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An efficient scanning algorithm for photovoltaic systems under partial shading

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ABSTRACT

This paper proposes a new technique of maximum power point tracking (MPPT) for a photovoltaic (PV) system connected to three phase grids under partial shading condition (PSC), based on a new combined perturb and observe (P&O) with scanning algorithm. This new algorithm main advantages are the high-speed tracking compared to existing algorithms, high accuracy and simplicity which makes it ideal for hardware implementation. Simulation was carried on MATLAB/Simulink. Results showed the effectiveness in speed and accuracy of our algorithm over the existing ones either during standard condition (STC) or PSC. Furthermore, conventional direct power control (DPC) was applied to synchronize successfully the injected power with the grid, which makes our algorithm global and works efficiently under severe conditions.

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1. INTRODUCTION

Solar energy is nowadays the first choice for a clean prominent energy, it replaces the fossil and polluted energy sources, and gives solution to energy deficiency due to the demographic increase in population. In that fact, photovoltaic (PV) systems constitute the best choice due to their availability, facility in implementation and maintenance and safe power distribution [1], [2]. From another perspective, their problem relies in their low conversion ratio not exceeding 20% with monocrystalline as the highest commercial cells with a ratio between 14% and 20% [3], [4]. To this matter, extracting maximum power point (MPP) is of the utmost importance to benefit from the maximum power generated at various weather conditions [5]–[7]. However other varying parameters influences the obtained PV power, especially partial shading condition (PSC) caused by the blocked irradiance by clouds, dust or buildings [8]. Partial shading condition (PSC) provokes multiple peaks with one global maximum power point (GMPP) as the highest peak and other local maximum power point (LMPP) as lowest peaks causing a decrease in PV power [4], [9], [10]. Various types of PV systems with maximum power point tracking (MPPT) algorithms could be implemented. Grid connected type with DC-DC converter is chosen due to its advantage compared to autonomous systems which are power limited because of the batteries that also increases the costs of the system and need supervising. Furthermore, grid connected type of the PV systems decreases the cost of PV systems, optimizes the energy which improves life quality [11], [12].

There are several studies in literature that intend to select the best MPPT algorithm in terms of stability, tracking speed and accuracy, that works best in both standard condition (STC) and PSC. An Improved team game optimization (ITGO) for PV system with PSC has been introduced by [1] to solve the iterative problem of metaheuristic algorithms. Results were satisfying with a 99.6% efficiency and 0.8 s in tracking speed. Mohammadinodoushan *et al.* [13] used an on grid variable step size perturb and observe (P&O) by modified shuffled frog leaping algorithm based sliding mode (SM), which performs very well under PSC with an efficiency of 99.3% and a track time of 0.15 s which is slower than the others. Alturki [14] performed an off grid comparison between P&O algorithm and meta-heuristic based MPPT like particle swarms optimization (PSO) and cuckoo search optimization (CSO) under PSC, results showed that these later outperforms the classic P&O in terms of PSC detection, but showed degrading waveform with high oscillations around the MPP and a slow tracking time with respectively 5.5 s and 3.2 s. Comparison under PSC between P&O, PSO and flower pollination (FP) algorithm was made in [15], the FP performed faster than both algorithms with a track time of 0.24 s. A single phase type of the grid tied PV system with artificial bee colony (ABC) and P&O algorithm under PSC was introduced by [16], comparison between ABC and hybrid ABC-P&O was performed, results showed that the hybrid ABC-P&O outperforms the ABC, but showed clear oscillation around MPP and a track time of 1 s to reach the MPP, the synchronization between inverter current and the grid seems to be a little off, which affect negatively the grid injection. Another technique introducing grey wolf optimization (GWO) was applied in [17]. It surpasses the P&O and PSO. An off grid enhanced P&O algorithm was introduce in [18] compared with traditional P&O and incremental conductance (IC) under PSC, results showed a significant improvement in the improved P&O with a track time of 0.13s and an efficiency of 99%. Simulated artificial intelligence (AI) based techniques like fuzzy logic (FL), PSO and moth flame optimization (MFO) with comparison to IC was performed in [19] under PSC, results showed that AI algorithm outperforms the IC algorithm which present significant ripples and is unable to track the MPP, the FL presents the fastest tracking time, the PSO successes to track the MPP however is slightly less than the MFO which is quiet fast with a settling time of 0.05s and over 99% from the PV power. A fuzzy grey wolf MPPT under PSC was introduced in [20], the new optimized FL showed higher results than both the P&O and FL with 99.97% efficiency and a good track speed of 0.038 s.

In this paper a new Scanning P&O GMPPT algorithm applied to a PV system connected with three phase grid under PSC is proposed. Classical P&O fails in tracking the GMPP, and is stuck in LMPP. The proposed combined scanning P&O algorithm overcomes the LMPP problem and improves the search of the GMPP. In other hand, a classical direct power control (DPC) as in [21], [22] was applied to the inverter to regulate the boost converter voltage and synchronize the grid injected current with a high quality. This paper is arranged: In the first section we have an introduction, the second one present the model of the chosen system. Section 3 present the proposed method, section 4 shows results and discussion of the simulation and finally came the conclusion.

2. METHOD

The problem in PSC is that LMPP are generated which affect the parameters of the PV system [23]. The classical P&O algorithm fails in tracking the GMPP with PSC and is forced to stay in LMPP [24], [25]. Other algorithms perform poorly or still need improvement. In that regard, we managed to develop a new combined scanning P&O algorithm that surpasses these existing algorithms in terms of both efficiency and rapidity. Secondly, in order to regulate the boost converter output voltage, control the inverter, a DPC is applied to perfectly synchronize the grid three phase voltage and the PV system inverter current.

2.1. System description and modeling

The proposed system as in Figure 1, consists of a PV generator with 91 kW as maximum power at standard conditions. A boost converter is utilized to obtain maximum available power. I_{pv} and V_{pv} are respectively the PV system current and voltage, C_{in}=0.0077 F and C_{dc}=3227 µF are the input and output capacitors for the converter with R=5x10 mΩ, L=1.2x10-5 H is the inductor value of the converter. The last part consists of an inverter controlled with pulse width modulation (PWM) to deliver a synchronous power in the grid. The inductor filter is used as a harmonic distortions filter and also to respect the rules of sources interconnection, where Lf=1.1 mH and r=0.06 Ω.

The three-phase balanced grid can be modeled by (1), (2) and (3).

$$V_a = \mathrm{V}.\cos(\omega \mathrm{t}) \quad (1)$$

$$V_b = \mathrm{V}.\cos\left(\omega \mathrm{t} - \frac{2.\pi}{3}\right) \quad (2)$$

$$V_c = V.\cos\left(\omega t + \frac{2.\pi}{3}\right) \quad (3)$$

V being the maximum voltage of grid, and ω its pulsation. The inverter current and the grid are connected as shown in (4):

$$\begin{pmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \\ \frac{di_c}{dt} \end{pmatrix} = \begin{pmatrix} -\frac{R}{L} & 0 & 0 \\ 0 & -\frac{R}{L} & 0 \\ 0 & 0 & -\frac{R}{L} \end{pmatrix} \begin{pmatrix} U_a - V_a \\ U_b - V_b \\ U_c - V_c \end{pmatrix} \quad (4)$$

where (i_a, i_b, i_c) and (U_a, U_b, U_c) are respectively the inverter output currents and voltages. The equation (4) is represented in three phase *abc* frame. The transformation of these equations into a rotational *dq* frame is shown in (5):

$$\begin{pmatrix} \frac{di_d}{dt} \\ \frac{di_q}{dt} \end{pmatrix} = \frac{1}{L}\begin{pmatrix} -R & \omega \\ -\omega & -R \end{pmatrix}\begin{pmatrix} i_d \\ i_q \end{pmatrix} - \frac{1}{L}\begin{pmatrix} V_d \\ V_q \end{pmatrix} + \frac{1}{L}\begin{pmatrix} U_d \\ U_q \end{pmatrix} \quad (5)$$

where (i_d, i_q), (U_d, U_q) are *dq* components of the inverter current and voltage respectively. And for V_d and V_q, they represent the *dq* grid voltage component. For simplification reasons, (5) became:

$$U_d = \left(L\frac{di_d}{dt} + Ri_d - \omega L i_q + V_d\right) \quad (6)$$

$$U_q = \left(L\frac{di_q}{dt} + Ri_q + \omega L i_d + V_q\right) \quad (7)$$

The next step presents the proposed method to implement the strategy adopted for the system.

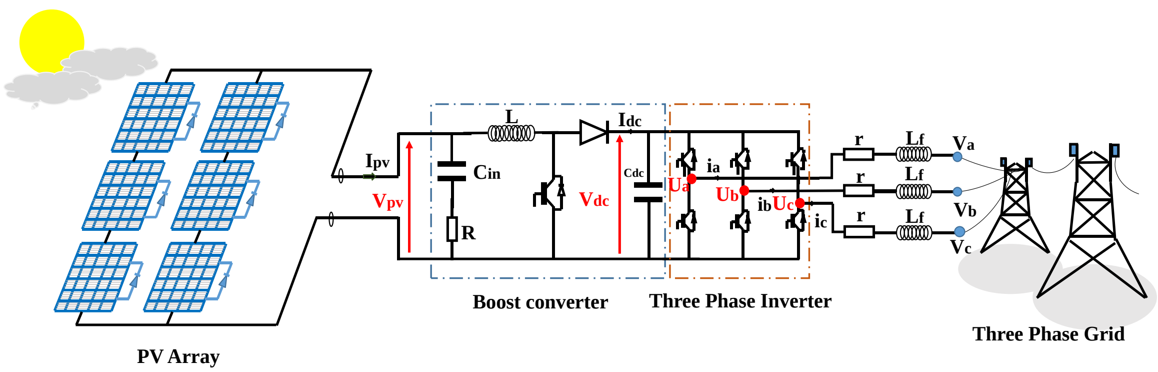

Figure 1. The grid tied PV system

2.2. MPPT controller

In this paper, a new GMPPT algorithm is proposed which is based on a combined scanning P&O algorithm that escapes LMPPs and reaches GMPP efficiently with fast tracking time. The controller working is: The scanning algorithm searches for the couple (Vmax, Pmax) which is near the GMPP by comparing the actual power value P(k) of the PV system with the previous one P(k-1), the result of this comparison is affected to a variable named Pmax, which after that is periodically compared with to finally have the maximum value of the couple (Vmax, Pmax) that is then transferred to the P&O to track the GMPP. A condition of irradiation change is then set to reinitialize the algorithm to search for new GMPPT. Larger step size ΔS was chosen for the searching algorithm to speed up the scanning, and reduce global time of the operation, and a smaller step size ΔV was chosen for the P&O in order to reduce ripples at the GMPP. Figure 2 shows the flowchart of the proposed algorithm. Where scan is a parameter set to reinitialize the search for the couple (Vmax, Pmax) when the irradiance changes. As to threshold, it is a limiting value for not exceeding the maximum voltage interval of the PV system and to know when the scan has finished when combined to the second condition of the actual power value being smaller than the previous value. When the scan is finished the couple values (Vmax, Pmax) is directly transferred to the P&O in order to start tracking the GMPP from these given values.

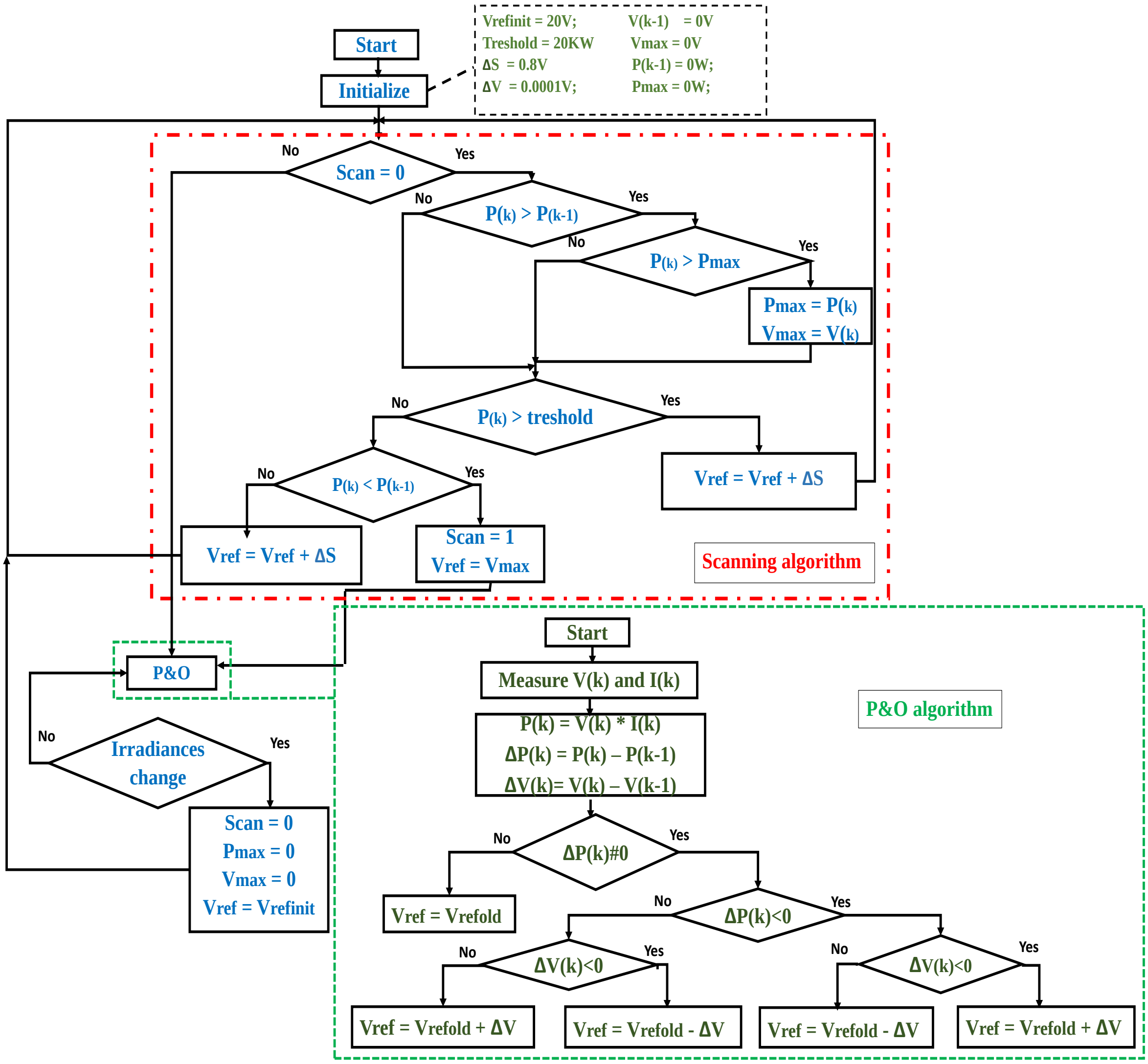

Figure 2. Flowchart of the proposed scanning P&O algorithm

2.3. Inverter controller

The equations (6) and (7) indicates the coupling equation in *dq* axis of the inverter command signal. A PI regulator is then used as in (8) and (9), equations that represent the inverter control law in *dq* axis to stabilize the system in close loop. Then, to ensure a perfect synchronization between the inverter current of the PV system and the grid three phase voltage, a PLL is applied to get the angular frequency as in [26].

The inductor filter removes the harmonic distortions of the current inverter, its frequency must respect the condition: 50 Hz $<F_c<F_{pwm}$. Figure 3 shows the flowchart of the DPC of the inverter. As for the complete control system it is shown in Figure 4. To verify the proposed method effectiveness, results of the simulation in MATLAB/Simulink will be presented in the next section.

$$C_d = \frac{1}{V_{dc}}\left[\left(K_p + \frac{K_i}{s}\right)\left(i_{dref} - i_d\right) - \omega L i_q + V_d\right] \quad (8)$$

$$C_q = \frac{1}{V_{dc}}\left[\left(K_p + \frac{K_i}{s}\right)\left(i_{qref} - i_q\right) + \omega L i_d + V_q\right] \quad (9)$$

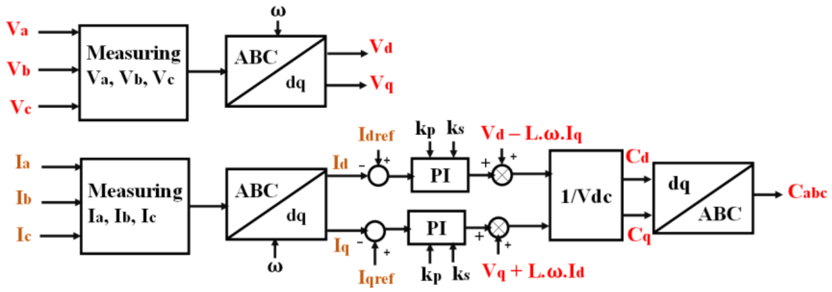

Figure 3. Flowchart of the DPC of the inverter

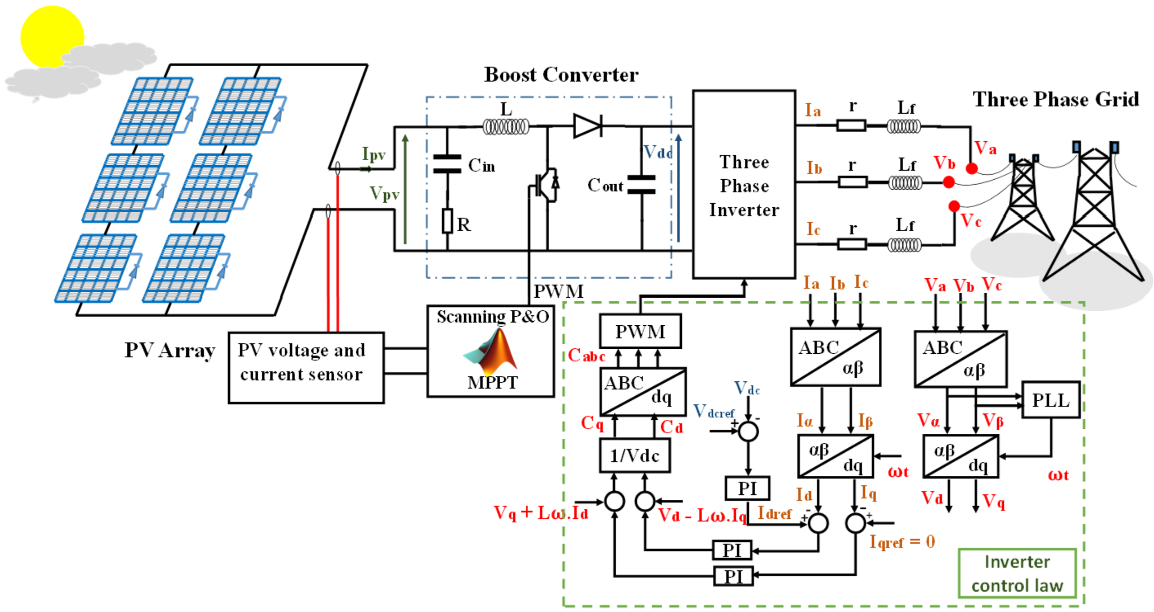

Figure 4. Control structure of the PV system tied to a grid

3. RESULTS AND DISCUSSION

This study introduces a new scanning P&O algorithm that successfully tracks the GMPP under STC and PSC. Simulation was carried in MATLAB/Simulink. The PV panels used was dimensioned to produce a maximum of 91 kW, to do so, 2 parallel sets of three series PV panels are used. Each panel consist of 19 parallel strings with 4 series modules per string. The cell module used for this work is Kyocera 200 W which model specifications is given in Table 1. The controller parameters are shown in Table 2.

Table 1. Specifications of solar cell module

Description	Specifications
MPP	200.143 W
Open circuit voltage (VOC)	32.9 V
Short circuit current (ISC)	8.21 A
Voltage of maximum power point (VMPP)	26.3 V
Current of maximum power point (IMPP)	7.61 A

Table 2. Controller parameters

Controllers parameters
ΔS=0.8 V
ΔV=0.0001 V
Threshold=20 kW
Switching frequency=20 KHz
PI proportional coefficient=10
PI integral coefficient=20

All simulated scenario of PSC is presented in Figure 5 which considers all possible pattern variations in PSC. The LMPP presents difficulties for the conventional P&O that is trapped in local peaks, and thus fails to track the GMPP. These difficulties are easily surpassed with the proposed scanning P&O algorithm. Results presented in Figure 6 shows the successful track of the proposed method of GMPP in all cases while the classical P&O fails to track the GMPP in two scenarios of PSC1 and PSC2 while it manages to track for the STC which is normal and PSC3 case. Figure 7, zoomed on the results, Figure 7(a) shows the first and difficult scenario of PSC when the GMPP is on the first peak, the P&O is stuck in LMPP while the proposed method succefully tracks the GMPP with a fast track time of 0.017 s better than recent literature, and an efficiency of 99.7% making it good enough compared to complexed algorithm [16]. Figure 7(b) presents the second scenario when the GMPP is in the middle peak which also a difficult one, the Conventional P&O fails again and the proposed algorithm correctly tracks the GMPP. Figure 7(c) present a STC with no partial shading, both the conventional and the proposed method tracks the MPP. The last scenario PSC3 is presented in Figure 7(d), the P&O luckily tracks the GMPP because the negative slope in each peak is reduced, which enables the P&O to go further to the last peak which is the GMPP. The overall conclusion is that the P&O fails to track the GMPP with different PSC. While for the proposed algorithm it is clear that it can track the GMPP for any given scenario of PSC with better performances. There are some fluctuations in dynamic regime which are due to the scanning behavior of the algorithm that scans the whole PV curve before tracking the GMPPT, also it is worth mentioning that these fluctuations exist for a very short time and does not impact the global system. Figure 8 demonstrates the good regulation of the V_{dc} Voltage around 600 V which is the reference value given. The second part concerns the injection of the inverter current in the grid. Results presented in Figure 9, shows that this injection is successfully done and is synchronized to the grid three phase voltage. Therefore, the proposed GMPPT based on scanning P&O algorithm and the DPC method are efficient, rapid and perform very well under any conditions.

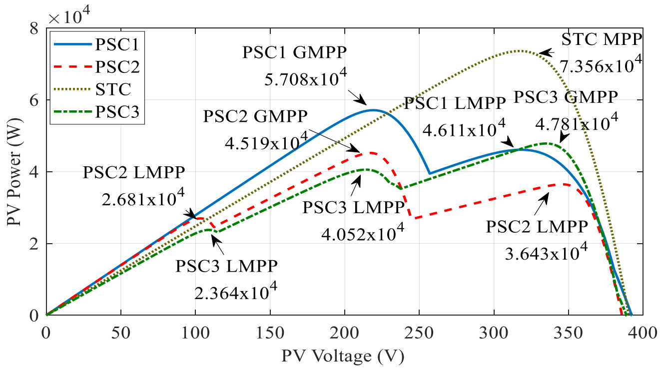

Figure 5. Partial shading scenarios selected for the study

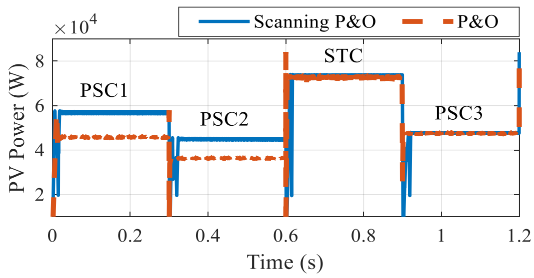

Figure 6. PV Power tracked under different PSC scenarios

Summarized comparison in Table 3, showed better results of the new proposed scanning P&O compared to existing algorithms described in literature with a track time of 0.017s which is 50% better than the fastest response time recorded in literature as far as we know, and an average efficiency of 99.4% making it the best and simple GMPPT algorithm capable of extracting the maximum available power under any weather especially under PSC.

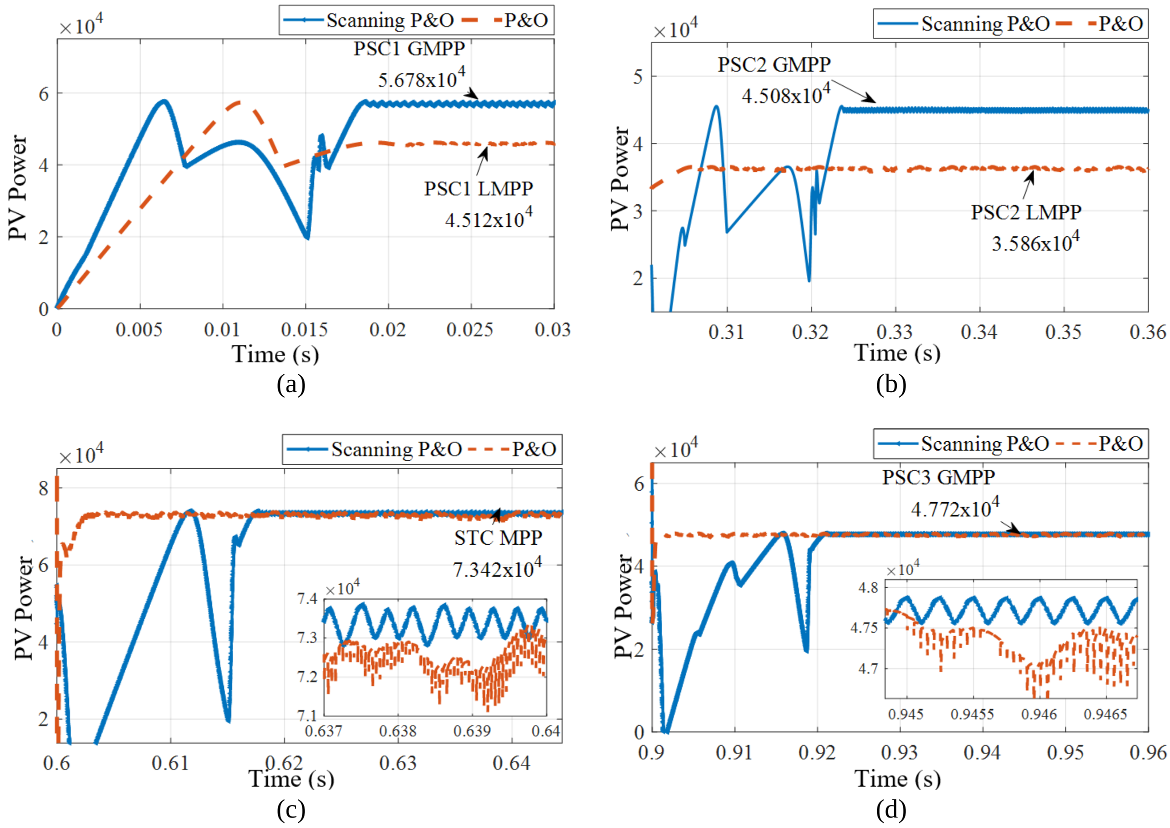

Figure 7. Zoomed view on PV power (a) PSC1, (b) PSC2, (c) STC, and (d) PSC3

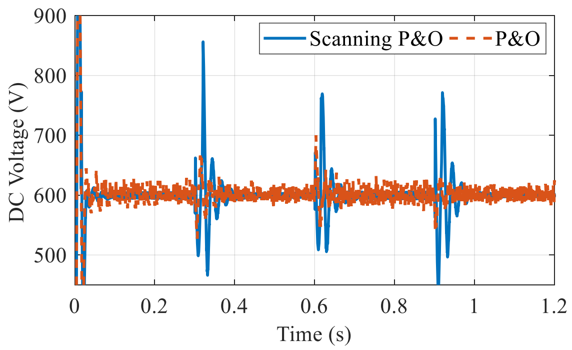

Figure 8. Regulated DC Voltage

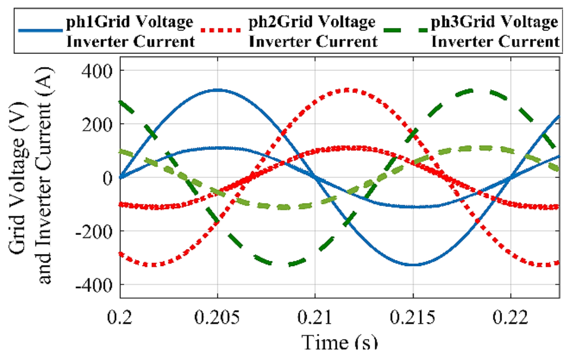

Figure 9. Grid voltage and inverter current of the proposed method

Table 3. Performances of the proposed scanning P&O against other techniques presented in literature

MPPT algorithms	Types of PV system	PSC	Efficiency (%)	Tracking speed (s)
Proposed Scanning	Three phase grids connected	Yes	99.4%	0.017
P&O	Three phase grids connected	Yes	79.04%	0.02
ITGO [1]	Off grid	Yes	99.6%	0.8
SMC-Frog [13]	grid connected	Yes	99.3%	0.15
CSO [14]	Off grid	Yes	----	3.2
PSO [14]	Off grid	Yes	----	5.5
FP [15]	Off grid	Yes	----	0.24
ABC-PO [16]	Single phase Grid connected	Yes	99.5%	1
Enhanced PO [18]	Off grid	Yes	99%	0.13
MFO [19]	grid connected	Yes	99.9%	0.05
FL-Grey wolf optimization [20]	Micro-grid	Yes	99.97%	0.038

4. CONCLUSION

This paper proposes a new Scanning P&O algorithm for GMPPT that overcomes the problem of classical P&O of not correctly tracking the GMPP under PSC. The proposed algorithm search for all available maximums, compare them and then tracks the maximum value in a very short time of 0.017s, with good efficiency of 99.4%. These simulated results proves that our scanning algorithm was better than recent algorithms in literature with a good efficiency and fast-tracking time. Furthermore, a classical decoupled controller was applied for synchronization between the inverter current and the grid. The goal of the complete strategy which was successfully done is to achieve GMPPT under normal and PSC and injecting this power into the grid with good synchronization and efficiency. Furthermore, the simplicity of the proposed algorithm makes it ideal for hardware implementation which will be the subject of future works.

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