Enhancement of Extracted Power from Photovoltaic Systems Through Accelerated Particle Swarm Optimisation Based MPPT

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Abstract. This paper presents a maximum power point tracking (MPPT) technique for photovoltaic (PV) system based on accelerated particle swarm optimisation (APSO) algorithm. The main purpose is to handle the multi-modal P-V characteristic curve under partial shading conditions. The APSO based MPPT has the advantages to be simple and accurate to track the global maximum power point (GMPP) under severe partial shading patterns. The simulation results have shown that the proposed technique can find the GMPP with high speed and efficiency and presents good dynamic behaviour. In addition, this technique is superior than the conventional Perturb and Observe (P&O) based MPPT in global peak tracking.

Keywords: Maximum power point tracking (MPPT) · Accelerated particle swarm optimisation (APSO) · Partial shading conditions · Photovoltaic (PV) system

1 Introduction

Solar photovoltaic energy is an important renewable energy that can be an alternative to other conventional sources of energy in order to meet the large energy demands in the future [1]. An important feature of photovoltaic panels is that the maximum available power is provided only at a single operating point, located by a known voltage and current, called the maximum power point. The problem is that the position of this point is not fixed but it changes according to the solar irradiance and temperature of the solar cells as well as the load. Because of the relatively expensive cost of this kind of energy, we must extract the maximum available power from the photovoltaic panels.

The photovoltaic module is an association of solar cells. When one or more cells of a PV module are illuminated differently from others cells (partial shading), a degraded behaviour appears for the latter. The cells receiving less energy must dissipate the

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surplus of the current delivered by those who are most enlightened, thus creating local heating up to the destruction of a part of the PV module if the defect persists. To protect the photovoltaic cells, a bypass diode is connected in parallel to the terminals of an elementary group of cells in series. When the photovoltaic panel is subjected to uniform irradiance conditions, the P-V characteristic is uni-modal and characterized by a single maximum power point. This situation is still not guaranteed and the photovoltaic panel is often subject to partially shaded conditions. Under these conditions, multiple peak power points appear on the P-V characteristic, several local maximum power points (LMPPs), and one global maximum power point (GMPP). The conventional maximum power point tracking (MPPT) techniques do not perform well under these conditions. For this, several improved techniques are proposed to take into account the multimodal character of the P-V characteristic curve in the presence of partial shading [2].

Due to their ability to handle multi-modal functions, swarm-intelligence-based algorithms, including particle swarm optimisation (PSO) [3], ant colony optimisation (ACO) [4], differential evolution (DE) [5], bat algorithm (BA) [6], cuckoo search (CS) [7] are proposed to tracks the GMPP. The PSO technique is proposed for MPPT by many researchers thanks to its simple structure and high accuracy to find the global MPP under partial shading condition. [3, 8] employed the conventional PSO whereas [9–11] proposed improved versions of this technique. For instance, [9] proposed a deterministic PSO where the stochastic factors are removed, which make the MPPT simpler. [10, 11] adopted adaptive PSO variants in order to enhance the tracking speed and the accuracy of GMPP tracking. Indeed, the control parameter are updated linearly according to iteration in [10] and with exponential form in [11]. In the basic variants of particle swarm optimization algorithm, the movements of the particles are guided by both their own best location and the global swarm's best known position. One of the reasons for using the individual best position is probably to increase the diversity in the quality solutions; however, this diversity can be simulated using some randomness. Subsequently, there is no compelling reason for using the individual best location unless the optimization problem of interest is highly nonlinear and multimodal. Yang [12] developed the so called accelerated particle swarm optimization (APSO), a simplified version that could accelerate the convergence toward the optimum using only the global best. Furthermore, the update strategy of particles doesn't use the velocity, and therefore, the APSO is much simpler to implement than the standard PSO algorithm.

The remainder of this paper is structured as follows. Section 2 presents the modelling of the photovoltaic panel and the P-V characteristic under uniform and partial shading condition. Section 3 gives a brief introduction of P&O and PSO algorithm followed by the description of the APSO technique. Section 4 shows the performance of the APSO algorithm under static and dynamic partial shading conditions. Finally, a conclusion is made in Sect. 5.

2 Modelling of the Photovoltaic System

The equivalent circuit of a photovoltaic cell is shown in Fig. 1. It includes a current source, two diodes D1 and D2, a series resistance R_s and a shunt resistance R_p. The photovoltaic module is composed of several photovoltaic cells connected in series. Based on the circuit, the current generated by the photovoltaic module can be presented by the following equation.

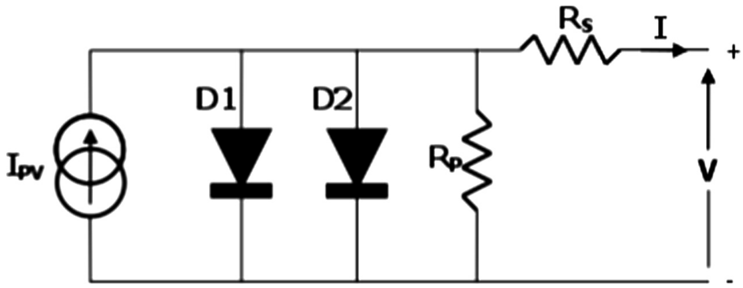

Fig. 1. Equivalent circuit of a solar cell.

$$I = I_{PV} - I_{01}\left[\exp\left(\frac{q(V + IR_sN_s)}{a_1kTN_s}\right) - 1\right] - I_{02}\left[\exp\left(\frac{q(V + IR_sN_s)}{a_2kTN_s}\right) - 1\right] - \left(\frac{V + IR_sN_s}{R_PN_s}\right) \tag{1}$$

In this equation, I_{PV} is the photo-current of the module, I_{01} and I_{02} are the inverse saturation currents of the diode D1 and D2, respectively. The parameters q, a_1, a_2, k and T respectively denote the charge of the electron, the ideality factor of the diode D1, factor of ideality of the diode D2, Boltzmann constant and the temperature of the cell. V is the voltage at the terminals of the PV module whereas I is the current of the cell.

Figure 2 shows the influence of solar irradiance on the P-V characteristic curve of three PV modules connected in series. Under uniform conditions, the P-V characteristic curve is uni-modal and has a single maximum power point. In practice, shadows are often projected on portions of the PV panel at a time of day, which could be caused by dust, clouds, trees, buildings or other objects around. When the photovoltaic panel is subjected to partially shaded conditions, irregularities appear on the P-V characteristic curve. Figure 2 shows the magnitude of the power deficit that can be caused by two partial shading patterns as well as the possibility of occurrence of several local power maxima.

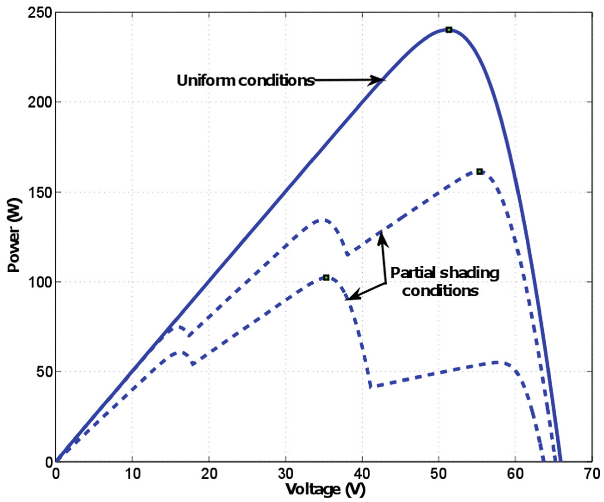

Fig. 2. P-V characteristics of PV panel under uniform and partial shading conditions.

3 APSO Based MPPT Controller

3.1 Conventional P&O Method

Fixed perturbation size based perturb and observation (P&O) method is the most popular MPPT algorithm due to its simplicity and easy implementation opportunity. The algorithm starts by sensing voltage or current from the PV array. Then it provides a perturbation in one direction by using either voltage (V) or current (I) or duty cycle (d). If the perturbation results in an increase in PV power increases in that direction, then the P&O algorithm will provide another perturbation in the same direction and continues to do so as the power keeps increasing. On the other hand if the change of power is negative, then the algorithm alters direction and provides perturbation in the opposite direction.

3.2 Particle Swarm Optimisation (PSO)

Particle swarm optimization (PSO) is a population based meta-heuristic which was developed by Kennedy and Eberhart in 1995. This technique is based on swarm behaviour in nature, such as fish and bird schooling. The PSO algorithm works on a population of agents called particles. To apply the PSO algorithm, it is necessary to define a search space consisting of particles and an objective function to optimize. The principle of the algorithm is to move these particles so that they find the optimum. Each of these particles has a position, a velocity and a neighbourhood. The position changes according to the particle best neighbour, the particle best position, and particle previous position.

At each iteration, the new particles in the swarm are determined taking into account their best positions and the best particle in the swarm. The new velocity of the particle *i* is calculated from the following equation:

$$v_i^{k+1} = \omega v_i^k + c_1 r_1 \left(Pbest_i - x_i^k\right) + c_2 r_2 \left(Gbest - x_i^k\right) \tag{2}$$

where: v_i^{k+1} and v_i^k are velocities of particle *i* at iteration $k+1$ and k, $Pbest_i$ is the best position of particle i, *Gbest* is the best particle of the swarm, d_i^k is the position of particle *i* at iteration *k*. ω, c_1, c_2 are constant parameters. r_1, r_2 are uniform random numbers generated in $[0, 1]$ at each iteration.

The new positions are calculated according to the equation:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{3}$$

3.3 Accelerated Particle Swarm Optimisation (APSO)

The standard particle swarm optimization uses both the current global best Gbest and the individual best particles $Pbest_i$. However, this diversity can be simulated using some randomness. A simplified version that could accelerate the convergence of the algorithm toward the GMPP is to use only the global best. Therefore, the accelerated particle swarm optimization (APSO) algorithm was developed by Xin-She Yang. In the standard APSO, the velocity vector is generated by a simpler formula

$$v_i^{k+1} = v_i^k + \alpha(\varepsilon - 1/2) + \beta\left(Gbest - x_i^k\right) \tag{4}$$

where $\boldsymbol{\varepsilon}$ is a random variable with values from 0 to 1. We can also use a standard normal distribution, where ε_t is drawn from $N(0, 1)$ to replace the second term. Now we have

$$v_i^{k+1} = v_i^k + \beta\left(Gbest - x_i^k\right) + \alpha\, \varepsilon_t \tag{5}$$

The update of the position is the same as Eq. 3. However, we can see later that the velocity is redundant in accelerated PSO. In order to increase the convergence even further, we can also write the update of the location in a single step

$$x_i^{k+1} = (1 - \beta)x_i^k + \beta\, Gbest + \alpha\, \varepsilon_t \tag{6}$$

This simpler version will give the same order of convergence. It is worth pointing out that the velocity does not appear in Eq. 6, and thus there is no need to deal with the initialization of velocity vectors. Therefore, the APSO is much simpler to implement for MPPT.

4 Simulations

Figure 3 presents the Block diagram of the simulated PV system. The architecture of the PV system is built in MATLAB/Simulink in order to assess the effectiveness of the proposed algorithm. The duty cycle of the PWM signal is chosen to be the optimization variable. Thus, it is adjusted directly by the MPPT controller. Three particles are used and the algorithm continues the optimisation process until constraint on convergence is satisfied. The condition shown in the Eq. 7 is used as a convergence criterion.

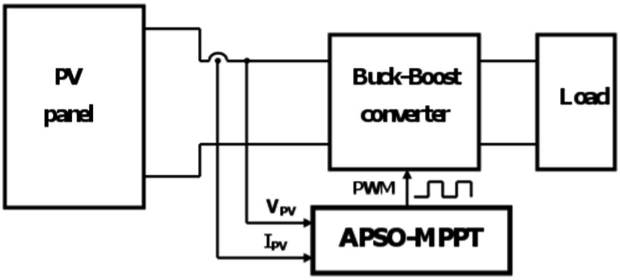

Fig. 3. Schematic diagram of the PV system.

$$\left|x_i^{k+1} - x_j^{k+1}\right| \leq \Delta x;\ i,j = 1,2,3;\ i \neq j \tag{7}$$

Due to varying weather and loading conditions, the global MPP is usually changing. The MPPT algorithm should have the ability to detect the variation of shading pattern and to search for the new global MPP. The search process is initialised when the following condition is satisfied

$$\frac{|P_{PVnew} - P_{PVlast}|}{P_{PVlast}} > \Delta P \tag{8}$$

In order to test and describe our proposed technique, firstly three static controversial conditions are selected and simulated. The PV array is composed of five modules connected in series arrangement.

The performance of the proposed technique is tested under the first condition. Figure 4 shows the output P-V characteristic curve of the PV panel along with the detailed simulation results of the proposed APSO method. The P-V curve is characterised by four MPPs. It is clearly observed that the APSO technique can ignore the local peaks and has converged accurately the GMPP.

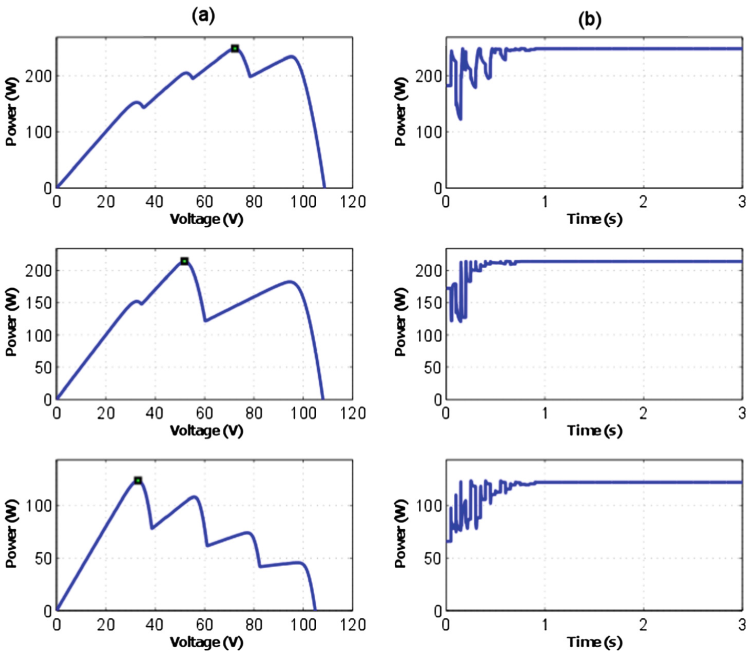

Fig. 4. APSO tracking results under different partial shading patterns.

For further verification, the system is tested under partial shading conditions. In this case, the first and second modules receive an equally distributed irradiance level of 1000 W/m^2, the third module receives irradiance level of 850 W/m^2 whereas the firth and fifth modules receives irradiance level of 400 W/m^2. In this case, the P-V characteristic curve contains three power peaks and the GMPP is located in the middle between the two local peaks. Most conventional MPPT methods cannot find the actual GMPP in such conditions and are normally trapped in the first MPP, which is not obviously the real GMPP. Thus, the efficiency of the PV systems drops dramatically. Figure 4 shows the simulation result of the proposed APSO technique applied to the second condition. The actual maximum power of the system is found and the operating point is maintained around the optimum voltage.

In the third shading pattern, the GMPP is located at left side of the P-V curve. In this condition, the PV panel is exposed to severe partial shading. Figure 4 presents the corresponding P-V characteristic and the power tracking results. The simulated power locus proves that the controller accurately tracked the actual GMPP.

Figures 5 and 6 asses the dynamic tracking capability of the proposed technique. Figure 5 shows the changing sequence of the test shading patterns. Figure 6 shows the measured waveforms for the dynamic tracking test. From Fig. 6, the proposed algorithm successfully detects the change in shading pattern and reinitializes the MPPT process accordingly. We can notice that the proper GMPP is captured accurately. On the other side, Fig. 6 reports also the results of tracking for the conventional P&O algorithm. It is clear that the P&O could not differentiate between the LMPPs and GMPP and get trapped in a LMPP.

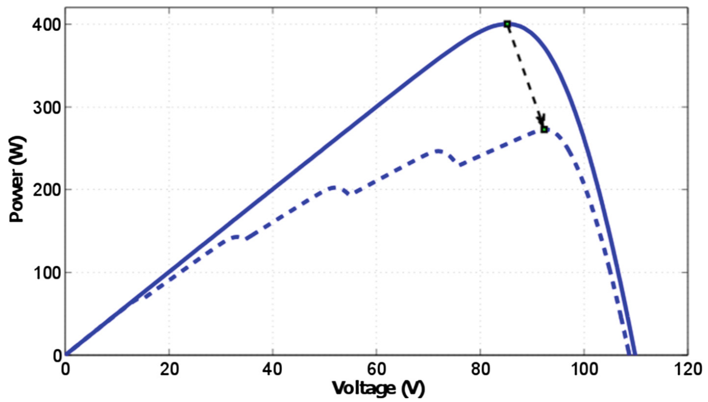

Fig. 5. P-V curves used for the dynamic tracking test.

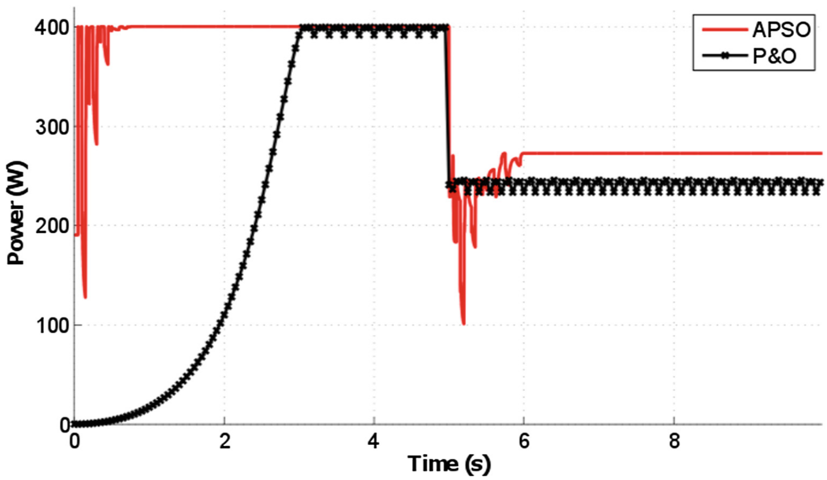

Fig. 6. Dynamic power tracking results for the proposed APSO and P&O techniques.

5 Conclusion

In this paper, the accelerated particle swarm optimisation (APSO) algorithm is proposed to track the GMPP of PV systems under partially shaded conditions. Under such situation, the P-V characteristic curve exhibits multiples peaks and the conventional MPPT techniques like the P&O algorithm don't perform well. The performances of the APSO algorithm are verified by simulation under extreme partial shading configurations. Despite its simple structure, the APSO algorithm based MPPT can track the GMPP with high accuracy and presents a fast convergence.

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