PSO-PI based Control of Photovoltaic Arrays

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ABSTRACT

In this work, we propose a new control law based on the combination between the Particle Swarm Optimization (PSO) method and the classical PI controller to extract the maximum power from a photovoltaic PV panel subject to partial shading. The photovoltaic PV panel has a nonlinear Power-Voltage (P-V) characteristic curve which is used in most controllers to find the Maximum Power Point (MPP). In the general case, a simple control law based on the P&O (Perturb and Observe) method is sufficient, but in cases where a partial shading is introduced or when the PV panel is subject to the soiling effect, the output power is highly affected by such disturbances and classical methods are unable to achieve maximum performance. In this paper a PSO based method is used to find the maximum power point in the case of shaded PV panels and the PI controller adjusts the performance of the system by reaching the reference value in less time and with minimum steady state error. Simulation results show the effectiveness of this method for the extraction of the maximum power available in the presence of different type of disturbances.

General Terms

Control Engineering, Solar Energy, Photovoltaic Panels.

Keywords

Particle Swarm Optimization (PSO), PSO-PI, Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Partial Shading.

1. INTRODUCTION

Although the increasing interest in research to improve the performance of Photovoltaic (PV) systems, there is a little work done so far on fault diagnosis of PV arrays. Mismatch, shading and soiling are some of the disturbances that affect the normal operation of the PV panel and reduce its life [1], [4], [11].

Many Maximum Power Point Tracking (MPPT) methods were developed to achieve a maximum power output in real-time. The “Perturb and Observe” (P&O) is a well-known method that is widely used in commercial controllers due to its good performance and simple implementation. The principal drawback of this method is the loss of power caused by the oscillations around the maximum power point (MPP) and its limitations at low irradiation [2]. The presence of shading or soiling is another problem that faces the control strategy and can’t be solved by the classical MPPT algorithms.

The PSO-based optimization algorithm is used to deal with the different disturbances that can affect the normal operation of the PV panel. The performance of this optimization algorithm is further improved by the introduction of a classical Proportional Integrator (PI) regulator that accelerates the rising time and eliminates the steady state error.

In the following Section we present the equivalent model of a PV panel and we develop the model of a PV array. The effect of shading on the PV array is discussed in the third section. The fourth section gives the details of the control strategy and the simulations results. Concluding remarks are given at the end.

2. MODEL OF A PV ARRAY

The Equivalent circuit of a PV cell is given in (Figure 1).

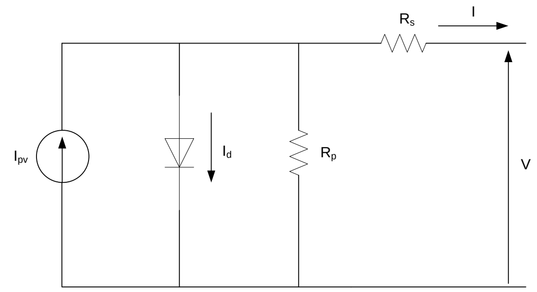

Figure 1: Equivalent circuit of a PV cell.

We adopted the one-diode model instead of the two-diode model because the steady state performance of the first one is accurate enough and the simulation cost is lower (faster convergence).

In (Figure 1) the controlled current source is dependent of the temperature and irradiation as follows:

$$I_{pv} = \left(I_{pv,n} + K_I \Delta_T\right)\frac{G}{G_n} \tag{1}$$

Where $I_{pv,n}$ is the nominal generated current (given at nominal conditions: $T=25°C$ and $G=1000\ W/m^2$), K_I is the short-circuit current/temperature coefficient, $\Delta_T = T\text{-}T_n$ (T and T_n are the current and nominal temperature), G and G_n are the current and nominal irradiation.

The current in the diode is given by:

$$I_d = I_0\left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] \qquad (2)$$

I_0 is the saturation current and is given as follows:

$$I_0 = \frac{I_{sc,n} + K_I \Delta_T}{\exp\left(\frac{V_{oc,n} + K_V \Delta_T}{a V_t}\right) - 1} \qquad (3)$$

Where $I_{sc,n}$ is the nominal short-circuit current, $V_{oc,n}$ is the nominal open circuit voltage (both parameters are given in the pv panel datasheet). K_V is the open-circuit voltage/temperature coefficient, a is a diode constant, V_t is the thermal voltage of the array: $V_t = N_s kT/q$, with N_s cells connected in series, k is the *Boltzmann* constant and q is the electron charge. R_s is the series resistance which depends on the material used to construct the cell and its effect is stronger in the voltage source operating region. R_p is the parallel resistance (R_{sh} in some references, for *shunt resistance*), its effect is stronger in the current source operating region.

Usually the values of R_s and R_p are not given in the datasheet of the pv panel, their values has to be identified online by iterative algorithms like the one developed in [8] or deduced from the technical data provided in the datasheet.

For a PV array with *Npp* parallel panels and *Nss* series panels the equivalent circuit is given in (Figure 2).

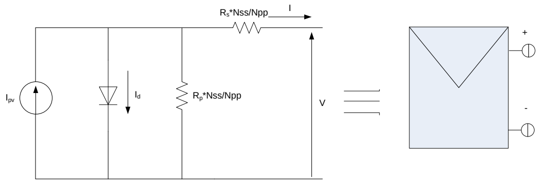

Figure 2: Equivalent circuit of a PV Panel.

The output current becomes then:

$$I = I_{pv} N_{pp} - I_0 N_{pp}\left[\exp\left(\frac{V + R_s \cdot \left(\frac{N_{ss}}{N_{pp}}\right) \cdot I}{V_t \cdot a \cdot N_{ss}}\right) - 1\right] - \frac{V + R_s\left(\frac{N_{ss}}{N_{pp}}\right) I}{R_p\left(\frac{N_{ss}}{N_{pp}}\right)}$$

Table 1 gives the parameters for the PV panel used in the following sections. Where *Iscn* is the short-circuit current at standard test conditions (STC) (25°C and 1000 W/m²), *Ipvn* is the nominal current of the photovoltaic panel, *Vocn* is the nominal open circuit voltage, *Ns* is the number of cells (in series) at each panel, *a* is a diode constant, *Ki* is the short-circuit current/temperature coefficient, *Kv* is the open-circuit voltage/temperature coefficient, *Npp* is the number of modules connected in parallel, *Nss* is the number of modules connected in series.

Table 1. PV Panel parameters.

Parameter	Value
Iscn	3.56A
Ipvn	3.8713A
Vocn	42.1V
Ns	72
a	1.3977
Ki	0.065 %/°C
Kv	0.080 V/°C
Npp	10
Nss	10

3. CONTROL OF ARRAYS WITH SHADED CELLS

A PV array is the combination of multiple PV panels connected in series and parallel, hence any fault in one PV panel will affect the performance of the overall PV array. This is why some research work considers the case where a small number of PV panels have their proper controller. In this work we consider that the PV array is composed of large number of PV panels and have a unique centralized controller due to the expensive cost of the proposed solution.

3.1 Controller Configuration

A DC/DC boost converter is used to obtain a high voltage at the output; the MPPT based on the PSO-PI method is used and compared with the classical P&O method. (Figure 3) illustrates the controller configuration. The parameters of the converter are given in (Table 2).

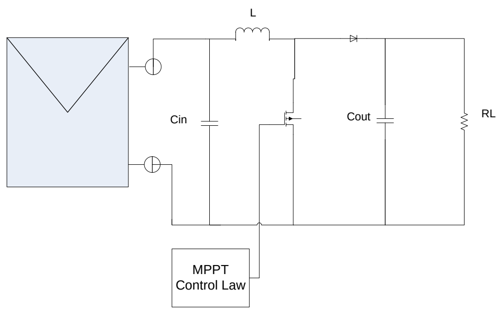

Figure 3: Controller Configuration.

Table 2. Boost converter parameters

Component	Value
Cin	478.6 uF
L	444 uH
Cout	154.69 uF
RL	24.3 Ohm

3.2 Control of the PV Array with Shaded Panels

As stated in [3]: mismatch, shading, soiling, cell degradation, different type of PV panels and cell heating have the same signature in the *I-V* characteristic. In this study, we consider the shading effect to represent all the other faults.

This type of disturbance is the most frequent because many of the PV arrays are placed in the presence of buildings and even when this is not the case, the soiling caused by the dust is more important in saharian regions.

The system depicted in (Figure 3) is modified to integrate the effect of shading, the resulted model is given is (Figure 4). The PV array is subject to partial shading, 3x10 of the panels are 70% shaded and 2x10 are 50% shaded the irradiation is 300W/m² and 500W/m² respectively, the rest of the panels are not shaded.

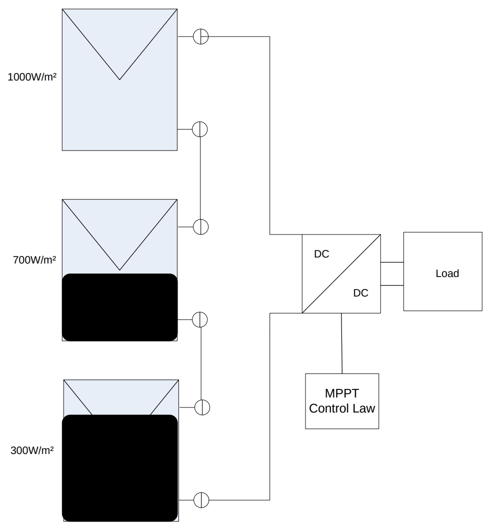

Figure 4: PV Array with partial shading.

The power-voltage curve of the photovoltaic array shows the effect of the partial shading on the system where multiple local maximum power points are present (see Figure 5).

Classical gradient-based MPPT algorithms begin the search process by scanning the P-V curve and when a maximum power point is found the controller keeps oscillating around it until a change in irradiation or temperature or other type of disturbances occurs.

The "Perturb & Observe" (P&O) algorithm is applied to the photovoltaic array subject to a partial shading presented earlier (see Figure 4). The results show the limitations of such control algorithm to extract the maximum power from the PV installation. The P-V curve and the output power obtained in this case are given (see Figures 6 & 7).

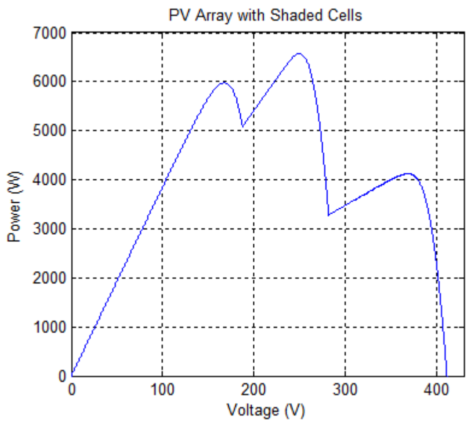

Figure 5: Power-Voltage (P-V) curve of the PV Array with partial shading.

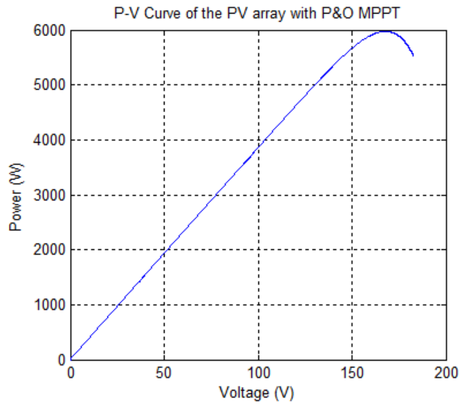

Figure 6: Power-Voltage curve of the shaded PV array with P&O MPPT algorithm.

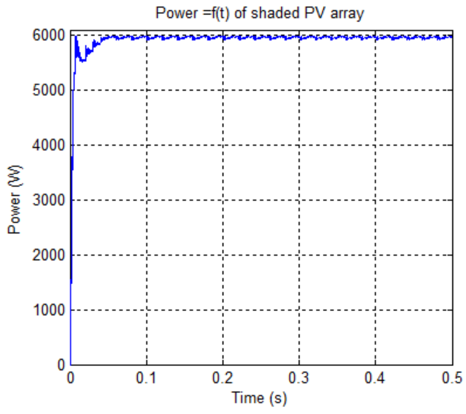

Figure 7: Power curve of the shaded PV array with P&O MPPT algorithm.

3.3 Particle Swarm Optimization (PSO) MPPT Algorithm

The PSO method is well known for the optimization of complex problems with multivariable objective function. This method is also effective in the case of the presence of multiple local maximum power points. The PSO algorithm is based on the cooperation of multiple agents that exchange information obtained in their respective search process [7].

The movement of agents is governed with the following equations:

$$v_i^{k+1} = w \cdot v_i^k + c_1 \cdot r_1 \cdot pbest_i + c_2 \cdot r_2 \cdot gbest \quad (5)$$

$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (6)$$

Where: w is a learning factor; c_1 and c_2 are positive constants; r_1 and r_2 are the normalized random numbers and are in the range [0 1]; $pbest_i$ is the best position that the i^{th} agent has found so far by evaluating the objective function; *gbest* is the best position of all agents.

In our case we take the agents to represent the reference current i_{ref} that is used to control the boost dc/dc converter as follows:

$$s^k = \left[iref_1^k \quad iref_2^k \quad .... \quad iref_n^k \right] \quad (7)$$

Where n represents the size of the swarm (the number of agents). The objective function used in this work is the measure of power delivered by the PV array.

$$f\left(s^k\right) = P_{PV}^k \quad (8)$$

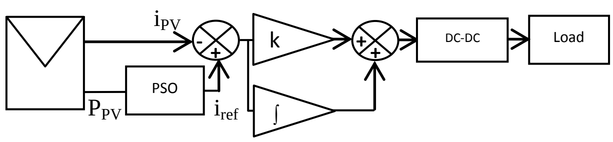

Figure 8: PSO-PI Based control architecture.

The control strategy used in this work is illustrated in Figure 8 the PSO algorithm gives the reference value of the current that is tracked using the PI controller to accelerate the response and eliminate the error between the actual value and the reference given by the PSO optimization algorithm.

The final result of the output power produced from the PV array in the presence of partial shading is given (see Figure 9). The control algorithm bypasses the first local maximum and extracts the maximum power available by reaching the global maximum.

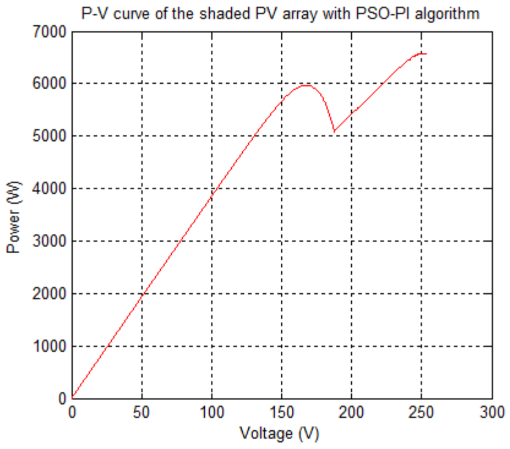

Figure 9: Power-Voltage curve of the shaded PV array with the PSO-PI algorithm.

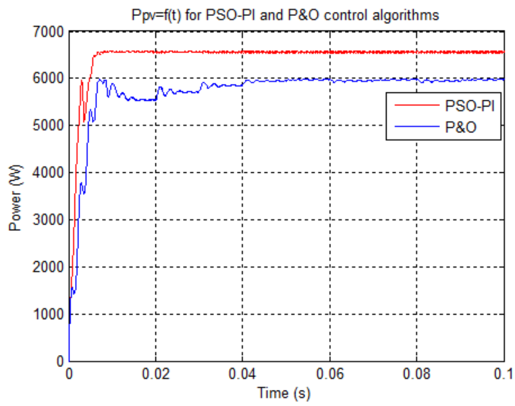

Figure 10: Power curve of the shaded PV array with the PSO-PI algorithm.

The performance of the PSO-PI based method is far better than the classical P&O algorithm; the global MPP is reached with better performance in terms of step response time and steady state value. The evolution of the particles of the swarm is presented (see Figure 11), and the last position is presented in Figure 12; most of the agents converge at the optimal value, the rest investigate other choices in the case of the presence of disturbances.

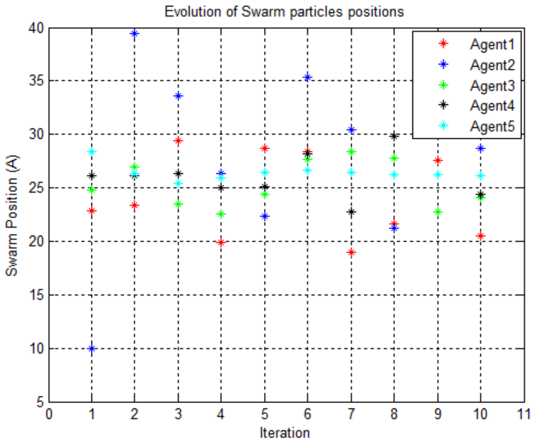

Figure 11: Evolution of particle swarm's position for each iteration.

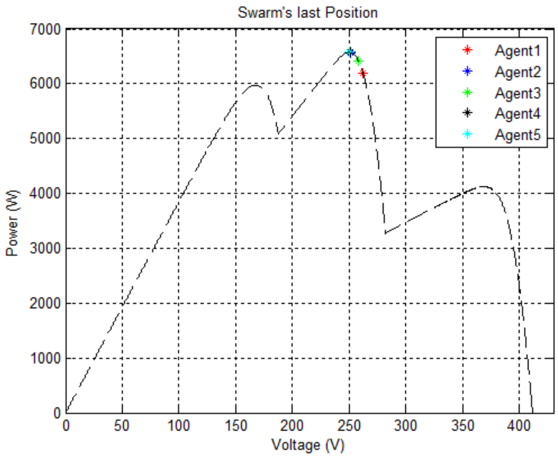

Figure 12: Swarm's last position in the *P-V* curve.

4. CONCLUSION

The *P-V* curve is an important tool for the study of the different faults that occur in any PV installation. In this study we proposed a method based on a metaheuristic algorithm that uses a swarm of particles to find the optimal operating point of the PV array the reference value is then tracked using a PI controller to achieve less response time and eliminate the steady state error. The simulation results show the effectiveness of the MPPT control strategy in the case of the presence of the partial shading effect. The proposed method is useful also in the case of shading-like faults (mismatch, soiling…). The performance of the algorithm is improved compared with the classical P&O algorithm.

5. REFERENCES

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