Improving and evaluating the performance of a real photovoltaic pumping system for agricultural irrigation purposes in a desert environment at Ghardaia, Algeria

Melhoria e avaliação do desempenho de um sistema de bombagem fotovoltaico real para fins de irrigação agrícola num ambiente desértico em Ghardaia, Argélia

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ABSTRACT
Algeria has one of the highest solar resources in the world. The availability of this significant solar energy can make photovoltaic (PV) water pumping applications a very attractive solution for many uses, including irrigation of agricultural areas, village water supply and domestic uses. The cost of water pumped by a PV pumping system is directly linked to the efficiency and reliability of the different elements constituting the system and also to the solar irradiation available at the installation site. Consequently, it is necessary to improve the reliability and efficiency of the PV generator in order to extract the maximum possible power at all times in order to achieve the most reliable and economic operation. On a real well of 25 m height in desert and semi-arid climate at the Sebseb site, Ghardaïa, Algeria, a typical PV pumping system for irrigation purposes is studied and optimized using two conventional methods, a P&O method and an incremental method. These methods are essentially based on the assessment of water needs to irrigate 70 palm trees, the data on solar irradiation and the average temperature for the studied site (Sebseb, Ghardaïa).

Keywords: PV water pumping systems, agricultural irrigation, solar radiation, hydraulic power.

RESUMO
A Argélia tem um dos maiores recursos solares do mundo. A disponibilidade desta energia solar significativa pode tornar as aplicações de bombagem de água fotovoltaica (PV) uma solução muito atractiva para muitas utilizações, incluindo a irrigação de áreas agrícolas, o abastecimento de água a aldeias e utilizações domésticas. O custo da água bombeada por um sistema de bombagem fotovoltaico está diretamente relacionado com a eficiência e a fiabilidade dos diferentes elementos que constituem o sistema e também com a irradição solar disponível no local da instalação. Consequentemente, é necessário melhorar a fiabilidade e a eficiência do gerador fotovoltaico para extrair a máxima potência possível em qualquer momento, a fim de obter o funcionamento mais fiável e econômico. Num poço real de 25 m de altura, em clima desértico e semi-árido, no local de Sebseb, Ghardaïa, Argélia, um sistema de bombagem fotovoltaico típico para fins de irrigação é estudado e optimizado utilizando dois métodos convencionais, um método P&O e um método incremental. Estes métodos baseiam-se essencialmente na avaliação das necessidades de água para irrigar.
With a territory made up of 86% Saharan desert and by its geographical positioning, the quality of Algerian solar radiation allows Algeria to rank among the three countries which have the best solar deposits in the world [1].

The duration of sunshine over almost the entire national territory exceeds 2000 hours annually and reaches 3700 hours (Sahara), with an average sunshine of 6.57kWh/m$^2$/day [2]. If we were to compare solar to natural gas, Algeria’s solar potential is equivalent to 8 times the country’s natural gas reserves, with the difference that solar potential is renewable, unlike natural gas [3].

Through the launch of an ambitious program for the development of renewable energies (EnR) and energy efficiency, Algeria has initiated a dynamic of green energy which is based on the development of inexhaustible resources to diversify sources of energy. Among the most important of these strategies is rural development which mainly relies on encouraging programs related to PV pumping in arid and semi-arid areas [4].

Sizing and optimizing a solar pumping system is a crucial task. Thus, inappropriate and inconsiderate sizing can lead to the system either no longer being able to ensure the satisfaction of water demand, or an oversized system that is unreliable and uneconomical. The efficiency of the complete solar pumping system was of the order of 1-3% in 1981, and it increased to 3.5-5% in 1990. New techniques are currently being developed to achieve efficiencies above 5% [5][2].

In order to better adapt to variations in weather conditions (sunshine and temperature), most systems are equipped with algorithms for tracking the optimal operating point (MPPT: Maximum Power Point Tracking) of the PV panels and the possibility of operating loads at variable frequency [5][1].

This paper provides a comparative study between two conventional algorithms to extract the maximum energy from a solar panel. The algorithm determines the optimal configuration and the maximum electrical power of the PV array. A case study from Sebseb-Ghardaïa region in Algeria has been selected to
satisfy the water requirement to irrigate 3 hectares of agricultural land during the most critical months of the culture cycle vegetative, which runs from Jun to August.

The PWPS consists of PV panels, PS2-1800 C-SJ5-12 pump kit (pump and controller), storage tank and real-time data monitoring system. Figure 1 shows the principal components of the standalone PWPS.

2 OPTIMIZATION OF THE PWPS

A PV generator can operate in a wide range of output voltage and current but it can only deliver maximum power. In fact, the I(V) and P(V) characteristics of a PV generator depend on solar irradiance and temperature. These climatic variations cause the variation of the maximum power point. Because of this variation, a controlled static converter is often inserted between the generator and the receiver (pump motor) allowing the maximum power point to be pursued [6][7].

Figure 2. P-V characteristics and PPM trajectory

Source: Authors.
The block diagram of a solar generator with a DC-DC adaption stage between is shown in Figure 3.

![Figure 3. Block diagram of photovoltaic coupling with MPPT](image)

The MPPT control varies the duty cycle of the static converter, using an appropriate electrical signal, to extract the maximum power the PV generator can provide [8][9].

2.1 METHOD OF PERTURBATION AND OBSERVATION (P&O)

This is the most used method due to its simplicity. The voltage across the panels is deliberately disturbed (increased or decreased) with a constant (dV) then the power is compared to that obtained before disturbance. Precisely, if the power is increased due to the disturbance, the next disturbance is made in the same direction. Conversely, if the power decreases, the new disturbance is carried out in the opposite direction [10][11].

Table 1 summarizes the operating principle of the disturbance and observation method [12].

<table>
<thead>
<tr>
<th>Disturbance</th>
<th>Power change</th>
<th>Next disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td>Positive</td>
<td>Negative</td>
<td>Negative</td>
</tr>
<tr>
<td>Negative</td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Negative</td>
<td>Negative</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Source: Authors.

The "P&O" algorithm has limitations that reduce its effectiveness. When the sunlight intensity decreases, it is difficult for the MPPT to discern the location of the MPP. Another disadvantage of the "P&O" algorithm is that it cannot determine when it has really reached the MPP. At this time, it oscillates around the MPP,
changing the sign of the disturbance (dV) after each measurement of (dP). In addition, it has been shown that the "P&O" algorithm can have an erratic behavior under a rapid change in the level of insolation (passage of a mobile cloud). The algorithm will continue to move the operating point farther from the actual point of maximum power, and there will be more power wasted. This incorrect adjustment will continue until the change in illuminance slows down or stabilizes [13][14].

2.2. THE INCREMENTAL CONDUCTANCE (IC) METHOD

The conductance increment algorithm was developed to improve the algorithm (P&O) especially the oscillation problem around the MPP. The generator’s voltages and currents are measured so that the controller may calculate the conductance G=I/V and incremental conductance dG= dI/dV and determine its behavior. The derivative of power with respect to voltage is[15][16][17]:

$$\frac{dP}{dV} = I + V \frac{dI}{dV}$$

(1)

This leads to the following equations:

$$\begin{align*}
\frac{dI}{dV} &= -\frac{I}{V}, & \frac{dP}{dV} &= 0 & (a) \\
\frac{dI}{dV} &> -\frac{I}{V}, & \frac{dP}{dV} &> 0 & (b) \\
\frac{dI}{dV} &< -\frac{I}{V}, & \frac{dP}{dV} &< 0 & (c)
\end{align*}$$

(2)

The direction in which a disturbance must occur to move the operating point towards the MPP is determined using equations 1 and 2. This disruption is repeated until the equation 2.a is satisfied. When the MPP is achieved, the algorithm continues to use that value until the current value changes. The latter is caused by a change in the amount of sunlight. The MPP advances to the right of the working voltage as the insolation increases. The MPPT must boost the operating voltage to compensate for the MPP’s movement. In the contrary scenario, as indicated in the image, when the sunshine diminishes, the MPPT must decrease the latter as shown in the figure 4 [18][19].
Figure 4. Variation of $dP/dV$ in the characteristic PV

Figure 5 shows the algorithm's (IC) flowchart. $dI$ and $dV$ are calculated after measuring the PVG's $I_{PV}$ and $V_{PV}$. If $dV$ and $dI$ are both 0, the atmospheric conditions have not altered, and the MPPT is remained at MPP. The sunshine has increased if $dV=0$ and $dI>0$. In order to regain the MPP, the operating voltage must be increased.

Unlike if $dI<0$, the insolation has decreased while requiring the algorithm to decrease the operating voltage. If the change in voltage is not zero, the ratios in equations $2-b$ and $2-c$ can be used to determine the direction in which the voltage must be changed in order to achieve the MPP. If $(dI/dV) > (-I/V)$ (i.e. the ratio $(dP/dV) > 0$), then the operating point is to the left of the MPP. Thus, the operating voltage must be increased to reach the MPP.

Similarly, if $(dI/dV) < (-I/V)$ (i.e. the ratio $(dP/dV) < 0$), the operating point is to the right of the MPP, meaning that the voltage must be reduced to reach the MPP [20][21].
Table 2. Characteristics of PV panel and PVG under STC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PV Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{mp}$ (W)</td>
<td>213.15</td>
</tr>
<tr>
<td>$V_{oc}$ (V)</td>
<td>36.3</td>
</tr>
<tr>
<td>$I_{sc}$ (A)</td>
<td>7.84</td>
</tr>
<tr>
<td>$V_{mp}$ (V)</td>
<td>30.2</td>
</tr>
<tr>
<td>$I_{mp}$ (A)</td>
<td>7.05</td>
</tr>
<tr>
<td>Panel Efficiency</td>
<td>10.1%</td>
</tr>
<tr>
<td>Fill Factor</td>
<td>67.6%</td>
</tr>
<tr>
<td>$N_s$</td>
<td>1</td>
</tr>
<tr>
<td>$N_p$</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: Authors.

3 RESULTS

This section presents the different results of the optimization of the PWPS by the two algorithm MPPT (P&O and IC) for variable solar radiations and variable temperature. We evaluate these algorithms from aspects: speed, accuracy and ripple. We took $t = 2.5$ s to clearly show the transient state.

Figure 6. Optimized $P_{PV}$ with IC algorithm

Source: Authors.

Figure 7. Optimized $P_{PV}$ with P&O algorithm

Source: Authors.
Figure 8. Optimized $I_{PV}$ with IC algorithm

Source: Authors.

Figure 9. Optimized $I_{PV}$ with P&O algorithm

Source: Authors.

Figure 10. Optimized $V_{PV}$ with IC algorithm

Source: Authors.

Figure 11. Optimized $V_{PV}$ with P&O algorithm

Source: Authors.
Figure 12. Pumped water flow depending on solar radiation

Source: Authors.

Figure 13. Seasonally solar radiation

Source: Authors.

Figure 14. Seasonally cell temperature

Source: Authors.

Figure 15. Monthly average PV generator, controller – pump and total system efficiency (%)

Source: Authors.
P&O controller is very simple and can be carried out easily. A drawback of P&O algorithm is that, at steady state, the system’s operating point oscillates around the MPP giving rise to the waste of the available power compared to the IC method.

The results obtained show that both algorithms reach the MPPT, but IC reach the MPP faster than P&O with no oscillates around the MPP.

3 CONCLUSION

The purpose of the presented work is to develop a test bench for a PV pumping system PWPS, with the aim of increasing the efficiency of PV conversion and the control of this type of systems.

The objective was to test the performance of the proposed MPPT methods. For this, we used Matlab-Simulink, which allowed us to simulate the ‘P&O’ and ‘IC’ methods applied to a PWPS. These techniques have been tested in a steady state and during variations in solar radiations.

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