Energy Conversion and Management 175 (2018) 151–163

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Particle swarm optimisation with adaptive mutation strategy for photovoltaic solar cell/module parameter extraction

Manel Merchaoui*, Anis Sakly, Mohamed Faouzi Mimouni

Electrical Department, National Engineering School of Monastir, University of Monastir, Tunisia

ARTICLE INFO

Keywords:
PSO
Adaptive mutation
Parameter extraction
Solar modules

ABSTRACT

Developing an accurate model for photovoltaic solar cell and module represents a challenge to improve the overall efficiency of the photovoltaic systems use. Parameter estimation of photovoltaic solar cell and module circuit model is a crucial task that is commonly transformed into an optimisation issue solved by metaheuristic algorithms. Among these algorithms, the particle swarm optimisation has gained great interest due to its structure simplicity and rapid response. However, its major disadvantage lies in the premature convergence. In an endeavour to deal with this problem, an improved mutated particle swarm optimisation algorithm with adaptive mutation strategy is proposed in this paper. The adaptive mutation is introduced to alleviate the premature convergence problem and ensure a suitable trade-off between the explorative and exploitative capabilities over the search process. The proposed algorithm is used to identify the optimal parameters of different photovoltaic models; single diode, double diode, and photovoltaic module. The performance of the used method is firstly evaluated on measured data reported in the literature. Then, the algorithm is tested based on measured data from the laboratory work and from the data sheet of different modules. Experimental results prove that the used algorithm achieves higher accuracy and provides the lowest root mean square error compared to other previously reported parameter extraction algorithms.

1. Introduction

The use of renewable energy, as an alternative to standard fossil-fuel, in electricity generation, is vigorously rising as a way to deal with the energy crisis circumstances. Among the diverse kinds of renewable energy resources, the solar energy is the most used for electricity generation all over the world. In fact, it presents a clean, sustainable, and eco-friendly energy resource to humanity.

The photovoltaic (PV) technology based on the conversion of solar energy to electrical power, has gained the interest of several researchers. In fact, the solar PV is an economic and inexhaustible energy source characterized by an easy maintenance [1]. The efficiency of the PV system is a paramount task to optimally exploit the converted energy. To ameliorate the performance of the PV system, an appropriate model of PV cells and modules is required. PV solar cell modelling consists of mathematically describing its non-linear (I-V) characteristic. In this context, several mathematical models have been provided by the literature. The most popular are based on the single and double diode models [2]. The single diode model (SDM) is commonly used in practice since it ensures the compromise between simplicity and accuracy. The double diode model (DDM) is more accurate, but requires an extensive range of computation. Regardless of the different types of models, the estimation of the PV model's optimal parameters is of crucial significance to design and simulate the optimal PV system behaviour [3].

Considering the great importance of the PV parameter estimation, different approaches have been established in the literature. These approaches have been classified into two common categories; analytical and numerical approaches. The first one is based on the information provided by the manufacturer's data sheet such as short-circuit current (I_{sc}), open circuit-voltage (V_{co}), and maximum power voltage and current (V_{mpp}, I_{mpp}) [4]. As the manufacturer provides information only at Standard Test Condition (STC), this approach remains inappropriate with regard to temperature and irradiation variation. In addition, the analytical methods commonly introduce simplifying assumptions that decrease the model accuracy and lead to improper parameter evaluation [5].

The numerical approach is based on curve fitting through non-linear optimisation algorithms regardless of climatic conditions. These optimisation algorithms may be organised into two categories: conventional or iterative and metaheuristic optimisation methods. To be appropriate for use, the conventional methods, such as Newton-Raphson technique [6] and Levenberg-Marquardt technique [7], require

* Corresponding author.
E-mail address: merchaouimanel@hotmail.fr (M. Merchaoui).

https://doi.org/10.1016/j.enconman.2018.08.081
Received 3 April 2018; Received in revised form 27 June 2018; Accepted 22 August 2018

convexity, continuity and differentiability, resulting in a wide range of computation. Moreover, the iterative methods often trap into local optima when the initialisation is far from the optimal parameters, as the reliability of the evaluated model is vigorously sensitive to parameters' initialisation.

Recently, metaheuristic optimisation methods have drawn significant interest toward PV parameter extraction problems to overcome the drawbacks of analytical and iterative techniques. In fact, they are characterised by their global search process to avoid leading to local optimum and their ability to handle non-linear problems without gradient calculation and initialisation constraints. Among the commonly used evolutionary algorithms (EAs): the Genetic Algorithm (GA) [8], the Pattern Search (PS) [9], the Simulated Annealing (SA) [10], the Bird Mating (BM) [11], the Artificial Bee Swarm Optimisation (ABSO) [12], and the Particle Swarm Optimisation (PSO) [13]. In case of the GA, significant shortcomings have been identified including low speed convergence due to enormous calculation effort, and degradation in efficiency for highly interactive fitness function [14]. Regarding the PS algorithm, if the chosen pattern is wrong, the algorithm can easily fall into premature convergence [9]. In case of the SA algorithm, the major issue is the trade-off between cooling schedules and matching temperature [10]. In Ref. [3] a mutative-scale parallel chaos optimisation algorithm is employed for PV model parameter estimation. In Ref. [15], Alam et al. utilised the Flower Pollination Algorithm (FPA) based solar cell and module parameter extraction. In [16] an enhanced variant of FPA was applied in this context. A hybrid algorithm based on FPA and Nelder-Mead simplex method is applied in [17] to improve the accuracy and convergence speed for PV model parameter estimation. Authors in [18], proposed an adaptive differential evolution algorithm to solve PV model parameter extraction. Five different variants of the Bacterial Foraging Algorithm (BFA) were developed, in [19], to identify the PV module parameters from nameplate data. In [20], an improved Jaya algorithm was developed to accurately extract the parameters of PV models. In [21], an imperialist competitive algorithm was used to extract the optimal parameter of the PV model.

The PSO algorithm is widely discussed and used for PV models parameters extraction. In fact, it is characterised by a simple structure, fast response and reduced number of tuning parameters. Ye et al. [22], used the PSO to evaluate the SDM and DDM solar cell parameters. In comparison with GA algorithm, the PSO has shown better performance with regard to the accuracy, complexity and convergence speed. The PSO algorithm is applied in [23] to estimate the parameters of a PV three diode model. However, as other metaheuristic algorithms, the major problem of the PSO lies in the premature convergence, so that the algorithm can converge to a local optimum resulting in a low quality solution. A great deal of effort has already been applied to alleviate the premature convergence of the PSO algorithm. In Ref. [24], the authors added a cluster analysis procedure to the PSO based extracting algorithm. However, this method is bulky enough and consumes more memory and time of computation as it memorises all the previous calculated data. An improved PSO algorithm with a modified inertia weight is applied in [25] for solar cell parameters extraction. In Ref. [26], authors employed Chaos Particle Swarm Optimisation to determine the unknown parameters of the SDM solar cell and module. The chaotic search process is required to reinitiate the particles when they are stagnated to improve the local and global search. To improve the search process, in Ref. [27], the author used a modified variant of PSO, where the acceleration coefficients and the inertia weight are varying with time to ameliorate the exploration and exploitation capabilities of the algorithm. However, this strategy may result in an inappropriate adjustment of the PSO parameters and lead to local convergence. In [28], to avoid possible premature convergence and improve the diversity of the swarm, the PSO algorithm with binary constraints is used to evaluate the diode ideality factor, shunt resistance and series resistance of the single diode model under varying environmental conditions.

The main contribution of this research is to propose an improved mutated PSO (MPSO) with adaptive mutation strategy to solve the PV parameter extraction problem. The main idea of the proposed MPSO is to ameliorate the explorative capability of the PSO algorithm to ensure the convergence to the global optimum. In this context, the mutation is important during the first generations, so that the algorithm may efficiently explore different areas of the search space and locate the region including the global optimum. Over the last generations, the mutation process decreases so that the PSO can perform a better exploitation capability. In this way, a suitable trade- off between the exploration and the exploitation phases of the PSO is achieved resulting in a high quality of the PV solar system modelling.

The remainder of the article is organised as follows. Section 2 briefly discuss PV models. The optimisation problem for PV parameter estimation is formulated in Section 3. Section 4 describes the standard PSO. In Section 5 the proposed mutated PSO is explained. Section 6 will discuss simulation and experimental results and the conclusion is presented in Section 7.

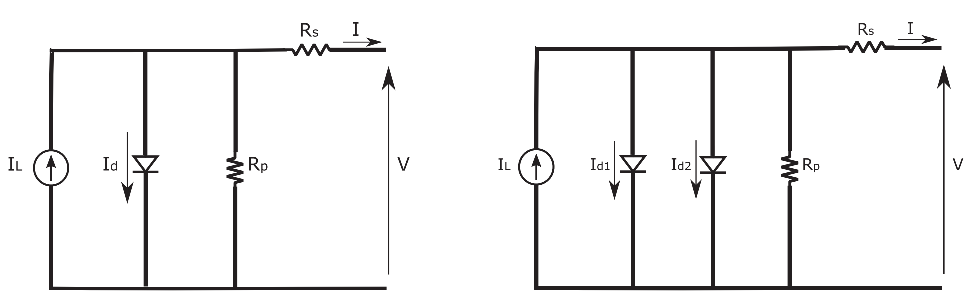
2. Solar photovoltaic modelling

The most commonly used models that illustrate the behaviour and the operation of the PV solar cells are the single and double diode lumped circuit models [16]. In this section, these models are briefly explained.

2.1. Single diode model

Under illumination and normal operating conditions, the single diode model (SDM) is commonly used for PV solar cell modelling. In fact, it guaranties the trade-off between accuracy and simplicity. The equivalent electrical circuit is illustrated in Fig. 1a. It contains an electric current source I_L associated in parallel with a diode, a shunt resistance R_p symbolising the leakage current and a series resistance R_s representing the ohmic losses and the material resistivity. According to this model, the output electric current is given by Eq. (1):

$$I = I_L - I_d - I_p \quad (1)$$



(a) Single Diode Model (SDM)

(b) Double diode model (DDM)

Fig. 1. PV solar cell modelling.