Hybrid MPPT Technique for PV Systems applied to a Two-Switch Buck-Boost Converter

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***Abstract*—Finding the maximum power point (MPP) of a photovoltaic (PV) system and staying close to it requires more effort, since PV panels are often subjected to partial shading. When this occurs, several local maxima appear on the P-V curve, and algorithms based on local search, such as perturb and observe (P&O) and incremental conductance (INC), are unable to reach this point. For this type of application, global maximum power point tracking (MPPT) algorithms are used, such as the particle swarm optimization (PSO) technique, but they present their difficulties. A hybrid approach using a global search technique and a local search technique solves this previous problem. This work proposes a hybrid MPPT, mixing P&O and PSO techniques, applied to a two-switch buck-boost (TSBB) DC-DC converter connected to a PV panel subject to shading conditions. Simulation results, using PSIM software, are presented in order to show the effectiveness of this proposal. In this case, tests are performed to demonstrate the correct functioning of the proposed algorithm.**

***Index Terms*—Maximum Power Point (MPP); Hybrid MPPT; P&O and PSO Techniques; Two-Switch Buck-Boost (TSBB) DC-DC Converter.**

I. Introduction

Currently, the growing demand for renewable energy for the energy transition has significantly increased the use of photovoltaic (PV) solar energy. In order to guarantee greater efficiency in these systems, it is necessary that the PV panels generate as much energy as possible. This search for greater efficiency encourages science to carry out new research and methods with regard to algorithms. Maximum Power Point Tracking (MPPT) is a critical technique used in photovoltaic systems to optimize the extraction of power from photovoltaic panels. Given the non-linear characteristics of solar energy generation, where the output power varies with both solar irradiance and temperature, achieving an optimal power output requires advanced MPPT algorithms [1].

This technique is applied to DC-DC or DC-AC converters, by activating their switches, so that the PV panels reach the maximum power point (MPP). Classical methods are found in the literature such as fractional short circuit current, fractional open circuit voltage, perturb and observe (P&O) and incremental conductance (INC) [1]. In the P&O method, a small disturbance is introduced to cause a power variation at the terminals of the photovoltaic module [2]. In this case, the PV output power is periodically measured and compared with the previous power, however, this algorithm does not converge to MPP when shading appears. In the INC method, incremental changes in the pv panel current and voltage are measured to predict the effect of a voltage change. The incremental conductance of the PV panel is used to calculate the sign of the change in power with respect to voltage. This method has shown better performance in some applications compared to P&O [3], but not converge to MPP when shading appears.

Recently, MPPT methods based on optimization algorithms or artificial intelligence have been developed, in order to solve the problem presented in the previous methods and track the global maximum power point (GMPP) [4], [5]. One of the most used method in the literature is the PSO algorithm [6]. This consists of applying a duty cycle value, called particle, and waiting until it stabilizes. The result of the power generated by the observed particle is compared with the results of the previous ones. Finally, the particle is changed towards the particle with the best power result, so that after a few iterations, all particles will converge to a single value, the GMPP. One of the biggest difficulties in this technique is the need to explore the entire sample space before converging to the GMPP, as this causes large variations in the power generated by the system and consequently causes a reduction in efficiency when subjected to variations in climatic conditions.

A hybrid approach combining the strengths of classical with novel techniques emerges as an effective solution to overcome the limitations of each individual technique. In the literature there are several works where this hybridization is applied to power converters, in order to track the MPP, providing rapid convergence and reducing oscillations. The paper developed by El-Helw et al. [7] introduces a hybrid MPPT that combines a traditional INC MPPT algorithm with the artificial neural network (ANN) technique. The results show the effectiveness of the proposed hybrid MPPT technique in tracking the GMPP accurately with a rapid response compared to the ANN under various shading patterns.

The hybrid MPPT technique proposed by Gosh et al. [8] is a combination of the Improvised Binary Sequence(IBS) MPPT algorithm and the well known P&O MPPT algorithm. The initial operating point is using the IBS algorithm, and is transferred to the P&O algorithm. In case rapid changes in operating conditions are sensed due to any reason, the entire algorithm restarts from the beginning by re-initializing the parameters and putting the IBS algorithm to use. The simulation results show that the proposed algorithm offers high accuracy along with an agile response.

The study developed by Figueiredo and Alencar [9] proposed a hybrid MPPT technique that uses PSO and P&O

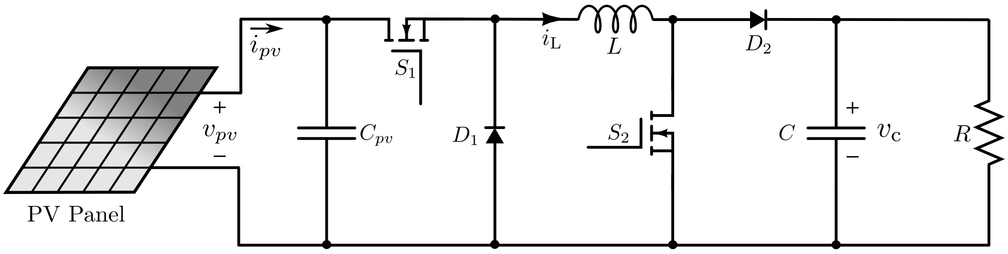

Fig. 1. PV panel connected to a TSBB converter.

methods. The proposed MPPT technique is compared with the classical P&O, standard PSO and hybrid P&O-PSO techniques. The simulation results showed that the proposed hybrid algorithm can track GMPP under uniform and partial shading conditions. Also, the research proposed by Santos et al. [10] uses the MPPT technique based on predictive control (MPC-MPPT) and the PSO algorithm. So this combination uses the tracking capabilities of PSO with the MPC-MPPT strategy, which is faster, but can get stuck at local maximums. The results show the effectiveness of the proposed technique accelerating the tracking ability of the PSO.

A hybrid MPPT algorithm combining the INC method with Harris Hawks Optimization (HHO) is developed by Astaomar and Erkal [11]. The HHO algorithm excels in balancing exploration and exploitation, making it effective in optimizing dynamic systems and avoiding local minima. By integrating HHO with INC, the hybrid approach dynamically adjusts key parameters, such as step size and convergence criteria, to track the GMPP more efficiently. This research highlights the potential of hybrid MPPT algorithms to enhance the performance and reliability of PV systems. Finally, the paper proposed by Karimi et al. [12] show a new MPPT approach that combines P&O and Fuzzy Logic Controller (FLC) with PSO algorithm. The FLC algorithm is then used to maximize search accuracy. The results demonstrate promising and dynamic performance under various environmental and shading conditions.

This paper presents a solution to decrease the disadvantages presented in global search techniques and local search techniques separately, proposing a hybrid MPPT method that combines either techniques, in a very simple way compared to previously referenced methods. Firstly, it uses the PSO to reach the GMPP convex region and then commutes the algorithm to the P&O method. As a result, the proposed strategy is able to reach GMPP quickly and work close to it without oscillations. To validate the proposal, a two-switch buck-boost (TSBB) DC-DC converter is connected to the output of the PV panel and partial shading is applied, as shown in Fig. 1. This variation of the conventional buck-boost converter can work in all possible MPP regions, which ensures better performance.

II. TSBB Converter

There are variants of the traditional buck-boost converter that can perform all functions in one, as is the case with TSBB non-inverting converter [13], shown in Fig. 1. This converter has synchronous rectification and consists of the use of two switches (S_1 and S_2), two diodes (D_1 and D_2), two capacitors (C_{pv} and C_c), one inductor (L) and the load (R). Also, note that this topology, formed by a cascaded combination of a step-down converter followed by a step-up converter, can operate in each mode separately, from the method of switching its switches. Furthermore, it works in buck-boost operation mode when S_1 and S_2 have identical PWM (*Pulse-Width Modulation*) signals.

TSBB converter is better than standard buck or boost converters in certain applications due to its flexibility, efficiency, and improved control over a wider range of input/output voltages. Unlike some basic buck-boost converters (like the SEPIC or traditional buck-boost), the TSBB maintains the same polarity of the input and output voltages. This simplifies control and integration with other electronics. In addition, by using two switches and operating in a synchronous manner (with complementary switching), it reduces conduction losses, and avoids diode losses present in simpler converters (like in boost mode where the diode forward drop can reduce efficiency). Also, the dual switch design distributes power stress more effectively, allowing better thermal management and scaling to higher power levels [14].

Then, in this work, the buck-boost operating mode is used, where depending on the duty cycle value, the converter operates as both a step-down and step-up converter, increasing its operating range. For this, the same PWM signal and duty cycle (D) are used to operate S_1 and S_2. The topological states of the converter in this operating mode, ON and OFF, are defined in equations (1) and (2):

$$ON : \begin{cases} L\dfrac{di_L}{dt} = v_{pv} \\ C\dfrac{dv_C}{dt} = -\dfrac{v_C}{R} \end{cases} ; \tag{1}$$

$$OFF : \begin{cases} L\dfrac{di_L}{dt} = -v_C \\ C\dfrac{dv_C}{dt} = i_L - \dfrac{v_C}{R} \end{cases} ; \tag{2}$$

where v_{pv} and i_{pv} are the voltage and current values in PV panel terminals, and v_C and i_L are voltage and current values in the converter.

Thus, applying linearization using the average model [15], it is possible to obtain the relationship between the voltage at the output of the converter (3) and the current in the inductor (4) with the duty cycle of the converter in this operating mode.

$$V_C = \frac{V_{pv}D}{(1-D)} \tag{3}$$

$$I_L = \frac{V_{pv}D}{R(1-D)^2} \tag{4}$$

Once the operating conditions of the TSBB converter have been defined, it is possible to determine the filter value to achieve the minimum design requirements. Therefore, the minimum inductance and capacitance values for the operating modes must be calculated and the largest among them must be chosen. To this end, inductors and capacitors must be sized to ensure continuous conduction mode (CCM) and that the ripples (ΔI_L and ΔV_C) does not exceed 5% at the switching frequency (F_{sw}).

The minimum inductance and capacitance values for the buck-boost operating mode are represented by the equations (5) and (6) respectively [16]:

$$L_{min} = \frac{V_{pv} D}{\Delta I_L F_{sw}}; \tag{5}$$

$$C_{min} = \frac{I_L D}{\Delta V_C F_{sw}}; \tag{6}$$

In addition, the input capacitor helps stabilize the input voltage and minimize the voltage ripple (ΔV_{pv}) from the PV panels. Thus, this can be obtained as:

$$C_{pv} = \frac{I_{pv} D}{\Delta V_{pv} F_{sw}}. \tag{7}$$

III. Hybrid MPPT Proposed

The hybrid MPPT algorithm proposed in this work is based on performing an initial global search and then using a local search to reach the MPP. The P&O technique is used as a local search and the PSO technique as a global search. The flowchart of the proposed method is shown in Fig. 2.

The algorithm is initialized measuring voltage and current values at the terminals of PV panel and then the power is calculated. This value is compared to the previous power value and the power variation given by the difference between the two divided by the current power is calculated. If this difference is greater than 5% the algorithm selects the PSO technique, which is responsible for reaching a region of global maximum power. Otherwise, the algorithm switches to the P&O technique in order to keep the search close to the point found by the PSO. Both methods will be explained separately below.

A. PSO

The PSO algorithm consists of a stochastic heuristic method for optimizing nonlinear continuous functions. In the approach, each individual is considered a particle, while the group of particles is called a swarm [17]. This technique is based on the search for the best solution to the problem within the hyperspace of possible solutions.

Initially, the particles are randomly distributed, occupying the entire hyperspace of solutions and with a defined cost function. The particles move individually, searching for the best desirable cost and sharing information about the best results already found with the other particles in the swarm. Thus, there is a tendency for all individual particles to converge to the best result. This technique is applied in the search for global maxima using a cost function according to the proposed problem [17].

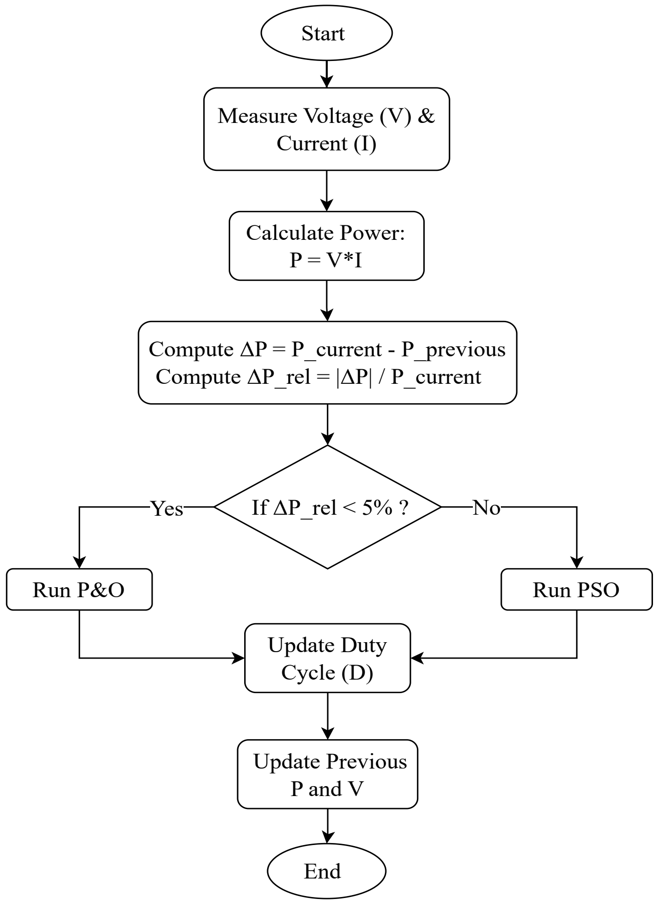

Fig. 2. Hybrid MPPT proposed.

For PSO applications in GMPPT of PV panels, the particle corresponds to the duty cycle applied in the converter switch used. The direction and displacement are based on the power measurements of each particle and group. The displacement speed depends on the distance the particle is from the best position in the swarm.

The flowchart of the PSO technique is illustrated in Fig. 3. The particle D_i represents the applied duty cycle. First, all the necessary variables are initialized. Then, the particle i is updated and the new duty cycle value is applied. Therefore, the output power is measured again and compared with the best power of the particle i ($P_{best,i}$). If the measured power is greater than the current best power ($P_{best,i}$) is updated. If this updated value is greater than $P_{best,i}$, the global maximum power value (G_{best}) is updated. If none of these conditions are met, the algorithm returns to the second block to update the next particle $i+1$. This process is performed for the N particles, and then the next set of particles k are updated to $k+1$.

B. P&O

After finding the GMPP, the proposed algorithm switches to the P&O technique [18]. The following Fig. 4 describes the flowchart for this MPPT algorithm. Here, the current and voltage pairs are measured at the terminals of the PV panel to calculate the photovoltaic power. The power obtained in the last iteration is compared with the power calculated in the previous iteration. Furthermore, the voltage value in the

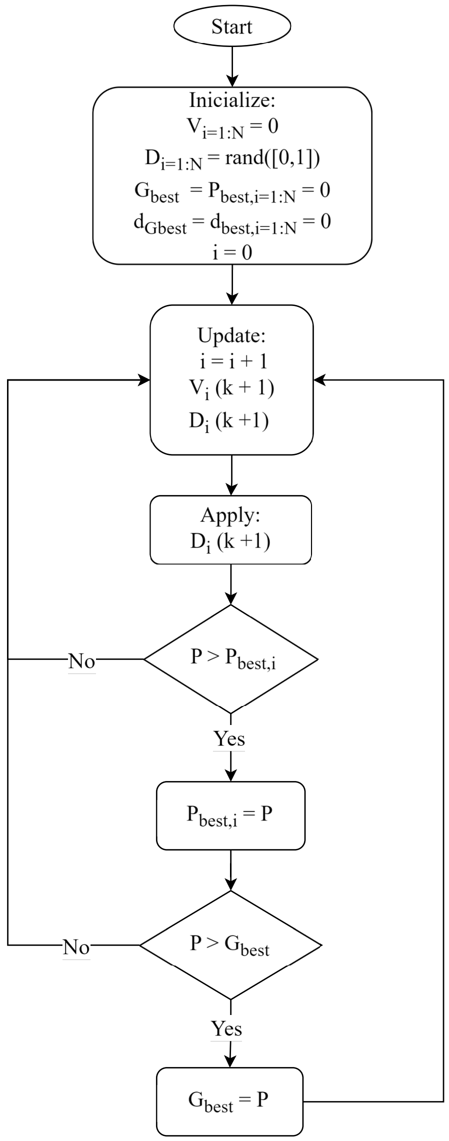

Fig. 3. PSO MPPT Diagram.

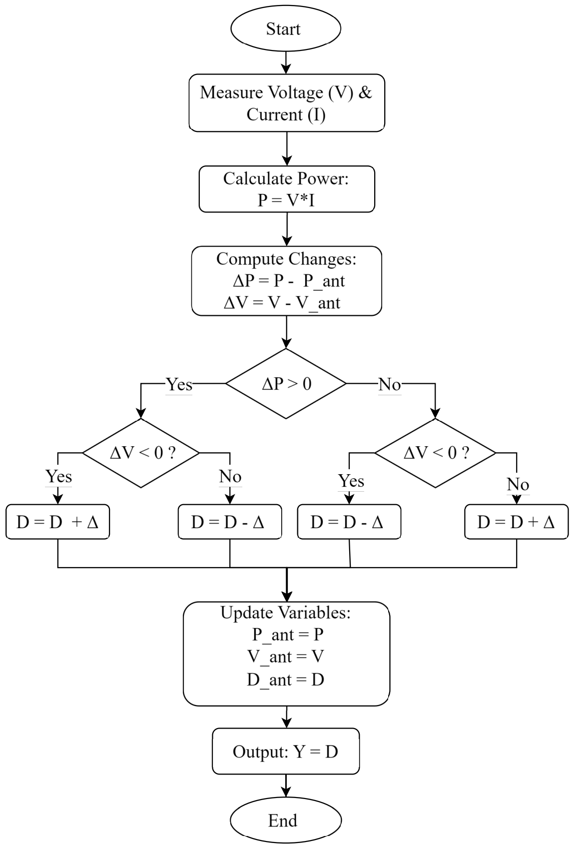

Fig. 4. P&O MPPT Diagram.

TABLE II
DESIGN VALUES

Parameters	Value
Inductor current ripple (ΔI_L)	0,2 A
Capacitor voltage ripple (ΔV_C)	0,5 V
Voltage ripple in the input (ΔV_{pv})	0,5 V
Switching frequency (F_{sw})	50 kHz
Duty cycle (D)	0,5

last iteration is compared with the previous voltage value to determine whether the converter duty cycle needs to be increased or decreased (using a step k) to reach the maximum power point. Finally, this duty cycle value is compared with a triangular carrier signal, and the obtained PWM signal is applied to switches of the TSBB converter.

IV. Simulation Results

In order to validate the proposition, in this section, a PSIM simulation of a PV panel with a TSBB DC-DC converter is performed. For this work, a PV panel model PW-96M-54 from Powitt Solar Energy is used as reference. The electrical characteristics of the PV panel are presented in Table I.

TABLE I
PW-96M-54 PANEL SPECIFICATIONS

Parameter	Value
Maximum Power Panel (P_{max})	540 W
Voltage at P_{max} (V_{mpp})	52,6 V
Current at P_{max} (I_{mpp})	10,27 A
Open Circuit Voltage (V_{oc})	63,5 V
Short-circuit Current (I_{sc})	10,85 A

For the design of the TSBB converter are used Eqs. (5), (6) and (7) with values founded in Tables I and II. In this last table, the values of frequency, duty cycle and voltage and current ripple were selected. Then, the passive components of the converter are sized and are presented in Table III.

Then, PSIM simulation is performed to compare the hybrid MPPT technique proposed with P&O and PSO separately, to track the power of the PV system. In the first simulation, where the hybrid method is used only, standard values of irradiation ($1000 W/m^2$) and temperature (25^oC) are selected, and applied to the PV panel, generating a total power of approximately 540 W. Therefore, the module is shaded half, thus losing 50% of its power. The results are shown in Fig. 5. In this figure, the input and output powers are compared and demonstrate the effectiveness of the proposal of this work. Thus, the hybrid MPPT can achieve its objective of finding and tracking the maximum power point after partial shading.

This same process carried out previously was applied to the system using the P&O and PSO methods separately. The Fig. 6 compares the three MPPT methods for 1s. In this case it can be observed that the proposed method has

TABLE III
TSSB COMPONENTS

Component	Value
Inductor (L)	500 μH
Output capacitor (C)	500 μF
Input capacitor (C_{pv})	50 μF
Load resistor (R)	10 Ω

a better performance compared to the other two. The P&O takes longer to find the GMPP (around 0,3s) compared to the PSO, but the PSO shows more oscillations around it. After applying shading to the PV panel, this behavior repeats itself. Therefore, the hybrid MPPT method finds the GMPP much faster (around 0,05s) and stays around it with less oscillation than the other methods.

The Fig. 7 shows the behavior of these three methods in a steady state in a more enlarged form, in order to show that the hybrid presents less oscillations than the other two. A time of 0,1s was selected for this magnification. Here it can be observed that the oscillations of the proposed method are 10 times less than the PSO and half of the P&O. This demonstrates that the hybridization fulfilled the proposed objective of finding the GMMP faster than the PSO and staying around it with less oscillations than the P&O.

V. CONCLUSIONS

In this work, a new hybrid GMPPT based on the P&O and PSO techniques was proposed. The proposed technique was validated in a TSBB DC-DC converter connected to a PV panel under partial shading. The simulation results corroborate the effectiveness of the proposed algorithm. The proposed hybrid technique proved to be more efficient than the PSO technique, which achieved reductions greater than 60% of the time to track the GMPP. The use of the P&O technique in the hybrid proposal allowed the maintenance of the maximum power point when the system is disturbed by small rapid variations, in addition to generating little oscillation around the maximum power point. Comparison of the proposed method with the other two methods separately demonstrated the effectiveness of this. Finally, the proposed technique can be easily implemented in microcontrollers and embedded systems, it can be used in other applications with other power converters.

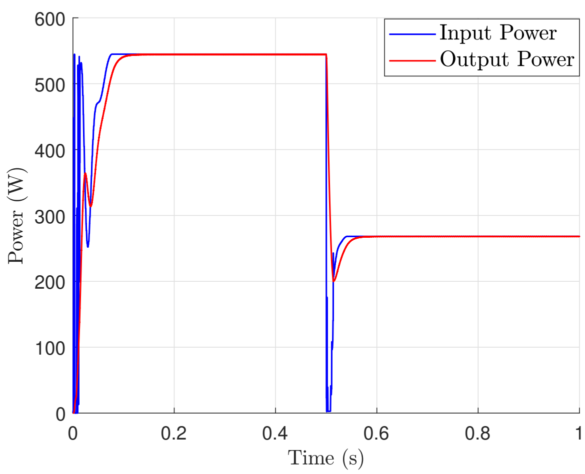

Fig. 5. Comparison between powers.

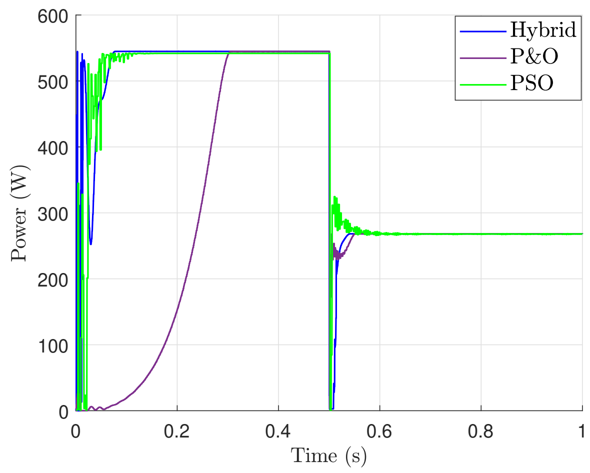

Fig. 6. Comparison between methods.

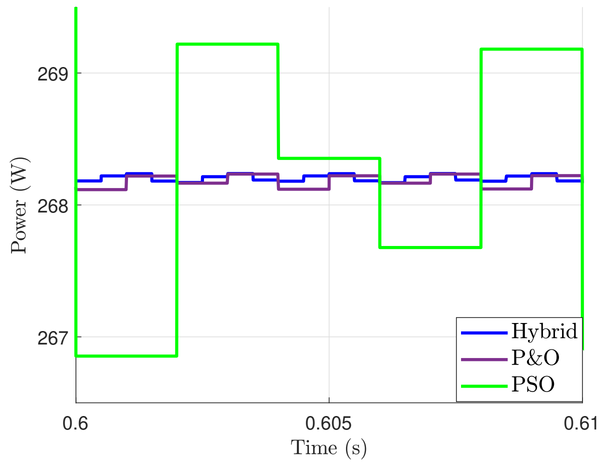

Fig. 7. Comparison between the methods in more detail.

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