A PSO-based Technique for Partial Shading Detection for PV systems

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Abstract—Partial shading effect causes a loss of power yield in PV generators. If one of the series connected modules is partially shaded, it operates as a load for other modules and is reversed biased. This module will then dissipate energy rather than generate it, hence leading to a module temperature rise. In this paper, a novel study is proposed based on a PSO concept in order to detect the partial shading effect and obtain the maximum power point (MPP). The obtained results show the effectiveness of the proposed technique.

Keywords — Partial shading effect, Photovoltaic system, PSO, MPPT.

I. INTRODUCTION

Partial shading is an unavoidable effect that causes a loss of power yield in many photovoltaic systems [01]. When connecting PV cells/modules in series, the current that flows through them is controlled by the cell/module that has the lower photo current $i_{ph}$. If one of the PV cells/modules is partially shaded, it operates as a load for other cells and is reversed biased. This cell/module will then dissipate energy rather than generate it, hence leading to a cell/module temperature rise. If the temperature is too high (Hotspot), the cell/module can be damaged and affect the whole PV module/array. To avoid Hotspots, manufacturers put bypass diodes across a set of PV cells, mostly 18 cells [02]. Hotspots can also be happened when PV modules with different open circuit voltages are connected in parallel, e.g., when one of the PV modules in parallel is shaded. In this situation, the PV module with lower open circuit voltage may behave as a load and consumes power generated by others. This PV module can be damaged if the temperature is too high. To avoid this problem, blocking diodes are sometimes connected in series with PV modules.

Under partial shading condition, the P-V characteristic shows multiple peaks. Generally, the global maximum output power in this case is about 56.2% of the maximum power of the PV array under uniform full illumination. Moreover, in some MPPT-based systems, algorithm fail to identify the
global maximum power point and work at one of the local maxima, which may affect seriously the power yield.

The shading condition could be more complicated in practical photovoltaic applications. This generally makes it difficult to perform an accurate maximum power point tracking [03].

In the paper, a PSO-based algorithm is developed in order to minimize the effect of partial shading. This algorithm is capable of identifying and track the global maximum power point.

II. PHOTOVOLTAIC SYSTEM

An efficient configuration suitable for medium to large scaled photovoltaic plant is described in [04]. This configuration is adopted and used in this study. Each PV module or string of modules has its own DC-DC converter with MPPT controller and feeds its power into a common DC link to be inverted into AC through a central inverter as illustrated in figure 1. In this way, the maximum power can be extracted from each PV string, and therefore, the overall power yield from the whole PV system can be maximized.

As the studied system is composed of three series connected modules with three bypass diodes, each scenario consists of the three different irradiance values. Figure 2 shows the GMPP voltage bands at different temperature values. We notice that the GMPP voltage can be located only at one of the three bands. The number of bands depends on the bypass diodes.
When the temperature increases, the bands move downwards, and when it decreases, the bands slide upwards. The obtained results are very useful as they help in improving the MPPT techniques under partial shading conditions. To find the GMPP, conventional MPPT techniques scan the full voltage range when a shading effect is detected. The scanning process is a time-consuming task, and minimizing this time will surely improve the MPPT time response. In other MPPT techniques, which are based on intelligent algorithms, initial conditions are required, and choosing the right ones leads to a rapid convergence towards the target \[05\]. Knowing the location and number of GMPP voltage bands in our system will help us to select the right number of bounded values for the initial conditions.

In our paper, a PSO-based MPPT algorithm is used to track the GMPP.

### A. PSO-based MPPT Technique

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling \[06\]. Due to its rapid convergence, simple structure, fast computation ability and ease of implementation, PSO technique has been studied by several researchers for MPPT application \[07\][08][09].
The PSO concept consists of initializing with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values: The first one is the best solution it has achieved so far and is called Pbest. The second "best" value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the population. This best value is a global best and is called Gbest [06].

After finding the two best values, the particle updates its velocity and positions with equations (a) and (b):

\[
v_{i}(k+1) = w v_{i}(k) + c_1 r_1 (P_{(best,i)} - x_{i}(k)) + c_2 r_2 (G_{best} - x_{i}(k)) \quad (a)
\]
\[
x_{i}(k+1) = x_{i}(k) + v_{i}(k+1) \quad (b)
\]

Where the velocity component, \(v_i\), represents the step size, \(w\) is the inertia weight. \(c_1\) and \(c_2\) are learning factors. \(r_1\) and \(r_2\) are random number between (0,1). Pbest and Gbest are defined as stated before.

**The pseudo code of the procedure is as follows**

```
For each particle
  Initialize particle
End
Do
  For each particle
    Calculate fitness value
    If the fitness value is better than the best fitness value (PBest) in history
      Set current value as the new PBest
    End
    Choose the particle with the best fitness value of all the particles as the GBest
    For each particle
      Calculate particle velocity according equation (IV.4)
      Update particle position according equation (IV.5)
    End
  Repeat while maximum iterations or minimum error criteria is not attained
```

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IV. SIMULATION AND RESULTS

To clarify how conventional MPPT techniques perform under shading conditions, a simulation has been conducted using P&O-based algorithm with voltage regulation loop [10].

During the simulation the system will experience a testing scenario in which the three PV-modules are subjected to different changing irradiances at a fixed temperature (T=25°C) as shown in Figure 3.

The scenario is chosen in this way in order to see how MPPT algorithms perform when the P-V characteristic changes its form due to the variation of meteorological conditions.

The first P-V characteristic, plotted in red line, is experienced during the first 10 milliseconds, when the first PV array is under 700 W/m², the second is under 1000 W/m² and the third is under 400 W/m². Three local maxims can be identified, and the global maximum is in the middle of them.

During the second 10 milliseconds, the three PV arrays are at 1000 W/m², 700 W/m² and 1000 W/m² respectively. The resulting P-V characteristic is plotted in the bottom of Figure 3, and numbered with “2”. In this case, only two maxima are identified, and the global maximum is in the left.

During the last 10 milliseconds, the three PV arrays are at 400 W/m², 1000 W/m² and 1000 W/m² respectively. The resulting P-V characteristic is plotted in the bottom of Figure 3, and numbered with “3”. Two maxima can be recognized, and the global maximum is in the right.

![Figure 3 Testing scenario (T=25°C)](image-url)
Figure 4 presents the results of the P&O-based algorithm with voltage regulation loop under partial shading conditions. The initial condition of the reference voltage is set at 50V. Hence, the P&O algorithm starts searching for the MPP in the region around the 50V, and then it reaches the local maximum at around 58V.

Power at this point is about 114W. When the PV...
characteristic changed (at $t=0.01s$) the PV voltage shifted a little bit to catch again the new MPP which represents, in this time, the global maximum with about 194W. A while after (at $t=0.02s$), the PV characteristic has changed over again, and the algorithm stuck at another the local maximum with 115W.

Figure 4- P&O with voltage regulation loop: Waveforms of $V_{pv}$, $I_{pv}$, $P_{pv}$ and the duty cycle of 03 series-connected panels under partial shading conditions ($V_{PV,\text{INITIAL}}=50V$)

When the initial condition is set at 30V as in Error! Reference source not found., the algorithm stuck at the MPP in the region around 35V. The power at this point, matches the global maximum, and is about 121W. As soon as the characteristic changed, the algorithm moved to new local maximum, and the same thing happened during the second transition.
From the results obtained in Figure 4 and Figure 5 one can conclude that P&O algorithm is not capable of identifying and tracking the global maximum. It catches only the maximum power of the region in which it was started.

*Figure 5- P&O with voltage regulation loop: Waveforms of Vpv,Ipv, Ppv and the duty cycle of 03 series-connected panels under partial shading conditions (VPV\_INITIAL =30V)*

The P&O algorithm can perform well if it is used with another algorithm that is able to identify the Global Maximum Power Point (GMPP) region, whenever the environmental conditions changed, and then initiate the P&O algorithm.

Identifying global maximum region requires a good knowledge of the PV characteristic behavior under partial shading effect. For this purpose, this paper is devoted to the analysis of the PV characteristic under partial shading conditions.
A. Maximum-power Voltage Bands

The idea of voltage band was first proposed and analyzed by N. Gokmen et al [11]. Soon afterwards, it was used and verified in [12]. It states that the global maximum power point can be tracked by considering only the possible voltage bands, which depend on the number of bypass diodes. To find the voltage bands of our system, 1000 partial shading scenarios are generated between 100 and 1000 W/m2 irradiance, and with a step of 100W/m2. The system was tested at T=25°C, -15°C, and 60 °C.

Figure 2 VPmax bands of 03 PV panels under partial shading conditions at T= 25 °C, T= -15 °C, and T= 60 °C for 1000 different scenarios

As the studied system is composed of three series connected modules with three bypass diodes, each scenario consists of the three different irradiance values. Figure 2 shows the GMPP voltage bands at different temperature values.

We notice that the GMPP voltage can be located only at one of the three bands. The number of bands depends on the bypass diodes. When the temperature increases, the bands move downwards, and when it decreases, the bands slide upwards.

The obtained results are very useful as they help in improving the MPPT techniques under partial shading conditions. To find the GMPP, conventional MPPT techniques scan the full voltage range when a shading effect is detected. The scanning process is a time-consuming task, and minimizing this time will surely improve the MPPT time response.

In other MPPT techniques, which are based on intelligent algorithms, initial conditions are required, and choosing the right ones leads to a rapid convergence towards the target [05]. Knowing the location and number of GMPP voltage bands in our system will help us to select the right number of bounded values for the initial conditions.

In this paper, a PSO-based MPPT algorithm is used to track the GMPP.

Using the results obtained by analyzing the PV characteristic under partial shading conditions in, the swarm is chosen to be composed of three (03) particles. The initial value of each particle is selected to be the minimal value the GMPP voltage can take in each band.

Figure 7 illustrates the progress of the particles during the simulation. It can be seen that convergence is each time achieved in less than 2.5 ms.

Comparing with the previous studied MPPT techniques, the PSO algorithm appears as one of the most powerful algorithms that can perform very efficiently under both uniform and partial shading conditions.
Figure 6 shows the curves obtained by PSO-based algorithm. One can observe that whenever there is a change in the PV characteristic due to partial shading effect, the algorithm succeeded in identifying the GMPP in short time.

Figure 6 PSO with voltage regulation loop: Waveforms of $V_{pv}$, $I_{pv}$, $P_{pv}$ and the duty cycle of 03 series-connected panels under partial shading conditions

Figure 6 illustrates the progress of the particles during the simulation. It can be seen that convergence is each time achieved in less than 2.5 ms.

Comparing with the previous studied MPPT techniques, the PSO algorithm appears as one of the most powerful algorithms that can perform very efficiently under both uniform and partial shading conditions.
V. CONCLUSIONS

In this paper, a novel MPPT technique was investigated and tested under partial shading effect. Under shading conditions, a classical P&O could not track the Global Maximum Power Point (GMPP), and therefore other intelligent technique was used instead: PSO-based algorithm.

The obtained results were very satisfactory in terms of detecting the GMPP and tracking speed.

REFERENCES