Comparative Study Of P&O and PSO Particle Swarm Optimization MPPT Controllers Under Partial Shading

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Abstract: Maximum power point tracking (MPPT) is a vital and essential requirement for photovoltaic (PV) systems under normal irradiance and partial shading conditions (PSCs). Although, perturb and observe (P&O) algorithm does not map the global maximum power point (GMPP), whereas the algorithm for particle swarm optimization (PSO) tracks it efficiently. This paper explores the rapid determination of GMPP under PSCs using a proposed particle swarm optimization MPPT technique which operates in conjunction with a boost converter. To achieve this analysis, MATLAB/SIMIULINK is used. The results of the simulation illustrate the high tracking performance of the proposed technique under various irradiance patterns.

Keywords: PV, MPPT, DC/DC, P&O, PSO,PARTIAL SHADING.

Received: September 12, 2021. Revised: August 12, 2022. Accepted: September 14, 2022. Published: October 2, 2022.

1. Introduction

It is well known that the electrical power generated by a photovoltaic module can be significantly reduced compared to the optimal production conditions (maximum power point), but also compared to the metrological conditions. Indeed, many factors, such as partial shading can have a considerable impact on the electrical production of a photovoltaic panel.

The first step to study about an appropriate control method in photovoltaic systems is to know how to model and simulate a PV system attached to the converter and power grid. In general, PV systems present nonlinear Power-Voltage (P-V) and Current-Voltage (I-V) characteristics which tightly depend on the receiving irradiance levels and ambient conditions. The mathematical model of the photovoltaic device is significantly valuable for studying the maximum power point tracking algorithms, doing research about the dynamic performance of converters, and also for simulating photovoltaic components by using circuit simulators.

This paper is organized as follows: we pursue the mathematical analysis of the responses of a single module under uniform irradiance levels. Afterwards, in a more practical scheme, by analyzing the effects of the partial shading phenomenon on the output of PV systems, the study is followed up by the modeling of the module and array under partial shading conditions. Finally, the simulation of the outputs for the proposed algorithms under different degrees of partial shading is presented.

2. Modeling of Photovoltaic System Parameters

A photovoltaic cell is described by the single diode model, this model is generalized to a photovoltaic (PV) module by considering it as a set of identical cells connected in series and/or in parallel.

2.1 Equivalent Electrical Circuit

The modeling of the elementary cell is based on an equivalent electrical circuit [2]. In our study we use a model with a single diode as shown in figure 1.

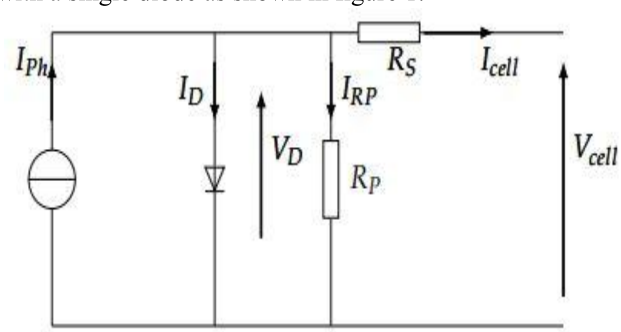


Fig. 1 PV equivalent circuit model.

An ideal photovoltaic cell under illumination can be defined in a simple way as an ideal current source that produces a current I_{Ph} in parallel with a diode.

the general equation of this model:

$$I = Iph - I0 \times [\exp\left(\frac{qV}{nKT}\right) - 1]$$

I_0*:* saturation current in Ampere(A);
n : quality factor of the dimensionless diode;
K : Boltzmann constant (1.38066×10-23 J/K= 8.61400×10-5eV/K);
T: absolute temperature in Kelvin (K);
q : absolute charge of an electron in coulomb (1.60281×10-19 C)

In the case of an ideal cell in the dark, the solar cell solar cell follows the behavior of a conventional diode.

$$ID = I0 \times [\exp\left(\frac{qV}{nKT}\right) - 1] \quad (4)$$

Thus:

$$Icell = ID = I0 \times [\exp\left(\frac{qV}{nKT}\right) - 1] \quad (5)$$

In the case of a real photovoltaic cell, we observe a voltage loss at the output resistor (RS) as well as leakage currents at the resistor (RP).

The characteristic equation is deduced from the equivalent circuit and from Kirchhoff's laws [3]:

$$Icell = Iph - ID - IRP \quad (6)$$

The parallel resistor current is given by the relation:

$$IRP = \frac{(V + Icell \times Rs)}{Rp} \quad (7)$$

The diode current is given by the following relation:

$$ID = I0 \times [\exp\left(\frac{qV}{nKT}\right) - 1] \quad (8)$$

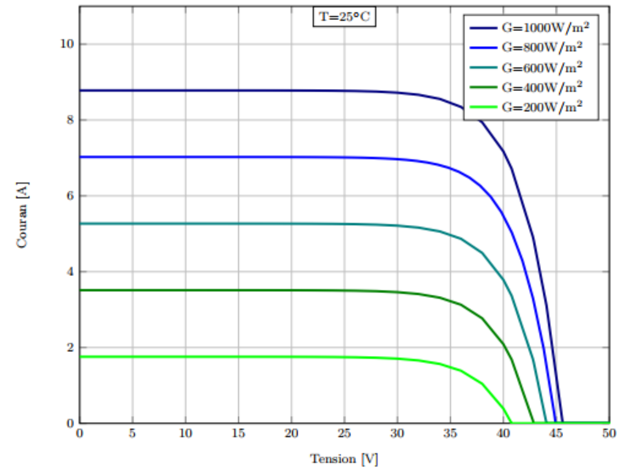
The photon current is given by the following relation:

$$Iph = Icc + K \times (T - Trf)) \times \frac{E}{Erf} \quad (9)$$

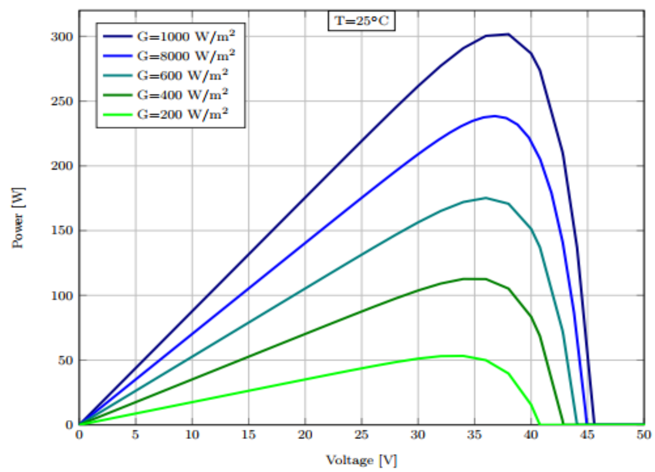
the output characteristic of the PV cell can be deduced by solving the following implicit form:

$$Icell = Icc + K \times (T - Trf)) \times \frac{E}{Erf} - I0 \times [\exp\left(\frac{qV}{nKT}\right) - 1] - \frac{(V + Icell \times Rs)}{Rp} \quad (10)$$

Figure 2 shows the output of the PV module, which employs 72 cells connected to provide a power (P) of 290 W at a terminal voltage (Vpvm) of 35.37 V.



(a)



(b)

Fig. 2 Output characteristics of PV module at normal condition (a) I-V characteristic; (b) P-V characteristic.

2.2 Characteristics of the PV System Under Partial Shading

In any outdoor environment, the whole or some parts of the PV system might be shaded by trees, passing clouds, high building, etc., which result in non-uniform insolation conditions. During partial shading, a fraction of the PV cells which receive uniform irradiance still operate at the optimum efficiency. Since current flow through every cell in a series configuration is naturally constant, the shaded cells need to operate with a reverse bias voltage to provide the same current as the illumined cells. However; the resulting reverse power polarity leads to power consumption and a reduction in the maximum output power of the partially-shaded PV module. Exposing the shaded cells to an excessive reverse bias voltage could also cause “hotspots” to appear in them, and creating an open circuit in the entire PV module. This is often resolved with the inclusion of a bypass diode to a specific number of cells in the series circuit.

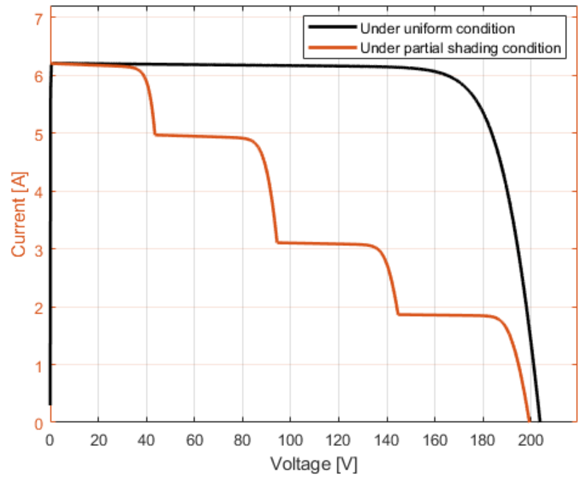


Fig. 3 Current-voltage curve of a PV array under partial shading condition.

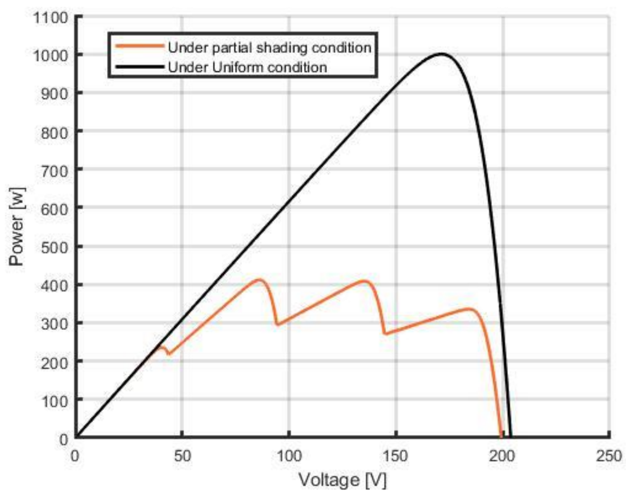


Fig. 4 Power-voltage curve of a PV array under partial shading condition.

Concerning the review mentioned in the introduction, conventional MPPT algorithms cannot distinguish the local and global maximum point existing on the P-V characteristic curve; this is contributed to the complexity of tracking the correct maximum point. In addition, a variation in PV current and voltage occurs in the system when there is partial shading, so the conventional MPPT is not able to detect the changes. The most interesting information obtained from the samples is that, although the P-V curve has more than one maximum power point, each power peak, including the local and global maximum points, exists at multiples of 70% to 85% of the PV module's open circuit voltage, except for the two rightmost sections of the curve, where the peak exists between 75% and 95%. We varied the manufacturer's PV module specifications (SunPower SPR-X20-250-BLK; Trina Solar TSM-170D, and Jinko Solar JKM310M-72) using Models A and B in Figures 5 and 6, as the studies can distinguish six cases. The P-V characteristic curves of all cases, including the power peaks, are shown in Figure 7, and the summarized information is presented in Table 1.

Figure 7 shows tests with three different PV modules, varying irradiation and temperature; the power peak, including local and global, exists in the highlighted researched regions. We can also observe in Table 1. that the increase of the temperature brings less measured VOC, which verifies the P-V characteristics. We can observe that although the location of the overall power peak varies in each model, the peaks always exist in the searched region. Thus, it is not necessary to search the entire regions of the P-V characteristic curves.

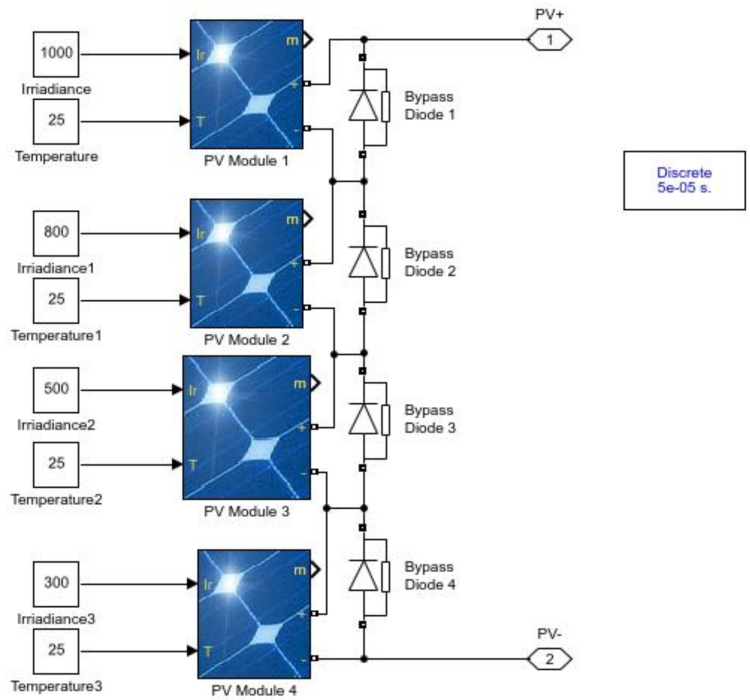


Fig. 5 Pattern A at 25 ◦C.

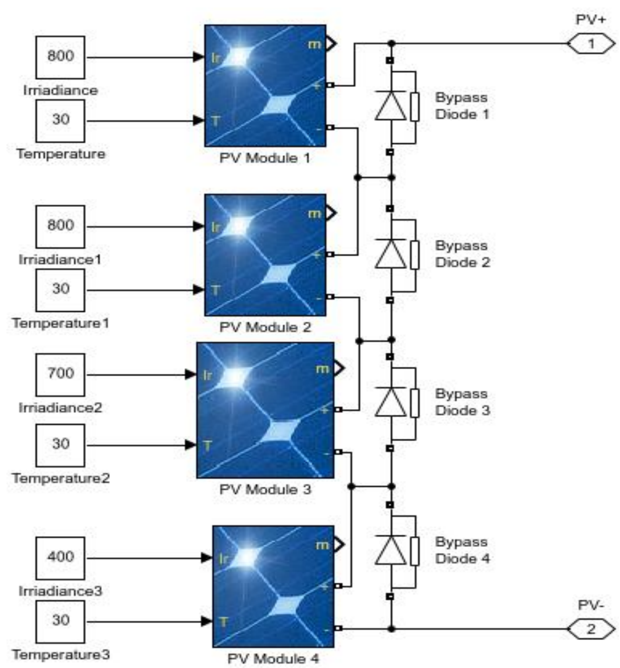
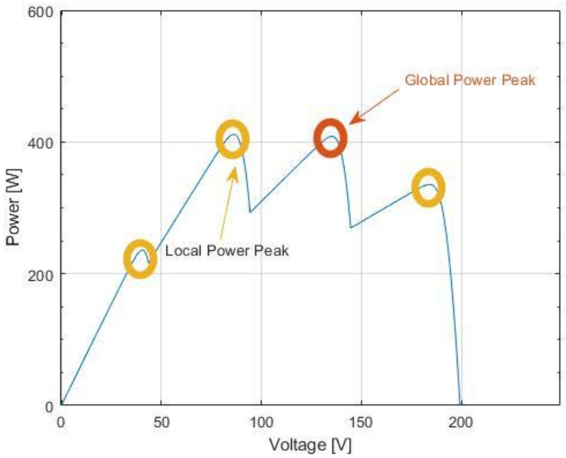


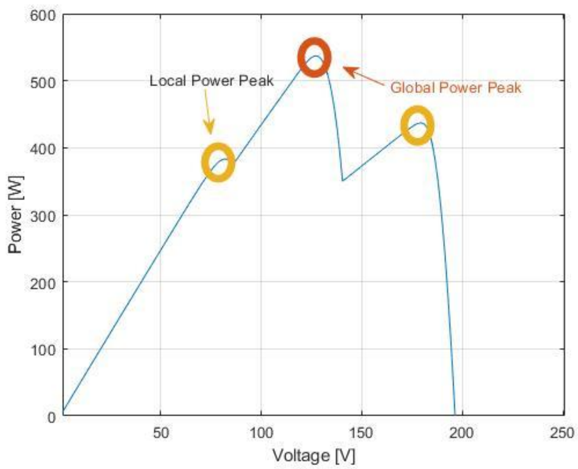
Fig. 6 Pattern B at 30 ◦C.

Case	PV Module's specification	Irradiation Pattern	V_{OC} per Module (V)
Case 1	SunPower SPR-	A	50.93
Case 2	X20-250-BLK	B	
Case 3	Trina Solar	A	43.6
Case 4	TSM-170D	B	
Case 5	Jinko Solar	A	47.1
Case 6	JKM310M-72	B	

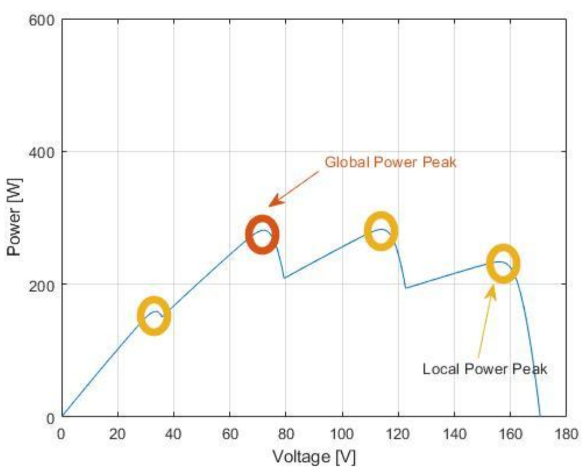
Table 1. Summarized information of example cases.



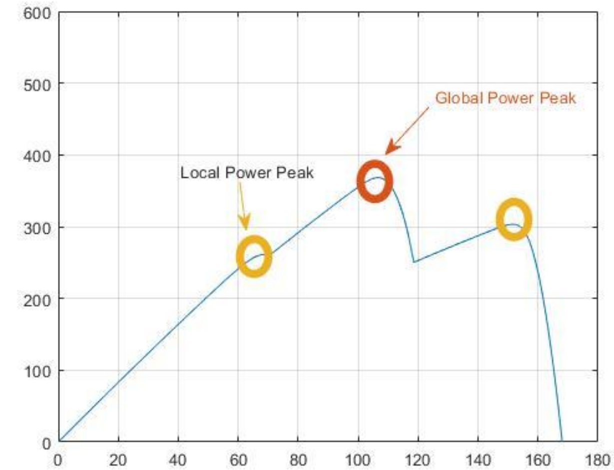
a. Case 1



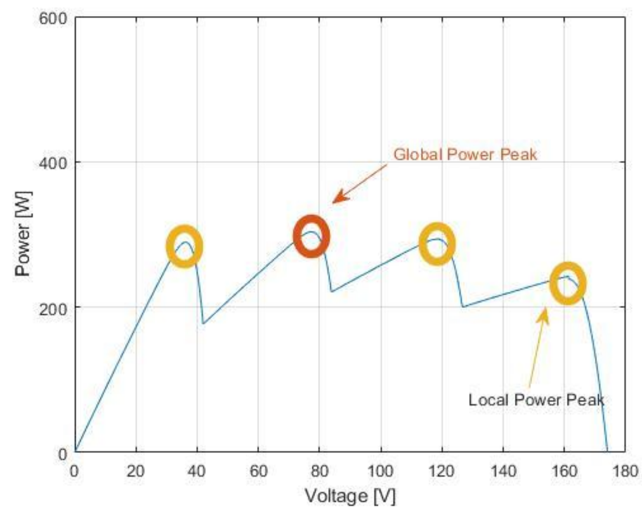
b. Case 2



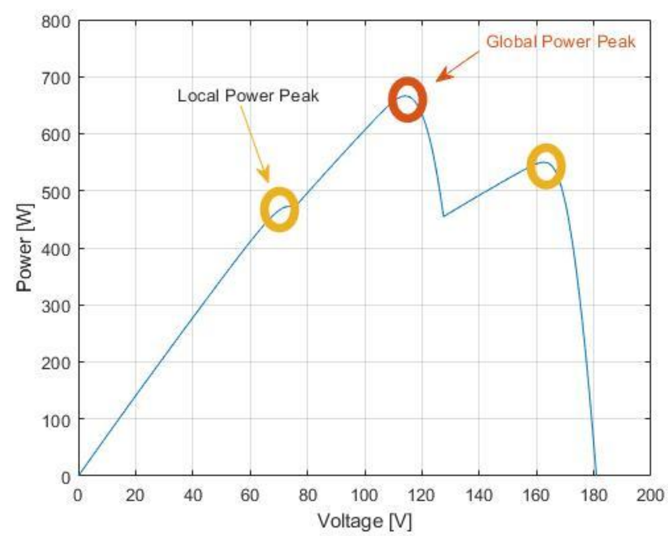
c. Case 3



d. Case 4



e. Case 5



f. Case 6

Fig. 7. P-V characteristic curves for Cases 1–6.

3. Siiimulation Result

In order to have the best power transfer between the photovoltaic generator and the load, we have modeled the whole conversion chain with MatlabSimulink. The following figure represents the block diagram of our photovoltaic system.

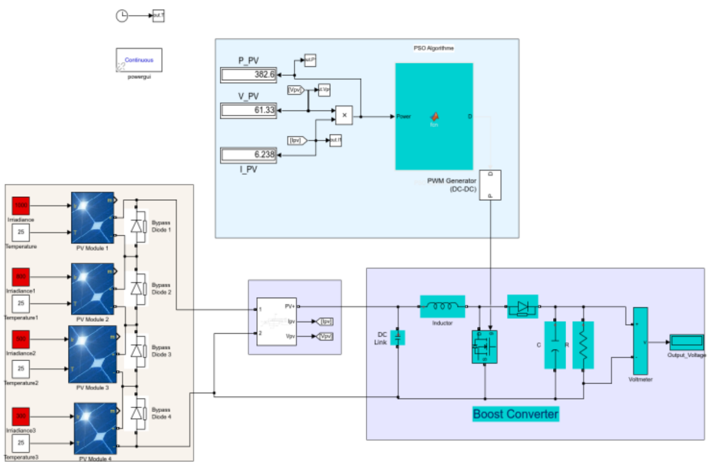


Fig. 8 block diagram of the photovoltaic system

To evaluate the robustness of the PSO algorithm in finding the GMPP under partial shading, the PV field was exposed to a non-uniform irradiance at start. The PV string 1 receives an irradiance of 800W / m² and the others receive 1000W / m², the temperature is maintained constant at 25°C. The results obtained are presented in Figure 9.

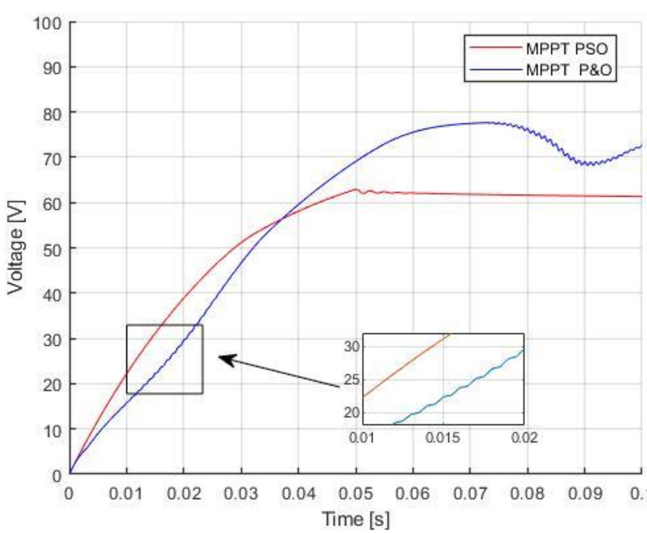


Fig. 9 simulation results of the PSO-MPPT and P&O-MPPT under Partial Shading.

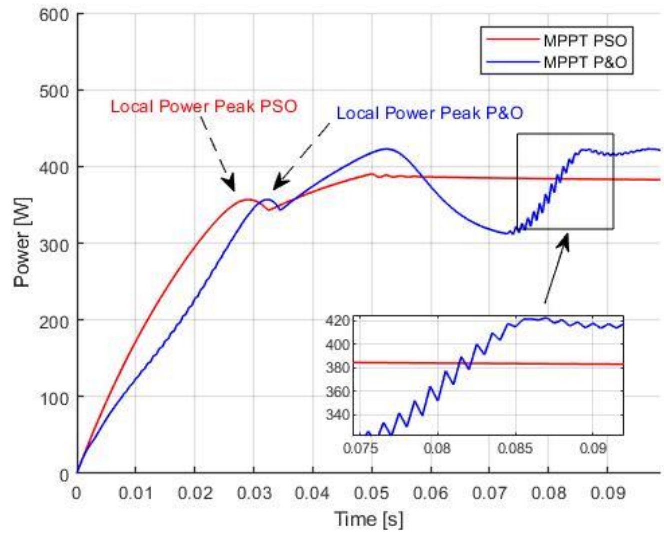


Fig. 10 output voltage of the PSO-MPPT and P&O-MPPT under Partial Shading

It is clearly observed that the PSO-MPPT is not trapped by the LMPP of the characteristic P-V and converged precisely to the GMPP.

We can also note that power oscillations do not exist at all, resulting in a constant output power of the PV field and avoiding energy waste due to oscillations, while the MPPT perturbation and observation controller presents very important undulations.

We have also tested PSO-MPPT and P&O with many
many other shading models. The results indicate that PSO-MPPT cannot accurately track the GMPP accurately when the shading pattern applied to the PVG is complicated.

In other words, when the P-V characteristic curve has power peaks greater than two, PSO-MPPT will not be able to accurately track the GMPP.

4. Conclusion

In this work, a model of PV system composed of 4 PV panels connected in series and a DC-DC converter are developed. Around the DC-DC converter, two MPPT controls: P&O and PSO are presented.

The PV system simulation was made for a non-uniform irradiance in order to make a comparison between the MPPT control based on the P&O algorithm and the PSO MPPT control and to determine the best control in terms of performance and robustness.

The simulation results showed that the PSO algorithm can guarantee a good performance compared to the classical P&O control when the shading pattern applied to the PVG is not complicated.

References

[1] M. Brahmi, B. R. Chiheb, H. Hamdi and Z. Abderrahmen (2022), "Comparative Study of P&O and PSO Particle Swarm Optimization MPPT Controllers for Photovoltaic Systems", 2022 8th International Conference on Control, Decision and Information Technologies (CoDIT).

[2] H. Hamdi, B. R. Chiheb and Z. Abderrahmen (2019), "Performance improvement of a photovoltaic system with a radial basis function network based on particle swarms optimization", 2019 International Conference on Signal, Control and Communication (SCC).

[3] Hamdi, H., Regaya, C. B., & Abderrahmen, Z. (December 2019). *A sliding-neural network control of induction-motor-pump supplied by photovoltaic generator.*

[4] Hichem, H., Chiheb, B. R., & Abderrahmen, Z. (2019). *Performance improvement of a photovoltaic system with a radial basis function network based on particle swarms optimization.*

[5] Hichem, H., Chiheb, B. R., & Abderrahmen, Z. (May 2019). *Real-time study of a photovoltaic system with boost converter using the PSO-RBF neural network algorithms in a MyRio controller* (Vol. 183).

[6] Jones, A. R. (01 January 2022). *Design and Implementation of Photovoltaic Powered SEPIC DC-DC Converter Using Particle Swarm Optimization (PSO) Technique.*

[7] Roy, S. S. (07 December 2021). *A PSO Based MPPT Controller for Solar PV System at Variable Atmospheric Conditions* (Vol. volume 1373).

[8] TaraEmail, B. B., & Suresh, H. L. (21 August 2021). *Comparative Analysis of MPPT Techniques in Grid-Connected and Stand-alone PV System.*

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Mahbouba Brahmi conceived the FMSPSO-MPPT algorithm.
Mahbouba Brahmi, Chiheb Ben Regaya and Hichem Hamdi carried out the simulation using MATLAB-Simulink.
Mahbouba Brahmi and Abderrahmen Zaafouri performed the analysis.
Mahbouba Brahmi, Chiheb Ben Regaya, Hichem Hamdi and Abderrahmen Zaafouri wrote the paper.

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