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Parameters extraction of the three diode model for the multi-crystalline solar cell/module using Moth-Flame Optimization Algorithm

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ABSTRACT

As a result of the wide prevalence of using the multi-crystalline silicon solar cells, an accurate mathematical model for these cells has become an important issue. Therefore, a three diode model is proposed as a more precise model to meet the relatively complicated physical behavior of the multi-crystalline silicon solar cells. The performance of this model is compared to the performance of both the double diode and the modified double diode models of the same cell/module. Therefore, there is a persistent need to keep searching for a more accurate optimization algorithm to estimate the more complicated models' parameters. Hence, a proper optimization algorithm which is called Moth-Flame Optimizer (MFO), is proposed as a new optimization algorithm for the parameter extraction process of the three tested models based on data measured at laboratory and other data reported at previous literature. To verify the performance of the suggested technique, its results are compared with the results of the most recent and powerful techniques in the literature such as Hybrid Evolutionary (DEIM) and Flower Pollination (FPA) algorithms. Furthermore, evaluation analysis is performed for the three algorithms of the selected models at different environmental conditions. The results show that, MFO algorithm achieves the least Root Mean Square Error (RMSE), Mean Bias Error (MBE), Absolute Error at the Maximum Power Point (AEMPP) and best Coefficient of Determination. In addition, MFO is reaching to the optimal solution with the shortest execution time when it is compared with the other tested algorithms.

1. Introduction

There are different types of the renewable energy resources, solar energy is the most important one due to its wide availability and its cleanliness. Solar energy is considered as an alternative solution to overcome the lack of the fossil fuels [1]. Therefore, the production of the photovoltaic cells has increased. Multi-crystalline solar cells in particular are widely used due to their low fabrication cost compared with the other types [2,3]. They are fabricated from a multi-crystalline silicon wafer which consists of single crystalline grains separated by grain boundaries with different crystallographic orientations [4,5]. The Losses in these cells are related to these grain boundaries, where the recombination is likely to take place [2,3,6–9]. Thus, introducing an accurate model which take into consideration the effect of the grain boundaries is a very essential target [10–12].

Generally, there are several mathematical models of PV solar cells that are starting from the simplest one which is the single diode model (SDM) and passing to the elaborated model such as the double diode model (DDM) until reaching to the more detailed models such as modified double diode (MDDM) and three diode (TDM). Utilizing more detailed models is an important aspect to deal with increasing the number of large PV installations especially at low irradiance conditions [13]. Furthermore, these detailed models are efficient in describing the physical behavior of the multi-crystalline silicon solar cells, because the effect of the grain boundaries, the carrier recombination and the leakage current are taken into account [10–14].

During the last decades, several optimization techniques for parameters identification of solar cell models have been proposed. These techniques can be classified into two categories; conventional and meta-heuristic algorithms. Some of the conventional techniques are presented in [15–17] for double diode model, for modified double diode model [12] and for three diode model [11]. However, these algorithms are time consuming and lose their ability to provide accurate solutions especially with the increased number of the estimated parameters [18]. Therefore, meta-heuristic algorithms are the alternative solution to overcome the problems of the conventional algorithms. The newest literature of the meta-heuristic algorithms for the parameters estimation process is as follows: In [19] Bacterial Foraging (BF) algorithm is

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applied under normal and shading condition. Generalized Oppositional Teaching Learning Based Optimization (GOTLBO) [20] is developed to accelerate the speed of conversion for the optimal solution. A Differential Evolution with Integrated Mutation per iteration (DEAM) [21] and Hybrid Evolutionary algorithm (DEIM) [22] have exhibited a good performance in terms of accuracy and CPU-execution time. Flower Pollination algorithm [1] has shown unnoticed deviation between the experimental and the estimated (I-V) curves specially at low solar irradiance levels. Furthermore, Mutative-scale Parallel Chaos Optimization algorithm (MPCOA) [23], Artificial Bee Colony algorithm (ABC) [24], Artificial Bee Swarm Optimization algorithm (ABSO) [25], Harmony Search-based algorithm (HS) [26] Simulated Annealing algorithm (SA) [27] and Pattern Search technique [28] are proposed to extract the parameters of SDM and DDM based on an experimental data presented in [29]. Genetic algorithm [30] is applied to extract the global optimal parameters for SDM and DDM. Moreover, in [31], Bird Mating technique (BM) is used to estimate the SDM parameters for PV solar array.

From the previous literature, it's observed that several recent researches are using the most common models such as SDM and DDM. The more complicated models such as MDDM and TDM are seldom used in the recent investigations to avoid estimating larger number of parameters. However, it has been proven in this study that these models are more efficient in dealing with the more complicated physical behavior of the multi-crystalline solar cell/module. Also, the researches which study the MDDM [12] and TDM [11] relied on conventional algorithms. This resulted in less accurate results in parameters extraction process and they consume a longer time. Therefore, a more efficient algorithm should be introduced to estimate the parameters of these complicated models with more accuracy and with minimum execution time.

In this paper, more complicated models such as MDDM and TDM beside DDM are investigated based on two sources of data. The first one is the experimental data reported at previous literature for multi-crystalline solar cell under different levels of irradiance [12]. The other one is an experimental data measured at the laboratory for multi-crystalline solar module under different levels of temperature and irradiance. A newest optimization algorithm which is called Moth-Flame Optimizer (MFO) is proposed to extract the required parameters of the three suggested models. MFO algorithm inspired from the navigation method of moths in nature called transverse orientation [32]. The performance of the introduced algorithm is compared to the recent and efficient algorithms in the literature such as DEIM [22] and FPA algorithms [1]. To assess its validation, an evaluation analysis which include root mean square error, mean bias error, absolute error at the maximum power point and coefficient of determination, is performed. The results demonstrate that FPA technique is resulted in fair accurate results with short execution time. The accuracy of DEIM algorithm was found to be also fair however the execution time was found to be three times that of the FPA algorithm. While, the MFO algorithm proved to be the most efficient optimization algorithm for the models' parameters estimation with both the accuracy and the execution time compared to the other mentioned algorithms. Therefore, it is adapted in this investigation. Consequently, this accurate modeling gives a better performance of the whole solar system design which is reflected on the cost reduction.

The rest of this manuscript is organized as follows: 2nd section will discuss Photovoltaic (PV) models. The 3rd section illustrates the problem formulation. In Section 4, the Moth-Flame optimizer (MFO) is presented in details. The 5th section will show the evaluation analysis, simulation and the results will be discussed in Sections 6 and 7 contains the outcome of the paper.

2. Photovoltaic modeling

There are several mathematical models that describe the operation and the physical behavior of the photovoltaic generator. The need of more detailed models are becoming essential to meet the physical requirements of the multi-crystalline solar cell and module such as the effect of grain boundaries and the leakage current [10–12]. Therefore, the MDDM and the TDM models are studied as well as the DDM.

2.1. Double Diode Model (DDM)

The DDM is represented by a light generated current source in parallel with two diodes and a shunt resistance in addition to a series resistance as shown in Fig. 1. The current of the first diode I_{D1}

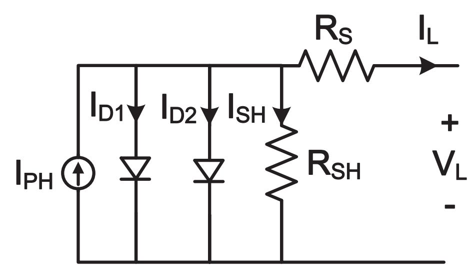

Fig. 1. Double diode model.

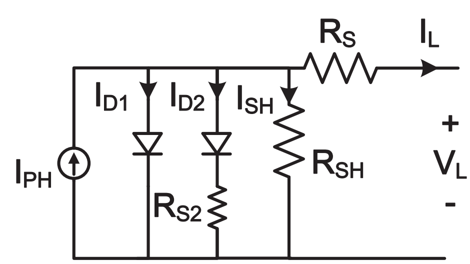

Fig. 2. Modified double diode model.

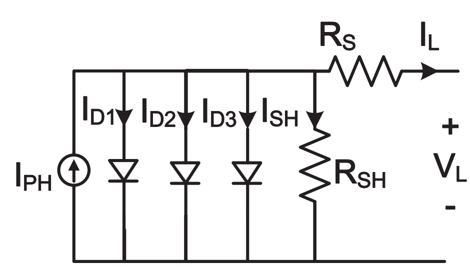

Fig. 3. Three diode model.

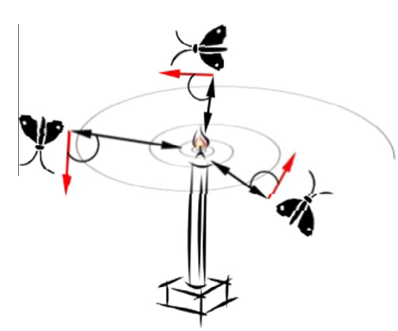

Fig. 4. Spiral flying path around close light sources [32].