPT techniques based on meta-heuristic algorithms for photovoltaic system subjected to partial shading conditions," *Renewable and Sustainable Energy Reviews*, vol. 74, pp. 377–386, Jul. 2017, doi: 10.1016/j.rser.2017.02.051.

[11] H. Chao, L.-Y. Chang, and H.-C. Liu, "Maximum Power Point Tracking Method Based on Modified Particle Swarm Optimization for Photovoltaic Systems," *International Journal of Photoenergy*, vol. 2013, pp. 1–6, 2013, doi: 10.1155/2013/583163.

[12] S. M. Mirhassani, S. Z. M. Golroodbari, S. M. M. Golroodbari, and S. Mekhilef, "An improved particle swarm optimization based maximum power point tracking strategy with variable sampling time," *International Journal of Electrical Power & Energy Systems*, vol. 64, pp. 761–770, Jan. 2015, doi: 10.1016/j.ijepes.2014.07.074.

[13] B. A. Koad, A. F. Zobaa, and A. El-Shahat, "A Novel MPPT Algorithm Based on Particle Swarm Optimization for Photovoltaic Systems," *IEEE Transactions on Sustainable Energy*, vol. 8, no. 2, pp. 468–476, Apr. 2017, doi: 10.1109/TSTE.2016.2606421.

[14] S. Daraban, D. Petreus, and C. Morel, "A novel global MPPT based on genetic algorithms for photovoltaic systems under the influence of partial shading," in *IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society*, Vienna, Austria, Nov. 2013, pp. 1490–1495, doi: 10.1109/IECON.2013.6699353.

[15] M. Ben Smida and A. Sakly, "Genetic based algorithm for maximum power point tracking (MPPT) for grid connected PV systems operating under partial shaded conditions," *2015 7th International Conference on Modelling, Identification and Control (ICMIC)*, Sousse, 2015, pp. 1-6, doi: 10.1109/ICMIC.2015.7409433.

[16] M. A. M. Ramli, S. Twaha, K. Ishaque, and Y. A. Al-Turki, "A review on maximum power point tracking for photovoltaic systems with and without shading conditions," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 144–159, Jan. 2017, doi: 10.1016/j.rser.2016.09.013.

[17] M. Seyedmahmoudian, R. Rahmani, S. Mekhilef, A. M. T. Oo, A. Stojcevski, T. K. Soon, et al., "Simulation and Hardware Implementation of New Maximum Power Point Tracking Technique for Partially Shaded PV System Using Hybrid DEPSO Method," Ieee Transactions on Sustainable Energy, vol. 6, pp. 850-862, Jul 2015, doi: 10.1109/TSTE.2015.2413359.

[18] M. G. Batarseh and M. E. Za'ter, "Hybrid maximum power point tracking techniques: A comparative survey, suggested classification and uninvestigated combinations," *Solar Energy*, vol. 169, pp. 535–555, Jul. 2018, doi: 10.1016/j.solener.2018.04.045.

[19] J. Bai, Y. Cao, Y. Hao, Z. Zhang, S. Liu, and F. Cao, "Characteristic output of PV systems under partial shading or mismatch conditions," *Solar Energy*, vol. 112, pp. 41–54, Feb. 2015, doi: 10.1016/j.solener.2014.09.048.

[20] R. L. Haupt and S. E. Haupt, Practical Genetic Algorithms. John Wiley & Sons, 2004.

[21] R. Malhotra, N. Singh, and Y. Singh, "Genetic algorithms: Concepts, design for optimization of process controllers," Computer and Information Science, vol. 4, no. 2, p. 39, 2011.

[22] C.Guo and X. Yang, "A programming of genetic algorithm in matlab7.0," Modern applied science, vol. 5, no. 1, p. 230, 2011.

[23] Y.-H. Liu, S.-C. Huang, J.-W. Huang, and W.-C. Liang, "A Particle Swarm Optimization-Based Maximum Power Point Tracking Algorithm for PV Systems Operating Under Partially Shaded Conditions," *IEEE Transactions on Energy Conversion*, vol. 27, no. 4, pp. 1027–1035, Dec. 2012, doi: 10.1109/TEC.2012.2219533.

[24] T. L. Nguyen and K.-S. Low, "A Global Maximum Power Point Tracking Scheme Employing DIRECT Search Algorithm for Photovoltaic Systems," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 10, pp. 3456–3467, Oct. 2010, doi: 10.1109/TIE.2009.2039450.

Authorized licensed use limited to: Consortium - Algeria (CERIST). Downloaded on December 28,2020 at 07:54:53 UTC from IEEE Xplore. Restrictions apply.