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Using Firefly Optimization Method to Extract the Parameters of Photovoltaic Model System

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Abstract

Metaheuristic methods are global optimization techniques that attempt to reproduce natural phenomena or social behavior. The flashing characteristic of firefly behavior has been depended to build up the firefly algorithm (FA). The present paper proposed a method for parameter extraction of photovoltaic (PV) module. Fine tune the parameters of the algorithm is quite important to get better results. Therefore, the concern in this paper also studies the test of the control parameters. Eleven case studies have been introduced to examine the results and to select the best case with powerful precision and speed of convergence with respect to other cases.
Keywords: Firefly algorithm, photovoltaic, flashing light, bioluminescence, Attractiveness, brightness.

الخلاصة:

ان طرائق الميتاهيروستك هي تقنيات ايجاد الامثل لمساحة بحث واسعة والتي تحاول ان تحاكي الظواهر الطبيعية او تصرفات المجتمعات . حيث اعتمدت مميزات اللمعان والاضاءة لتصرف اليراعة لبناء نظرية اليراعة. ان هذا البحث اقترح طريقة لاستخراج معلمات موديل الخلية الشمسية. ان الضبط الدقيق لمعلمات الخوارزمية يعتبر من الاشياء المهمة للحصول على افضل النتائج خلال البحث. لذلك فان هذا البحث يدرس ايضا اختبار المعلمات التي تسيطر على الخوارزمية المقترحة. حيث قدمت احدى عشر حالة لتفحص النتائج ولاختيار افضل حالة و التي لها دقة عالية وسرعة تقارب مقارنة لبقية الحالات.

1. Introduction

Photovoltaic are frequently referred to as PV [1]. This source supplies a dependable, quiet, and clean electricity for the customers. The energy of light can be altered straightforwardly to the electricity by the photovoltaic frameworks which contain cells and devices. It is named as solar cells because the light is typically coming from the sun. In order to define the photovoltaic term, it can be separated into "photo" which comes from the light and "voltaic" which is referred to delivering electricity. In this way, the photovoltaic procedure is that the sunlight is directly provided the electricity [2].

Ismail et al. [3] proposed an algorithm for calculation of the PV parameters based on a method which is improved by genetic algorithm (GA). It is mandatory in any PV module to estimate the exact values of these parameters due to the PV applications which can be represented by simulation, optimization, and the design of the hybrid systems that contain PV. The algorithm has been applied also for a wide range of radiation and temperatures. Keeping in mind the end goal to optimize the parameters and then drawing I-V relation, they used Manufacturer's Data Sheet information, fitness function of average absolute error, and a numerical method does iteratively. Also, their paper discussed other cases for comparison. Their results have been simulated using Matlab Simulink software. The comparison has been done between the proposed strategy results and the experimental results to demonstrate the ability of the algorithm.

Parameter estimation for the PV model utilizing different metaheuristic algorithms is suggested and compared in Siddiqui & Abido [4] . The constraint set on the estimation process is that only the data directly accessible in module Datasheets can be utilized for evaluating the parameters. The electrical model precision utilizing the evaluated parameters is then compared to various electrical models listed in literature for different PV cell methods.

Firefly algorithm (FA) is an evolutionary algorithm which simulates the flashing light of fireflies . The algorithm has been proposed to settle various optimization problems [5-7]. Firefly algorithm is easy with the idea and the construction and it has many similarities to the some techniques like particle swarm optimization (PSO) [8]. The algorithm works in parallel manner, where if the population with four fireflies then they will generate four solutions.

Firefly algorithm is used to optimize the system coefficients of the infinite impulse response system identification problem in the paper of Upadhyay et al. [9].The suggested algorithm in their paper has lightened from the drawbacks of premature convergence and stagnation, compared to other algorithms . Benchmark examples have been utilized in the results to prove the activity of the system identification approach using FA compared to other methods in terms of convergence speed, identifying plant coefficient, and mean square error fitness.

Gandomi et al. [10] introduce a technique based on the chaos and the canonical firefly algorithm. They depended a way of fine tune the FA attraction parameters (light absorption coefficient and attractiveness coefficient) based on Twelve of various chaotic maps. As a result, they find the best map which is Gauss map after they compare all the maps, then introduce from this map the chaotic FA . The results of the paper show enhancement in the reliability of the global optimality and improvement in quality for the tuned FA.

In this research, the suggested firefly algorithm has been utilized to settle the nonlinear equations and acquire the exact estimations of the PV module of the proposed I-V equation. Then detailed study on the control parameters of the algorithm which have significant influence on the behavior of the algorithm is also discussed. The work is sorted out as follows: Section 2 is the description of the problem; Section 3 displays the firefly algorithm ; while the simulation results are delivered in Section 4; and finally, the conclusion is given in Section 5.

2. Problem Description

The conduct of photovoltaic cells has always been depicted using models, such as the single diode lumped circuit model, which is quite ubiquitous [11]. The representative of an equivalent circuit of a solar cell with a parallel current source and a diode is depicted in Fig. 1. This model is preferred due to its balance of simplicity and precision [12, 13]. The output of the current source is straightforwardly proportional to the light falling on the cell (photocurrent I_{PV}) [2], while the current source stands for the current generated by photons (at times indicated as I_{ph}), and its output is steady under constant temperature and incident radiation of light [14].

In order to create an accurate representative PV cell circuit, it is vital that the each cell's component's physical and electrical parameters be understood. It was determined that an ideal representation would be a current source that runs parallel to a single-diode [15].

Fig. 1 Ideal PV circuit model

The procedures of modeling the solar cell could theoretically be developed using the equations (1-5). The output current I_L from the PV cell is determined via the application of the Kirchoff's current law upon the simplified circuit demonstrated in Fig. 1.

$$I_L = I_{PV} - I_D \quad \text{……(1)}$$

Where I_{PV} is the current produced by the incidence of light , I_D is the current shunted through the intrinsic diode.

$$I_D = I_o \left[\exp\left(\frac{V_L}{a\,V_t}\right) - 1\right] \quad \text{……(2)}$$

Where V_L is the voltage across the PV cell, I_o is the reverse saturation current, and a is the diode ideality factor [14]. The photovoltaic thermal voltage is:

$$V_t = \frac{T_{tem} \times k_{Bol}}{q_{charge}} \quad \text{……(3)}$$

Where the charge of electron is q_{charge} which is equal to ($1.60217646 \times 10^{-19}\ C$), the constant of Boltzmann is k_{Bol} equal to ($1.3806503 \times 10^{-23} J/K$), and the p-n junction temperature is T_{tem} which is in K (Kelvin) [14].

Replacing I_D of the equation (1) with equation (2) results in a representative I-V relationship of the PV cell.

$$I_L = I_{PV} - I_o[\exp\left(\frac{V_L}{a\,V_t}\right) - 1] \quad \text{……(4)}$$

The detailed equation of a single diode model is as follows [16]:

$$I_L = I_{PV} - I_o \left[\exp\left(\frac{V_L + I_L R_{series}}{a\,N_s V_t}\right) - 1\right] - \left(\frac{V_L + I_L R_{series}}{R_{parallel}}\right) \quad \text{……(5)}$$

Where the collection of combined PV cells results in PV module and N_s is the number of cells in the module, R_{series} is the equivalent series resistance of the module, while $R_{parallel}$ is the equivalent parallel resistance. Hence, in equation (5), the accuracy exceeds the single-diode model, but it is not problem-free.

In order to measure the performance of the proposed technique, root mean square error (RMSE) is introduced as objective function as follows:

$$Obj(x) = \sqrt{\frac{1}{N}\sum_{j=1}^{N} f_j(V_L, I_L, x)^2} \quad \text{……(6)}$$

$$f(V_L, I_L, x) = I_{PV} - I_o \left[exp\left(\frac{V_L + I_L R_{series}}{a N_s V_t}\right) - 1\right] - \left(\frac{V_L + I_L R_{series}}{R_{parallel}}\right) - I_L \quad \text{……(7)}$$

The objective function is the root mean square error between the actual current and the calculated current where N is the number of points taken into account. The PV parameters are identified within the range of each one using the suggested method until the stopping criterion is met. In each iteration the algorithm will enhance the solution which is:

$$x = \{I_o, R_{series}, R_{parallel}, a\} \quad \text{……(8)}$$

to get best objective function, where:

$$f(V_L, I_L, x) = 0 \quad \text{……(9)}$$

Which is obtained for each point.

3. Firefly Algorithm

3.1 Overview of the algorithm

Fireflies are glowed worms that incandesce during bioluminescence [17]. It depends on the group dashing behavior of fireflies, or lighting bugs, in the summer sky in the tropical temperature areas [18]. Firefly algorithm is based on the swarm behavior like fish, insects, and bird-schooling [19]. FA has some similarity with a bacterial foraging algorithm . The attraction among bacteria in bacterial foraging algorithm depends on partially the fitness, and partially the distance [6]. FA is population-based, metaheuristic, and a powerful in obtaining the global optimum solution [20]. The algorithm is multimodal which has been constructed for continuous space. This swarm intelligence, method depends on the presumption that the solution of the problem to be optimized is represented by a firefly, where the quality of this firefly specify the value of gleam. Firefly algorithm is regarded as simple algorithm in terms of the idea and construction.

Three idealized rules have been introduced for firefly algorithm [21]:

- ❖ The sex of fireflies are not required, so each firefly will move to the others because all fireflies are unisex.
- ❖ In firefly algorithm, the more brighter firefly will attract the others because of the proportional relation between the attractiveness and the brightness of fireflies. Increasing the distance causes the attractiveness and brightness to decrease.
- ❖ The objective function is used to calculate the brightness. In the minimization problem, the brightness is inversely proportional to the objective function.

3.2 The initialization

According to the Apostolopulos and Vlachos [22]. The initialization procedure can be done based on the following:

$x = lower\ limit + rand * (upper\ limit - lower\ limit)$……………………..(10)

Where x is the firefly initial population. The upper limit and the lower limit are the upper and the lower of the firefly x .Finally, rand is a random number distributed uniformly in [0,1].

3.3 Attractiveness

There are two vital focuses, in the first place, the light intensity variation. Second, the attractiveness form. The brightness of a firefly can produce the attractivness where this brightness is associated to the objective function. The brightness I of a firefly at a specific location x can be selected as

$I(x) \propto f(x)$ ……………………………………………………………………...…(11)

Therefore , the attractiveness β is relative to the intensity of light which should be visible by the other fireflies. Subsequently, the attractiveness will be changed as the distance r_{ij} change between firefly i and firefly j .

As well as, when the distance from the source increase, the light intensity will decrease. The media will dissipate the light, therefore the attractiveness should be replaced with the absorption.

The intensity of light $I(r)$ varies according to the law of square inverse

$I(r) = I_{source}/r^2$ …………………………………………………………………..(12)

Where the source intensity is represented by I_{source}. With a specific γ coefficient, which is the absorption of a fixed light, the intensity of light I changes with the distance r . Then

$I = I_{initial}e^{-\gamma r}$ ……………………………………..……………………..….(13)

where $I_{initial}$ is the initial intensity of light. The combined effect of both the inverse square law and absorption can be in the following form [20].

$I(r) = I_{initial}e^{-\gamma r^2}$ ……………………………………………………………..(14)

The main form of attractiveness function $\beta(r)$ can be any monotonically decreasing functions such as

$\beta(r) = \beta_o e^{-\gamma r^m}$ ……………………………………………………………..…(15)

Where $m \geq 1$ and β_o is the attractiveness at $r = 0$ [20].

3.4 Distance

The firefly i at position x_i and firefly k at position x_k are separated by Cartesian distance which is

$r_{ik} = \|x_i - x_k\| = \sqrt{\sum_{j=1}^{d}(x_{i,j} - x_{k,j})^2}$ ……..………………………………………(16)

Where $x_{i,j}$ is the jth component of the spatial coordinates x_i of ith firefly. In $2 - D$ case, i.e. for $= 2$, then [20]

$r_{ik} = \sqrt{(x_i - x_k)^2 - (y_i - y_k)^2}$ …………………………..………...……..……(17)

3.5 Movement

If the firefly j is brighter than firefly i, then firefly i will be attracted to firefly j according to the formula:

$x_i = x_i + \beta_o e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha(rand - 0.5)$ ……………………………..……(18)

Three parts in the equation (18), the first is the current location for firefly , the second is the attractive part, and finally the third part is the randomization with parameter α.

3.6 Parameter Choosing

The best parameters should be evaluated by firefly to find the optimum solution. The algorithm will converge gradually and it depends on the parameter values. First, as γ approximates to zero, then the attractiveness and brightness take constant values. This is the case where a firefly is visible by the others which is considered as a special case of PSO. On the other hand, the attractiveness will reduce drastically and the firefly will be short-sighted as γ approaches to high value and means that all fireflies move almost haphazardly, this implies a random search method. Hence, the γ should be chosen between these values [23]. The convergence speed and the generally speaking conduct of the FA is affected by γ parameter. Then the range of γ is in range [0, ∞), $\beta_o = 1$ and $\alpha \in [0,1]$.

The procedures of the proposed algorithm can be shown as follows:

<u>Algorithm</u>

1: Control parameters : popsize, generation, and the PV module information
2: Random population of n fireflies
3: State objective function $Obj(x)$ as in equation (6)
4: The intensity of light I_i at x_i is by $Obj(x_i)$
5: Read the actual values of voltages and currents
6: Calculate the V_t of equation (3)
7: loop=0
8: While (Loop < generation)
9: For $i = 1{:}\,n$
10: For $k = 1{:}\,i$
11: If ($I_k > I_i$)
12: The distance between i and k
13: The variation of attractiveness with distance r

14: The movement of firefly i towards k
15: New solutions calculation and intensity of light updating
16: end if
17: End for k
18: End for i
19: Rank the fireflies and find the current best
20: End while

4. Simulation Results

Firefly algorithm is currently utilized to settle the extraction parameter problem. The extraction included the obtaining of the values for the four parameters of the photovoltaic system which the boundary of the them shown in table 1 as well as the other PV specifications in [24]. After the calculations of these parameters by using the proposed method, the test for the control parameters is performed. This test is very important to select a suitable value of control parameters.

Table 1: The boundary of the parameters

Parameter	Lower bound	Upper bound
$I_o(\mu A)$	0	50
R_s (Ω)	0	2
$R_p(\Omega)$	0	2000
a	1	50

In this work, the population size of fireflies (popsize), the number of generations (generation), β_o , γ , and α are used as control parameters which should take different values as shown in table 3 to see clearly the effect of them on the progress of the algorithm. Table 2 illustrates the reverse saturation current , the series resistance , the parallel resistance , the ideality factor , the root mean square error , and the standard deviation (SD) for each case.

Table 2: Comparison among different cases for the PV module

Parameter	$I_o(\mu A)$	$R_{series}(\Omega)$	$R_{parallel}(\Omega)$	a	RMSE	SD
Case 1	50	0.050000275	32.89624325	1.870787289	0.200128057	0.125701
Case 2	50	0.776000001	1361.712	1.776000045	0.16539671	0.103489
Case 3	50	0.025	32.805	1.85	0.198982871	0.121756
Case 4	0	0	25.55602671	28.308267	0.318996172	0.128419
Case 5	50	0.714	1096.004	1.714	0.016729678	0.004569
Case 6	11.9	1.204	1980	1.441	0.326483519	0.034059
Case 7	50	1.39957	1224.18557	1.67557	0.177428477	0.106198
Case 8	50	1.1411	1772.2631	1.6633	0.216469947	0.155392
Case 9	9.9	1.428	58	28.832	0.425835497	0.140574
Case 10	50	0.911	884.8	2.081	0.474741144	0.087090
Case 11	50	0.406	1433.222	1.661	0.236869472	0.124069

Table 3: The values of the cases

Case	Popsize	Number of iterations	β_o	γ	α
1	50	300	1	0.0001	1
2	50	300	1	0.001	1
3	50	300	1	0	1
4	50	300	1	0.00001	1
5	50	300	1	10	1
6	50	300	1	10	0.001
7	50	300	1	10	0.01
8	50	300	1	10	0.1
9	50	300	1	10	0
10	50	300	1	10	1
11	50	10	1	10	1

Figs. 2,3, 4, and 5 introduce the comparison between the different cases in each group in terms of precision and the speed of convergence. In fig. 2 the values of γ have been changed from zero and up, it is seen that increase the γ from zero will enhance the results.

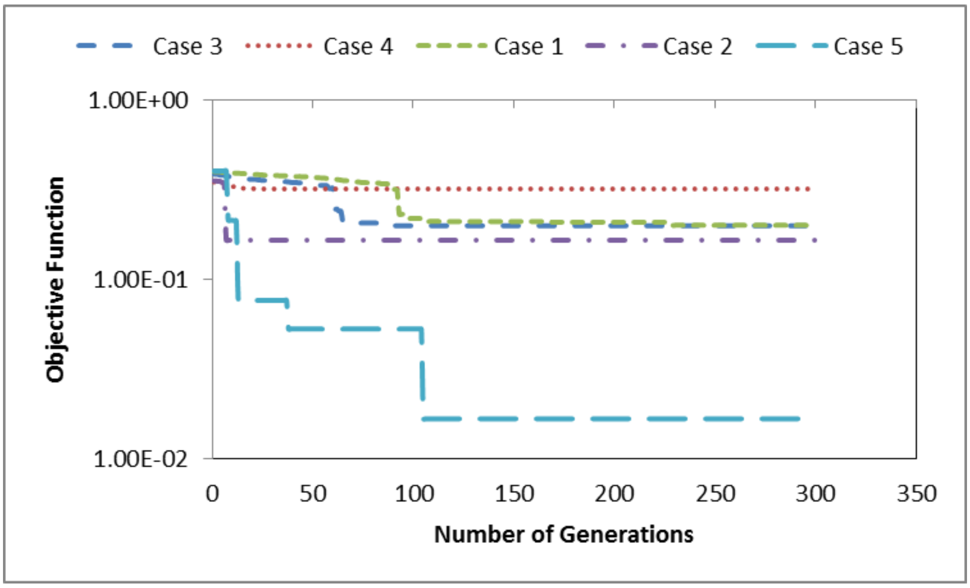

Fig. 2 Comparison for the objective function of cases 1,2,3, and 4

In figs. 3 and 4 the accuracy will reduce because of the small number of fireflies and generations.

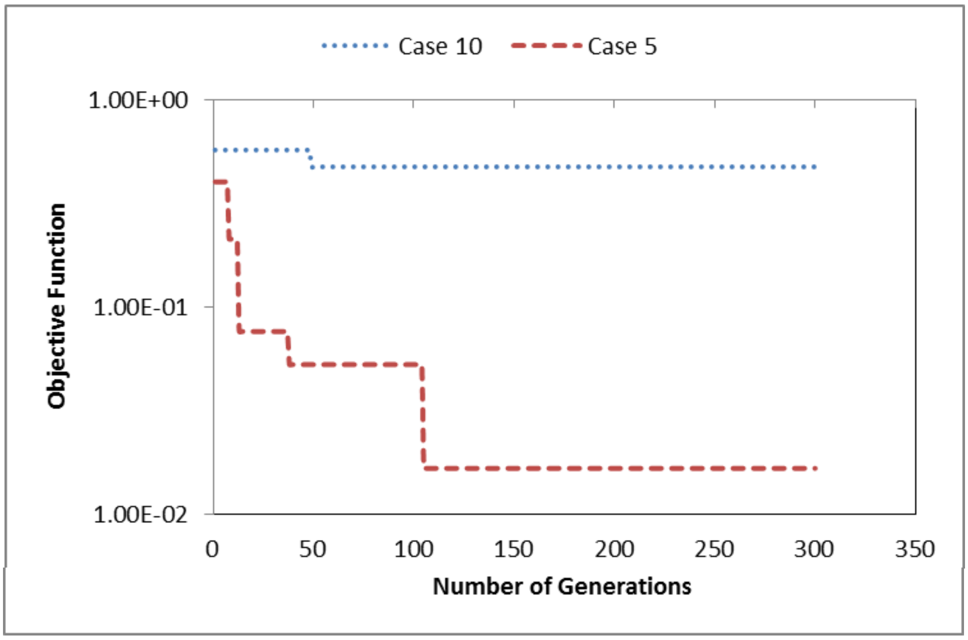

Fig. 3 Comparison for the objective function of case 10

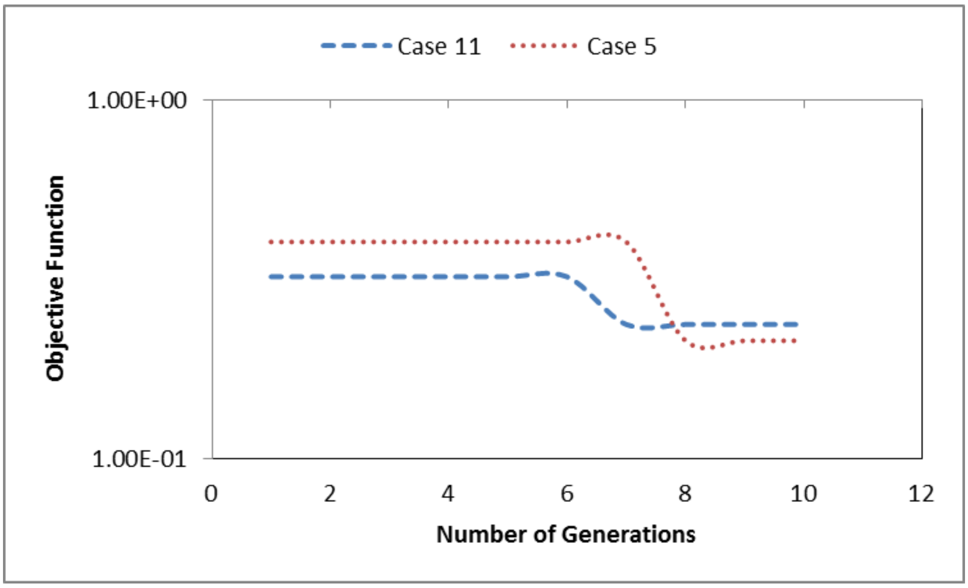

Fig. 4 Comparison for the objective function of case 11

The effect of parameter α on the accuracy and the speed of convergence is illustrated in fig. 5 where α control the value of the randomization in the movement procedure. The randomization part in the movement step has an effective role in the diversification, which is an important characteristic of the metaheuristic methods. With a specific end goal to explore the search space effectively, the diversification process should be done. Case 5 outperforms the other cases in terms of the accuracy, convergence, and standard deviation.

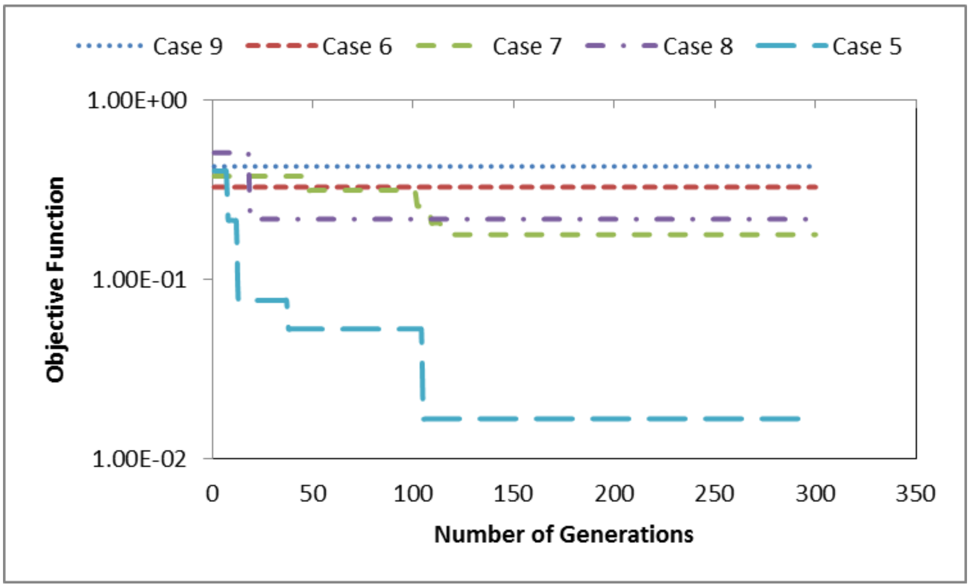

Fig. 5 Comparison for the objective function of cases 6,7,8, and 9

Then Figs.(6-16) illustrate the current-voltage curves for the suggested cases which show that the Fig. 10 of case 5 is the best performance.

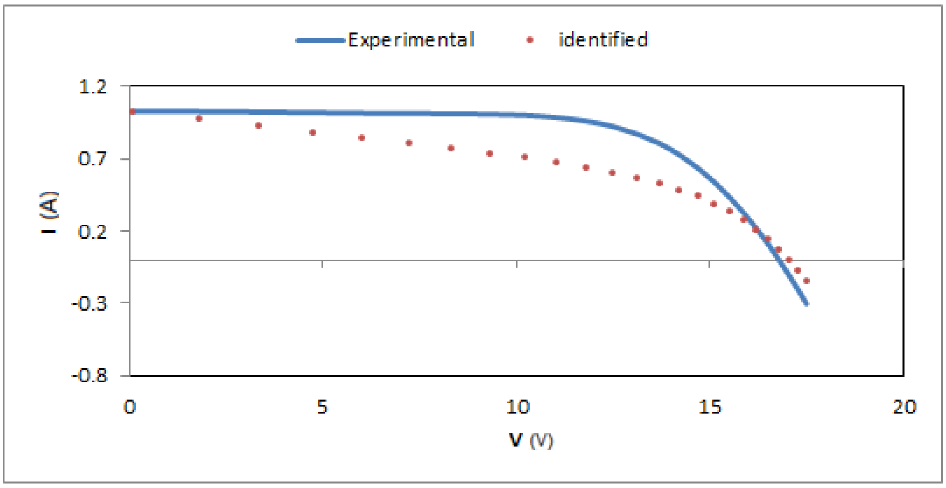

Fig. 6 I-V characteristic for case 1

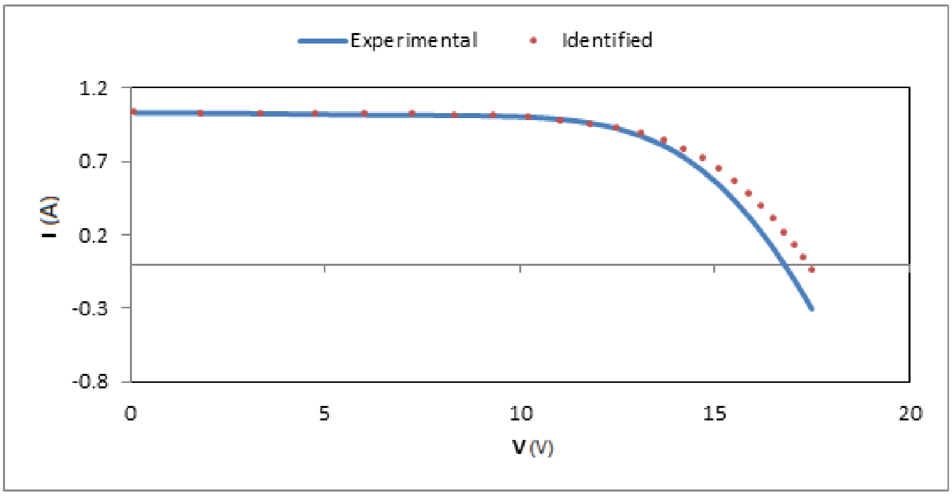

Fig. 7 I-V characteristic for case 2

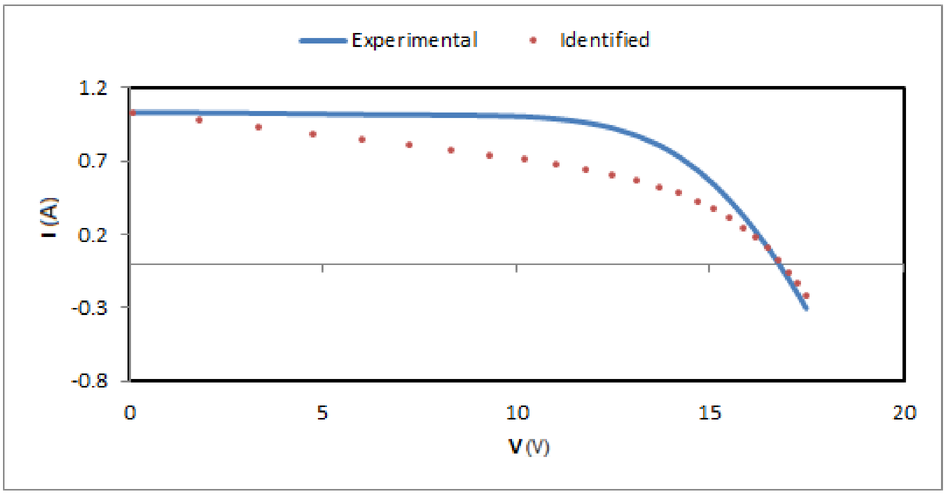

Fig. 8 I-V characteristic for case 3

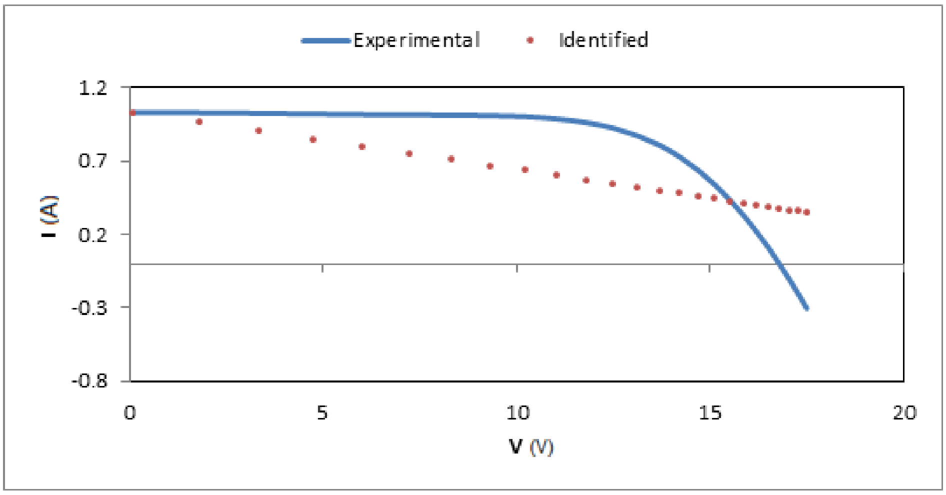

Fig. 9 I-V characteristic for case 4

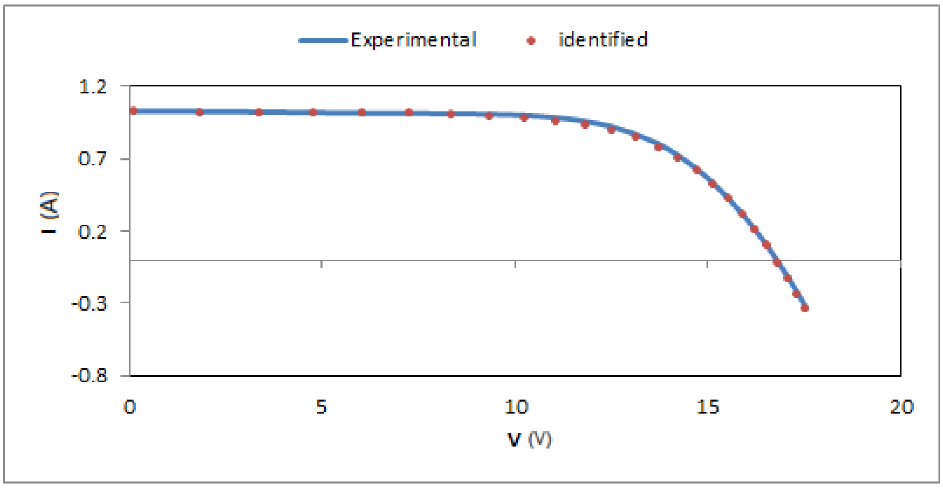

Fig. 10 I-V characteristic for case 5

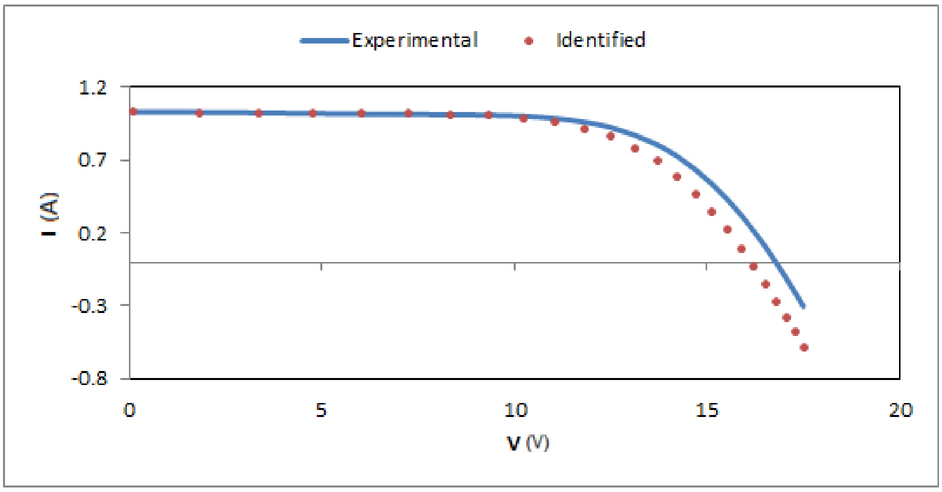

Fig. 11 I-V characteristic for case 6

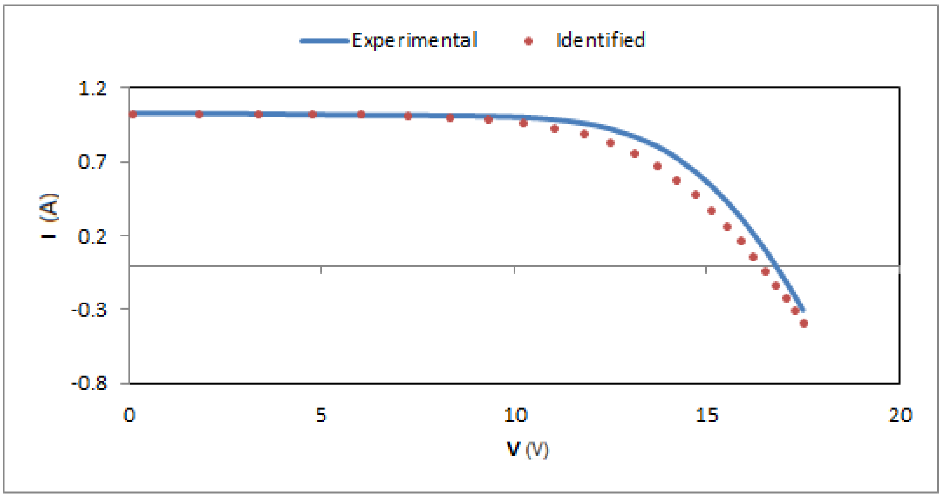

Fig. 12 I-V characteristic for case 7

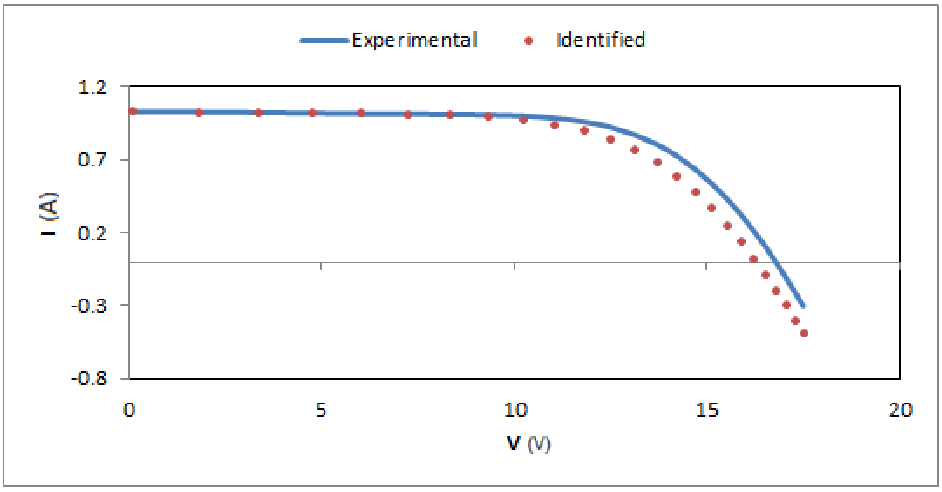

Fig. 13 I-V characteristic for case 8

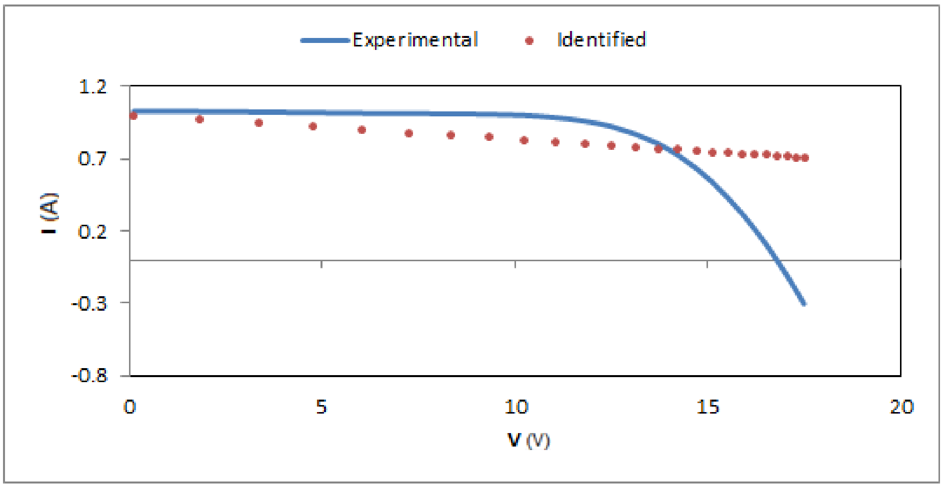

Fig. 14 I-V characteristic for case 9

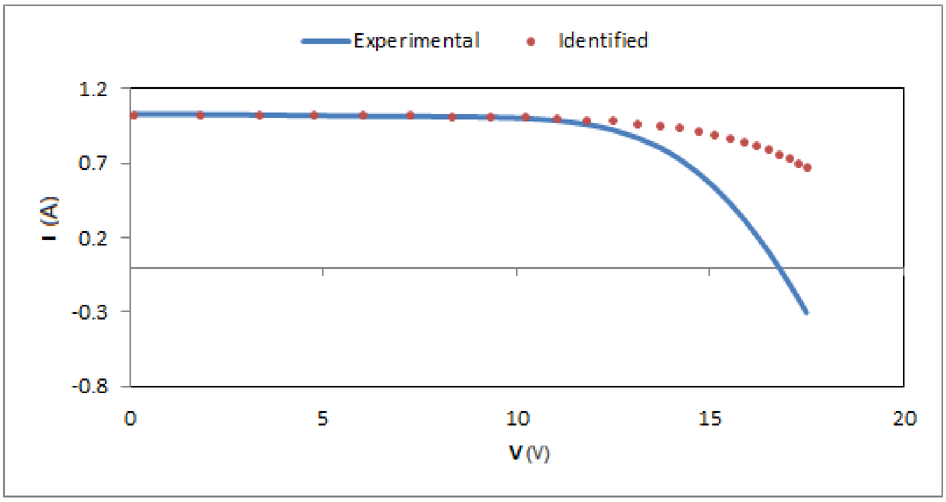

Fig. 15 I-V characteristic for case 10

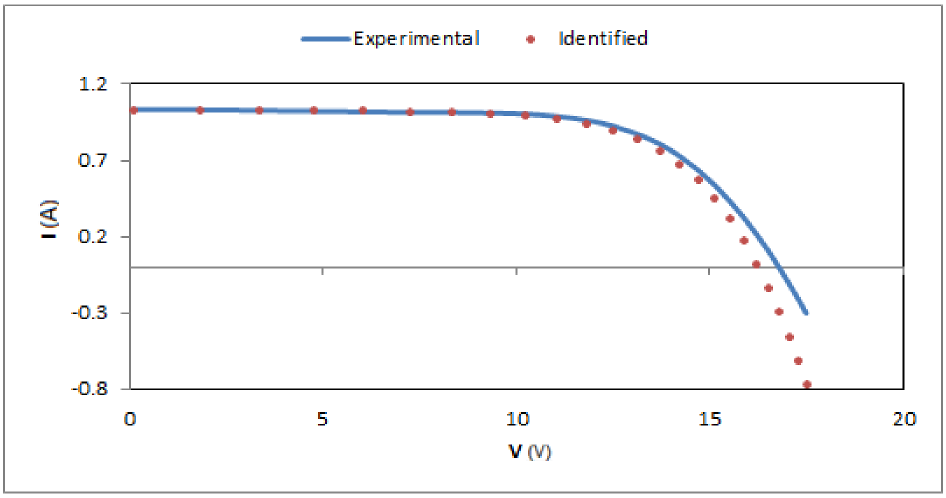

Fig. 16 I-V characteristic for case 11

5. Conclusion

The suggested work is based on a firefly algorithm to solve the nonlinear proposed problem. Multiple local optimum results in different optimization problems due to the non-linearity. The firefly algorithm is proposed in order to obtain the photovoltaic model parameters. The more accurate parameter means the best characteristic of PV module. Therefore, comparison test has been done to realize this objective. The results prove that the light absorption coefficient and the parameter of randomization partition should be with values more than zero as well as enough selection of population size and iterations.

In short, the parameters of a PV module are extracted using the proposed evolutionary algorithm. The strategy are assessed in light of the precision of solution, and convergence speed, by choice appropriate estimations of control parameters. Results demonstrate that case 10 is not proper to be utilized as a part of parameter identification. Somewhat better outcomes in case 2 can to be the most encouraging. Hence, case 5 among that is outstanding in all parts of the assessment. The plausibility of the proposed technique has been approved by the contrasting with the experimental data.

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