Optimization of the P&O-MPPT controller by the adaptive method (Ad-P&O) for stand-alone PV systems

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Abstract:
This work is devoted to an Optimization of the Maximal Power Point Tracking (MPPT) Perturbation and Observation controller by the Variable Pitch Adaptive (Ad-P&O) method for stand-alone Solar Photovoltaic Systems (SPVS). Indeed, to extract the maximum power in photovoltaic systems, MPPT (Maximal Power Point tracking) techniques are used to search and track the maximum power point. The most popular MPPT techniques are reviewed such as: the P&O MPPT control, the Incremental Conductance (InC). The P&O control is considered too slow and has a difficulty to track the maximum power point (MPP), and during sudden perturbations of the atmospheric conditions, the MPP can move in the wrong direction. However, a method based on Perturbation and Observation which consists in varying the increment or decrement step (Ad-P&O) is studied to improve the P&O method performances. Thus, a comparative study between the Ad-P&O control and the InC is made to optimize the power of a SPVS. A validation with real data of a photovoltaic power plant is done on two seasons in tropical area. The Matlab/Simulink Software is used for the simulation and the results show that the Ad-P&O control has a better performance than InC with 99.49% and 80.6% respectively in March and August. Moreover, the error criteria for the Ad-P&O.

Keywords: MPPT, Ad-P&O, InC, Optimization, Photovoltaic.

1. INTRODUCTION

Nowaday, with a dire energy deficit, solar photovoltaics systems are the solution to lower energy dependence and reduce greenhouse gas. Solar technologies use the sun, for domestic and industrial applications, to provide heat, electricity [1, 2, 3]. To enhance or modernize our energy sector, we must reduce the use of fossils source and the urgency is to invest in renewable energy resources that would allow us to feed ourselves sufficiently in the future without degrading the environment through the emission of greenhouse gases. The State of Senegal in its program of the Senegalese Emerging Plan (PSE) aims to reduce the cost of electricity production and diversify the sources of decentralized production by increasing the use of renewables energies by a project of energy-mix [4]. Thus, the potential of renewable energy like solar is hugely, but the intermittence of the source and the low energy conversion of photovoltaic limit it exploitation [5]. Extracting the maximum power from the SPVS system is one main challenge of using these systems. For this purpose, researchers have developed MPPT control techniques for power optimization of PV systems [6, 7] in order to improve the efficiency of the overall system, while reducing costs. In the literature, many MPPT techniques have been proposed and improved but these present a number of challenges namely slow tracking, oscillations around the Maximal Power Point (MPP) and low efficiency. Among these controls, the most widely used are Perturbation and Observation (P&O) [8], Incremental Conductance (InC), constant voltage [9].

Indeed, these MPPT commands vary in terms of accuracy, complexity, application but also popularity etc. Thus, for more accuracy and speed, MPPT techniques using genetic algorithms and particle swarm optimization (PSO) have been proposed [10]. In addition, neural networks and fuzzy methods are well adopted to handle nonlinearity in many applications [11, 12]. Despite these methods, they have good performance in handling nonlinear features of the I = f(V) curve [13, 10]. However, these methods have implementation difficulties and high costs. The Perturbation and Observation (P&O), Incremental Conductance (InC) and Hill Climbing (HC) methods based on a fixed step size are simple and have good performance. However, these methods present some problems with respect to the slow extraction and the ripple rate present around the maximum power point in case of rapid change in irradiance and temperature. Thus, a large number of MPPT Adaptive Perturbation and Observation step (**Ad-P&O**) algorithms, in which the perturbation step size must be carefully chosen, have been proposed and studied. On the one hand, it is noted that the convergence speed can be increased if the perturbation step size is large while the oscillations of the operating point around the MPP will be larger. Therefore, an important loss of power is noted [14]. On the other hand,

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if the disturbance step size is decreased, the oscillations around the MPP can be reduced and the tracking speed will also be reduced. With this in mind, authors such as Ansari et al proposed in [15], a variable step P&O MPPT algorithm to reduce the oscillations of the operating point with respect to the maximum power point and increase the convergence speed. Mei et al proposed in [16], a new variable pitch MPPT technique that simultaneously improves the response speed, steady state performance and accuracy. In the same vein, authors such as Shang et al proposed in [17] an improved MPPT control strategy based on an incremental conductance algorithm that not only optimizes the system but also improves the efficiency, response speed, and tracking efficiency of the PV system, thus ensuring the stable operation of the power system. In [18], Oussalem et al developed a low-cost controller to track the maximum power point of the PV system by strategy (InC) using the Arduino board via Matlab/Simulink as the control interface.

The latter has shown its ability to reach the PPM under uniform and sudden irradiation changes. In this context, we propose a new method based on disruption and observation which consists in varying the increment or decrement step in order to find the PPM and optimize the performance of the PV system under non-uniform weather conditions.

To overcome the problem of low efficiency due to the intermittency of PV sources, many researchers have worked to optimize the power of the PV system. Moreover, solar power plants in Senegal use the P&O control to search and track the maximum power point and optimize the efficiency of these plants, but this control has difficulty in adapting to abrupt variations in weather conditions.

The scientific contribution of this paper is to propose an adaptive optimization control (Ad-P&O) of an SPVS that takes into account the two seasons in Senegal. A dry season where the meteorological conditions are stable and a rainy season which corresponds to many disturbances of the meteorological conditions. These disturbances have a negative impact on the production efficiency of solar systems. According to the literature review above, the optimization techniques (P&O and InC) used so far are effective only over one season (the dry season). To validate the performance of the proposed method, we divided the database into two parts. Data from March (dry season) is used for performance testing. The robustness test is carried out with data for the month of August (rainy season).

This paper is organized as follows. The methodology is studied in section 2. In section 3, the simulation results are presented and discussions are made. Finally, we concluded the paper in section 4 and gave an outlook.

2. METHODOLOGY ET MATERIALS

To perform the optimal control of a system, it is first necessary to determine its mathematical model. In this section, we have modeled the production source (the solar source).

2.1 Solar source modeling

The study system consists of photovoltaic modules, an Electrical Energy Storage Battery System (SBS2E), a Static Boost Converter (SBC) that raises the voltage produced by the photovoltaic generator, and a bi-directional converter that supervises the charge and discharge of the battery. The whole system is connected to a DC link voltage supplying DC loads.

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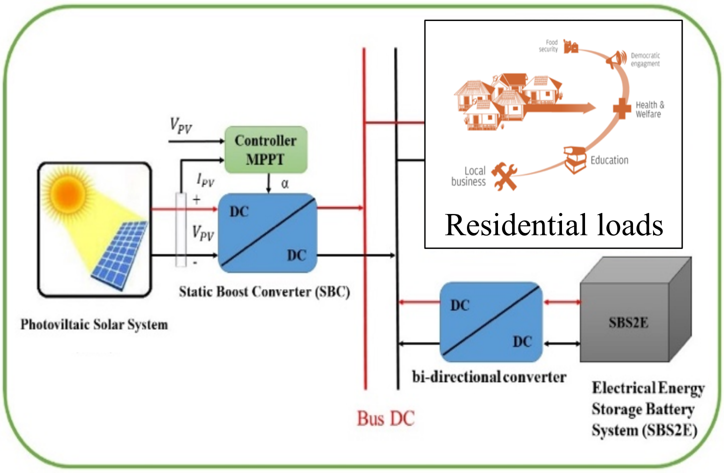

Fig.1. Studied system scheme

A photovoltaic generator is an electrical assembly of photovoltaic module or panel composed of one or more photovoltaic cells, whose function is to transform sun radiation to electricy. Thus, several electrical models have been proposed in the literature to translate or highlight its non-linear behavior. We distinguish mainly the model with one diode [19] and the model with two diodes [20]. Indeed, in our work we use the one-diode model because it provides a good compromise between accuracy and simplicity. The model presented in figure 2 is an electrical model that contains a parallel and a series resistor.

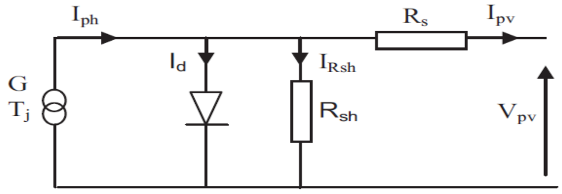

Fig.2. Single diode electrical model of a solar cell [21].

The current of the diode is given by equation (1).

$$I_D = I_0 \left(\exp\left(\frac{V+I*R_S}{\eta*V_{Th}}\right) - 1\right) \quad (1)$$

With V_Th the thermodynamic potential of the diode given by equation (2).

$$V_{Th} = \frac{K.T}{q} \quad (2)$$

The current at the parallel resistor is given by equation (3).

$$I_{Sh} = \left(\frac{R_{Sh}*I+V}{R_{Sh}}\right) \quad (3)$$

Applying the law of knots, we obtain equation (4).

$$I = I_{PH} - I_D - I_{Sh} \quad (4)$$

After replacement, we obtain the expression of the current delivered by the cell (equation (5)).

$$I_{PV} = I_{PH} - I_0 \left(\exp\left(\frac{q*(V+I_{PV}*R_S)}{\eta*K*T}\right) - 1\right) - \left(\frac{R_S*I_{PV}+V}{R_{Sh}}\right) \quad (5)$$

Where :

I_{PV} (A) : Photo-current of the module ;
K : Boltzmann constant = 1,33 10^{-23} $J.K^{-1}$;
q: Charge of the electron = 1,67 10^{-19} C ;
R_{Sh} (Ω): Parallel resistance ;

Rs (Ω) : Series resistance ;
I_0 (A) : Saturation current of the diode ;
I_D (A) : Current of the diode ;
T (°K) : Temperature of the cell diode;
V : Voltage imposed on the diode ;
η : Ideal factor of the diode;

2.2 Power optimization method:

PV systems provide their optimal powers at a particular point called MPP. For this purpose, in order to optimize their output, MPPT control techniques are used for tracking this point (see Figure 3). In this study, two methods will be discussed namely InC and P&OV for power optimization with real climate data.

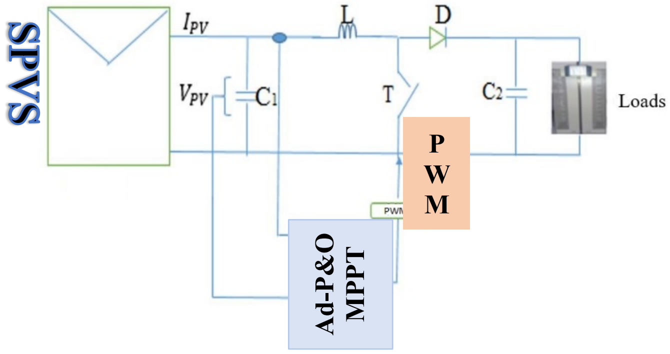

Fig.3. Power optimization by MPPT control

In incremental conductance method (InC), the conductance G=I/V and its increment of the conductance (dG) are used to found the position of the operating point in relation to the Maximum Power Point (MPP): (see figure 4). If the conductance increment (dG) is greater than the opposite of the conductance (G), the duty cycle is reduced. On the other hand, if the conductance increment is lower than the opposite of the conductance, the duty cycle is increased (see figure 5). This process is repeated until the Maximum Power Point (MPP) is reached [22]. The size of the increment determines how fast it is tracked but also how accurate it is.

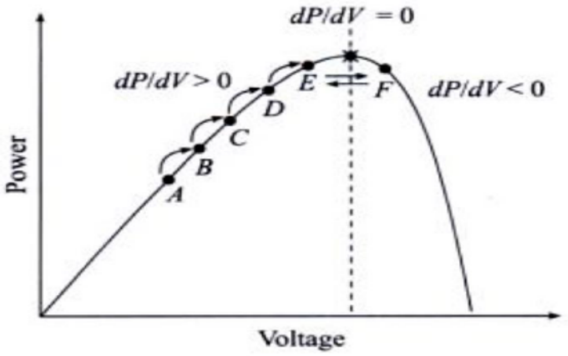

Fig.4. Power point search using the Incremental Conductance method [23].

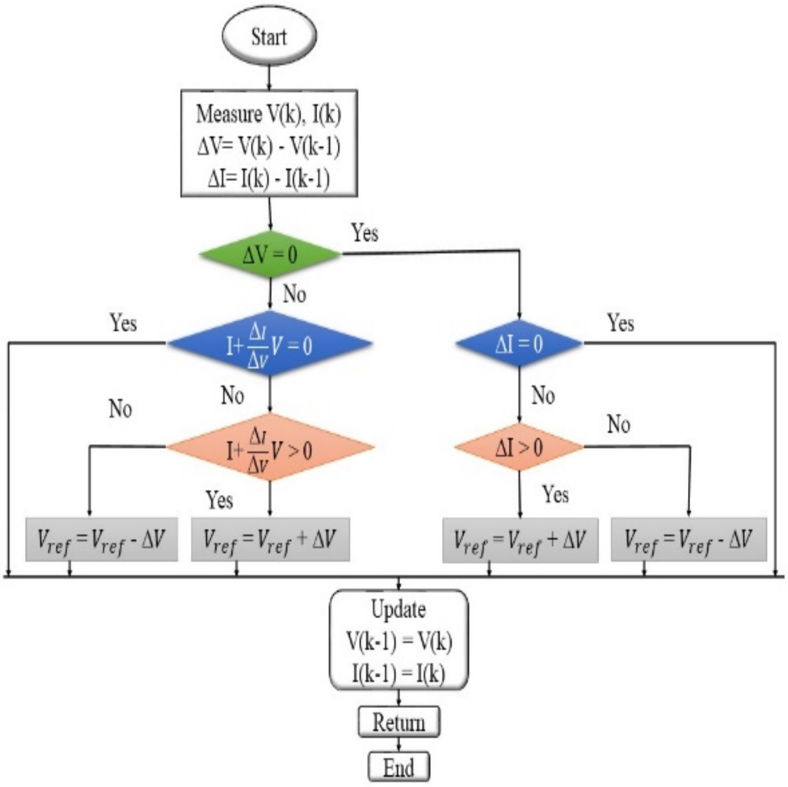

Fig.5. Flowchart of the InC algorithm [23].

The InC method provides a reduced number of oscillations around the PPM and stable operation. The drawback of this method is its higher complexity compared to the perturbation and observation (P&O) method [24]. To overcome the complexity issues of the InC control, an adaptive control is proposed. It is the Perturbation Observation method with variable increment/decrement steps. For this purpose, we will treat the P&O control with fixed step. The latter consists to perturb the input voltage of the CSB, varied the duty cycle α and observe the change on the output power. Indeed, following this perturbation, the power supplied by the 2SPV is calculated at time k and then compared to the previous one at time (k-1) [25]. If the power increases, the system approaches the Maximum Power Point (MPP) and the

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variation of the duty cycle is keeped direction. In the opposite case, when the power decreases the system moves away from the Maximum Power Point (MPP). In this case, the direction of variation of the duty cycle must be reversed [26]. However, this control has some limitations, as it is considered too slow and oscillates around the maximum power point. The latter can move in the wrong direction in case of strong variation of the weather conditions, hence the importance of proposing a control based on Perturbation and Observation but this time with Variable pitch (Ad-P&O).

This command consists in varying the increment or decrement step. Indeed, it is an improvement of the P&O method. However, at the power difference from one instant (k) to one instant (k+1), the value of the increment of the duty cycle changes in order to guarantee a better tracking. This method also shows that, the larger the difference between the two powers, the larger the increment step and vice versa.

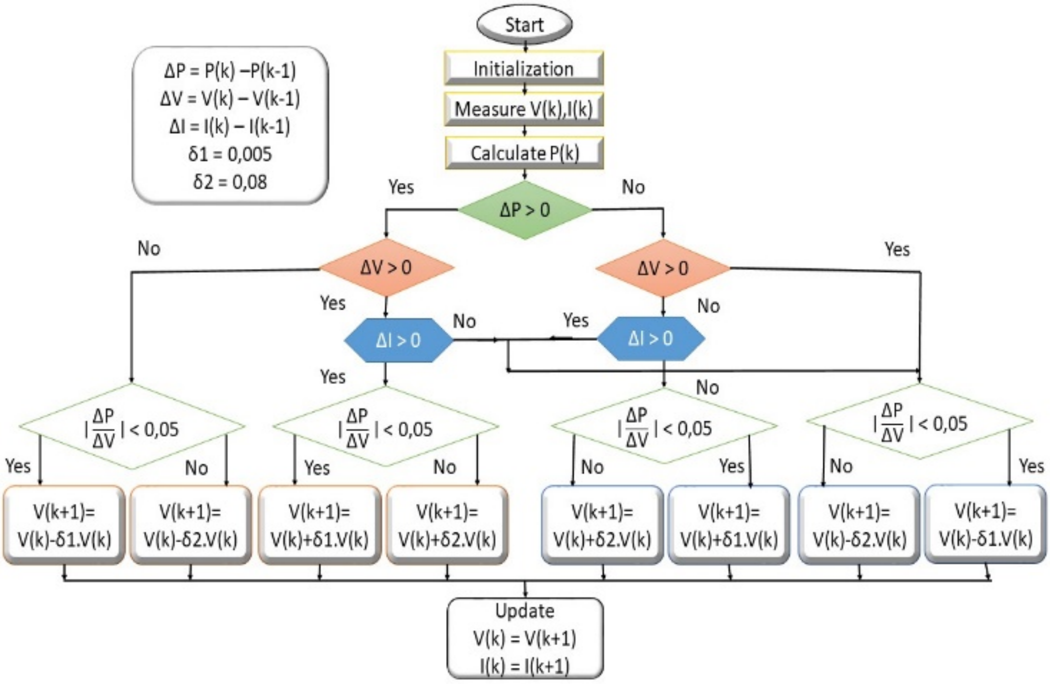

Fig.6. Flowchart of the **Ad-P&O** algorithm.

With conventional P&O control, a fixed disturbance step size is used. A larger step size increases the convergence speed but the operating point will oscillate around the PPM and slightly reduce the efficiency. On the other hand, if the step size is small, there is a reduction in oscillations around the PPM but this will result in a slower convergence to the PPM and notably some power will be lost. The Variable Pitch Observation and Disturb (Ad-P&O) control can solve this problem and make the tracking system much more attractive. With this control (Ad-P&O), the step size will be large when the operating point is far from the MPP and small when the operating point is close to the MPP. Therefore, the convergence speed as well as the tracking accuracy can be improved with the **Ad-P&O** control.

3. RESULTS AND DISCUSSION

In the case of our study, the data needed to validate our models are obtained on an experimental setup (see Figure 7). The components are two solar panels whose electrical characteristics will be measured with a measurement center, a pyranometer and a thermocouple used to measure the irradiation of the site and the temperature of the panels respectively and all the data are recorded in a computer.

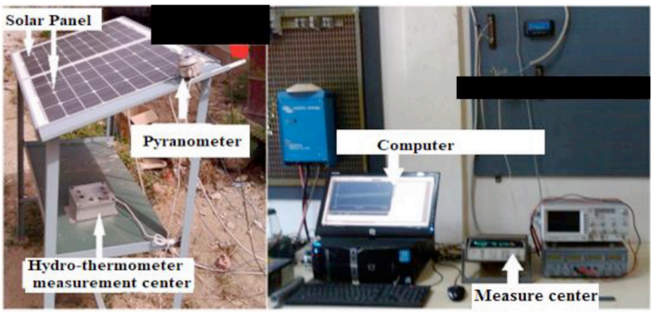

Fig.7. Experimental setup for database collection.

This experimental setup is installed at the Polytechnic high school of Cheikh Anta Diop University in Dakar, Senegal. This last is marked by two seasons, the rainy season which runs from July to October and the rest of the year is characterized by the dry season from November to June [26]. The data obtained are the characteristics of the panel under different weather conditions. Each radiation value (Ens) is related to a temperature value (T). The panel provides a maximum power only for particular point namely MPP that depend on the weather conditions. This power varies according to the conditions of irradiation and temperature change. Figures 8 and 9 show the characteristics of current and power as a function of voltage.

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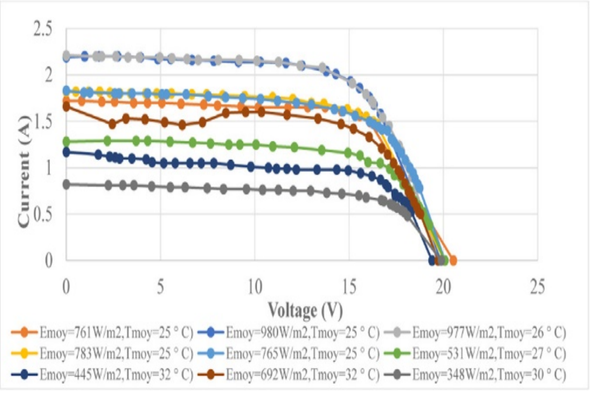

Fig.8. Characteristic of current versus voltage under different weather conditions.

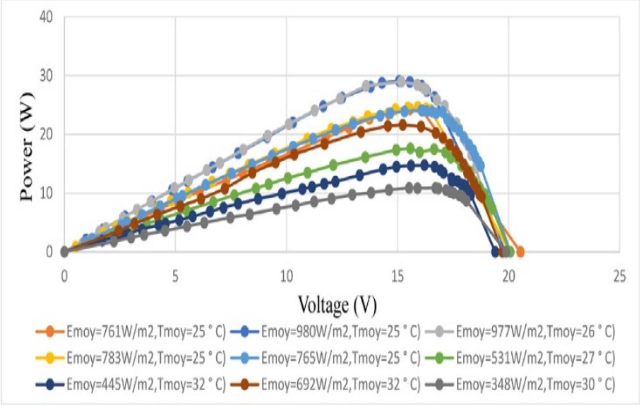

Fig.9. Characteristic of power versus voltage under different weather conditions.

These figures show that the power of the PV system is sensitive to variations in weather conditions, namely sunshine and temperature. Therefore, to maintain this power, it is necessary to use MPPT algorithms to track the optimal point. Table 1 gives the parameters of the PV panel.

TABLE 1: Parameter of the PV panel

$I_{sc}(A)$	$V_{oc}(V)$	$V_{mp}(V)$	$I_{mp}(A)$	P (W)
2.24	22.5	16.7	1.81	30

Figures 10 and 11 represent the sunshine and temperature profiles for the validation of the studied method.

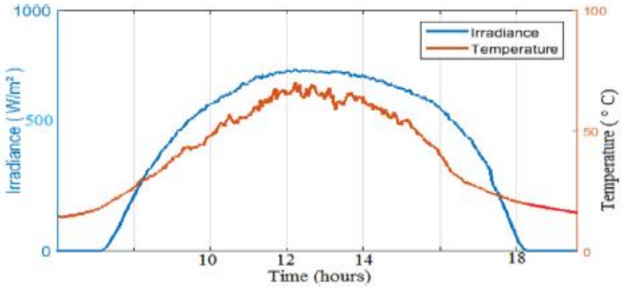

Fig.10. Solar Irradiation in Mars.

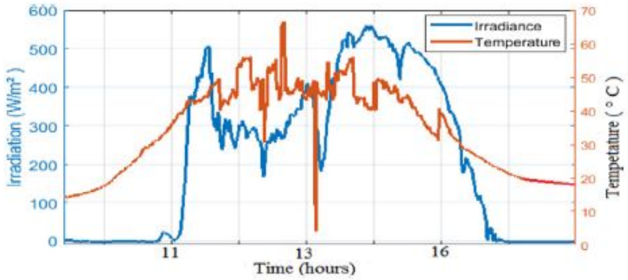

Fig.11. Solar Irradiation in August

This study aims to make the experimental validation of a Ad-P&O-MPPT control. For this purpose, a comparative study is performed, namely the Ad-P&O and InC control. To intuitively measure the performance of the proposed controls and facilitate the comparison of the latter that we calculate, the mean absolute error (MAE), the mean absolute percentage error (MAPE) and the root mean square error (RMSE) have been introduced as follows whose expressions are presented respectively by equations 6, 7 and 8.

$$MAE = \frac{1}{n}\sum_{i=1}^{n} | P_{opt} - P_{pred} | \qquad (6)$$

$$MAPE(\%) = \frac{1}{n}\sum_{i=1}^{n} \left| \frac{P_{opt}-P_{pred}}{P_{opt}} \right| \qquad (7)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_{opt} - P_{pred})^2} \qquad (8)$$

With :

n : Size of the database ;
Popt : Desired power;
Ppred : Predicted power.

RMSE measures the average value of the errors, ranging from 0 to infinity, with lower values being better. The mean absolute percentage error MAPE is used to evaluate the accuracy of the optimization. It indicates by how much the optimized value deviates from the actual value.

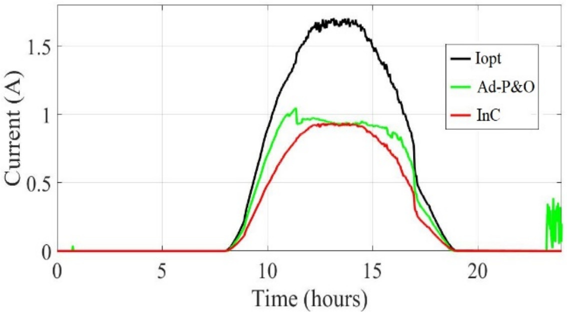

Fig.12. Current variation on a sunny day in March.

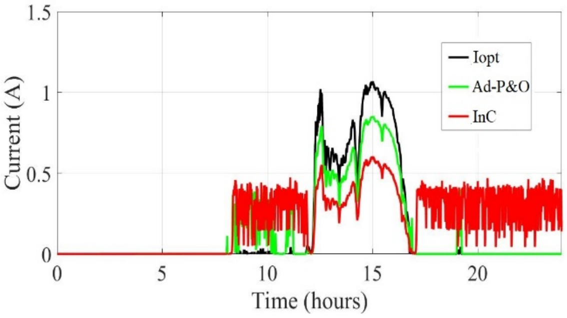

Fig.13. Current variation for a cloudy day in August

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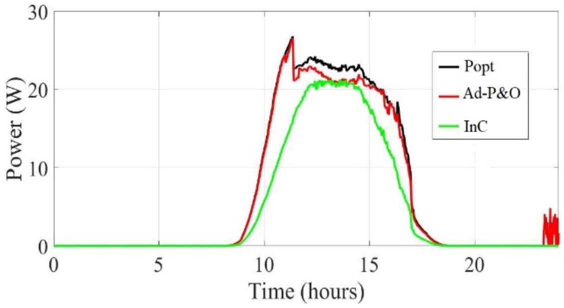


Fig.14. Power variation for a sunny day in March.

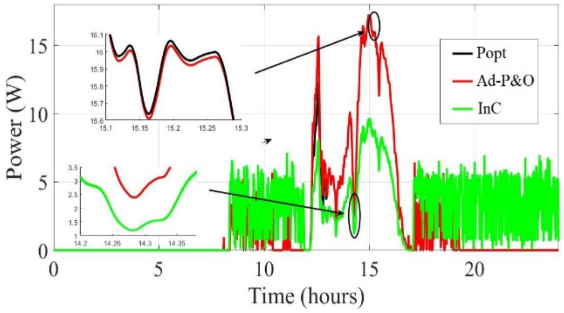


Fig.15. Power Variation for a cloudy day in August

The performance tests on the static error calculation namely mean absolute error, mean percentage absolute error and square error are listed in Table 2.

TABLE 2: Performance study of the Ad-P&O and InC commands

Month	March			August		
Model	MAE	MAPE (%)	RMSE	MAE	MAPE (%)	RMSE
Ad-P&O	$1.03\ 10^{-06}$	$2.04\ 10^{-05}$	$1.62\ 10^{-04}$	$1.44\ 10^{-05}$	$9.63\ 10^{-04}$	0.0023
InC	$1.23\ 10^{-06}$	$2.55\ 10^{-05}$	$1.94\ 10^{-04}$	$7.05\ 10^{-05}$	0.0090	0.0112

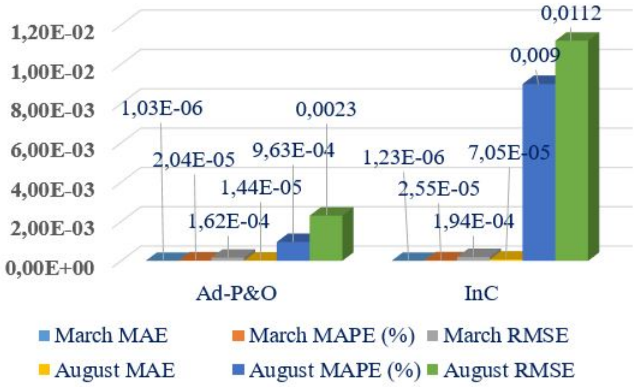


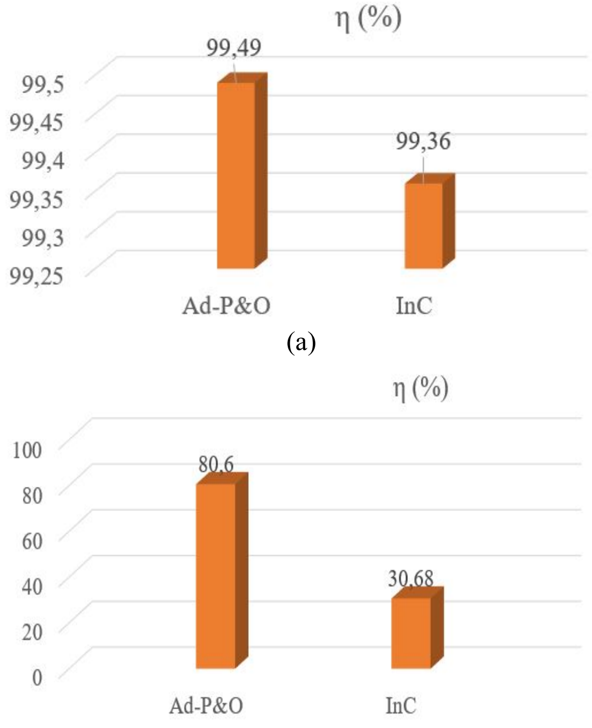
Fig.16. Error diagrams of the optimization algorithms (AO) for the months of March and August.

Figures 12 and 13 represent the current variations for a sunny and cloudy day in March and August respectively.

In this study, the results show that the Ad-P&O control perfectly follows the optimal power in August (see figure 15), i.e. during the rainy season when the atmospheric conditions are not homogeneous with weak and strong fluctuations. On the other hand, we note a slight difference between the optimal power and the Ad-P&O command in the month of March, with uniform weathers conditions (see figure 14). The latter performs better than the InC command because it is closer to the optimal power in both months (March and August). In this analysis, we can confirm that the Ad-P&O command is a solution for tracking the maximum power point.

Table 2 shows the error criteria and that the Ad-P&O control gives better results compared to the InC control for the two months (March and August) corresponding respectively (dry season and rainy season). The Ad-P&O control reduces MAPE by two months to $2.04\ 10^{-05}$ and $5.13\ 10^{-04}$ in March and August respectively. In contrast, the InC command has a MAPE equal to $2.55\ 10^{-05}$ and 0.0028 in March and August, respectively. Figure 16 represents the error criteria of the optimization algorithms for both months (March and August). So we can say that this study is in good agreement with the measured and predicted curves for March and August. Because the three error criteria of the Ad-P&O command are lower than those of the InC command.

$$Efficiency\ (\%) = \frac{MPPT\ power}{PV\ power} * 100$$



(a)

(b)

Fig.17. Efficiency: (a) March and (b) August

Tests on the calculation of the average values of the yield are presented in (Figure 16a and 16b) respectively for the month of March and August. The results show that with the InC command, the average value of the yield is less important compared to the Ad-P&O command respectively of the order of 99.36% and 99.49% for the month of March. Moreover, we also note that the average value of the yield is better for the Ad-P&O command than that of InC for the month of August respectively 80.60% and 30.68%.

4. CONCLUSION

The work done in this paper is the power optimization of PV systems by adaptive Ad-P&O control. However, in this work

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an adaptive control strategy that consists of varying the increment or decrement (Ad-P&O) step in order to find the maximum power point and optimize the PV system performance is study. For this purpose, we made a comparative study of the InC method with the developed adaptative method. The results show that the Ad-P&O control is more efficient and robust in terms of system efficiency with 99.49% and 80.6% in March and August respectively. Moreover, the Ad-P&O control has less error criteria than the InC control. So we can say that the P&OV command is a better solution for finding and tracking the maximum power point. In the future, we would like to make a comparative study between the Ad-P&O control and intelligent controls such as Artificial Neural Networks (ANNs) for the two months (March and August) and the whole yeard.

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