An Improved Technique Based on Firefly Algorithm to Estimate the Parameters of the Photovoltaic Model

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Abstract *This paper present a method to enhance the firefly algorithm by coupling with a local search. The constructed technique is applied to identify the solar parameters model where the method has been proved its ability to obtain the photovoltaic parameters model. Standard firefly algorithm (FA), electromagnetism-like (EM) algorithm, and electromagnetism-like without local (EMW) search algorithm all are compared with the suggested method to test its capability to solve this model.*

***Index Terms*— Firefly algorithm, photovoltaic, flashing light, bioluminescence, attractiveness, local search.**

I. Introduction

The PV cell is produced using semiconductor materials fundamentally of junction manufactured in a layer of semiconductor or a thin wafer , which are specially processed to produce an electric field, positive on one side (rear) and negative on alternate (towards the sun) [1] . Due to the photovoltaic , the electricity can be obtained by transforming the radiation of the electromagnetic of solar energy [2]. The electron-hole pair can be produced by falling the sunlight on the PV. Therefore, the photons which have greater energy than of the semiconductor will be lost. As a result, the irradiation is proportional to the this pair. P-n junction has internal electric fields and carriers will influence by these field. Therefore, they are moving away and produce the photocurrent [3].

The behavior of photovoltaic cell has been depicted by photovoltaic cell models. The single diode model is the common circuit which is used to provide the energy in PV system [4]. The construction of the ideal circuit is a source of current which is connected with a diode [5] this is appeared in Fig.1. This is the least difficult utilized model as it offers a good compromise in the middle of simplicity and precision [6, 7]. There is a straightforwardly relation between the light that falls on the cell and the output of the source of current (I_{PV}) [8]. The photons current (I_{ph}) is considered as the current source in the PV. As long as the incident of radiation and temperature are constants, this source will be constant [9].

Firefly algorithm (FA) is a new evolutionary algorithm which simulates the flashing of light of the fireflies . The algorithm has been proposed to settle various optimization problems [10-12]. Firefly algorithm is easy with the idea and the construction and it has many similarities to the some other methods like particle swarm optimization (PSO) [13]. FA works in parallel manner, where if the population with four fireflies then they will generate four solutions.

Fig. 1 Circuit model for ideal PV

The paper by Verma et al. [14] presented firefly with the following alterations. In order to enhance the convergence speed of standard FA, they initialize the solution by utilizing of opposition based learning method, which encompasses initializing the opposite number of positions of each firefly. Then, the dimensional-based method is utilized where the location of each firefly is updated along several dimensions and it is produced extra optimal solutions. This algorithm is for high dimensionality problems, particularly for accuracy and speed of convergence in obtaining the best solution. In their work, different complex multidimensional functions are utilized. The authors have been concluded that their algorithm outperforms the standard FA in terms of accuracy and speed of convergence .

Alweshah & Abdullah [15] have been built on the probabilistic neural network (PNN) to introduce an efficient technique for classification issues which can obtain high-quality solutions at a high speed of convergence. They hybridize the FA with simulated annealing (SFA). SA has been used to manage the randomness within the FA while optimizing the weight of probabilistic neural network. In order to get best investigate for the search space, the authors extend the work by utilizing Levy flight inside the firefly (LFA). Besides, they merged SFA with Levy flight (LSFA) that help to enhance the PNN characteristic. Finally, the results prove that the LSFA outperforms the others.

This work applies firefly algorithm in PV modeling. In order to reduce the shortages of FA and increase the searching ability of the FA, firefly has been modified and enhanced. The other parts of the paper are in the following arrangement: An introduction in Section I ; Section II gives the description of the PV modeling; Section III represents the objective function; improved firefly has been introduced in Section IV; Section V presents the results and at last, conclusions are appeared in Section VI.

II. Description of PV System Modeling

The procedures of modeling the solar of Fig. 2 can be developed based on the below equations

$$I_d = I_o[\exp(V/aV_T) - 1] \quad (1)$$

$$-V - I_{out}R_s + I_pR_p \quad (2)$$

$$I_p = (V + I_{out}R_s)/R_p \quad (3)$$

I_{out} is the output current which comes from the photovoltaic cell. This current is calculated by Kirchoff 's current law (KCL) on the circuit shown in Fig. 2. The current shunted out of the intrinsic diode is I_d . I_o is the current of reverse saturation, the voltage in the terminal of the cell is V , and the factor a is the ideality of the diode. From (1), (2), and (3) yields:

$$I_{out} = I_{pv} - I_d - I_p \quad (4)$$

$$I_{out} = I_{pv} - I_o\left[\exp\left(\frac{V+I_{out}R_s}{aV_T}\right) - 1\right] - \left(\frac{V+I_{out}R_s}{R_p}\right) \quad (5)$$

Where I_{pv} is the current produced by the incidence of light and:

$$V_T = kT/q \quad (6)$$

In this case V_T is the thermal voltage of the PV, the constant of Boltzmann (k) is equal to($1.3806503 \times 10^{-23} J/K$), the p-n junction temperature (T) is in K (Kelvin) , and the charge of electron (q) is equal to ($1.60217646 \times 10^{-19}$ C) [9].

The circuit of Fig. 2 has resistor (R_s) [16] which comes from the material of semiconductor, grid of metal, and the collecting bus of current that represent as losses resistance in series. In addition, there are two parallel components which are the intrinsic equipment and leakage current that pass through the resistive way represents a parallel resistor (R_p) [16].

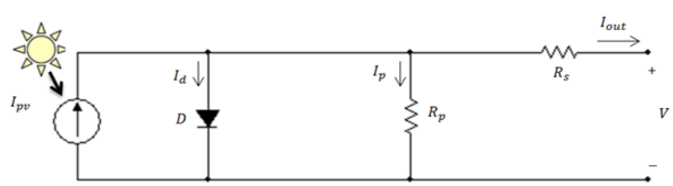

Fig. 2 Photovoltaic model

PV cells are the essential building blocks of PV modules as shown in Fig. 3. For almost all applications, the one-half volt delivered by a single cell is not enough. In this manner, cells are connected together in series to increase the voltage. Several of these arrangement series of cells may be connected together in parallel to increase the current also [8]. At that point (5) gets to be:

$$I_{out} = I_{pv} - I_o\left[\exp\left(\frac{V+I_{out}R_s}{a\,N_s V_T}\right)-1\right]-\left(\frac{V+I_{out}R_s}{R_p}\right) \tag{7}$$

Where N_s is the number of cells in the module.

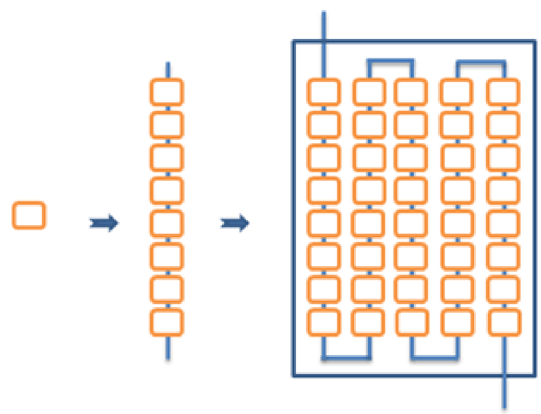

Fig. 3 Represents PV cell, string of series cell, and PV module

III. Objective Function

In this work, the root mean square error (RMSE) is utilized as the objective function as shown in (8):

$$Obj(ff) = \sqrt{\frac{1}{N}\sum_{k=1}^{N} f_k(V, I_{out}, ff)^2} \tag{8}$$

$$f(V, I_{out}, ff) = I_{PV} - I_o\left[exp\left(\frac{V+I_{out}R_s}{aN_sV_T}\right)-1\right] - \left(\frac{V+I_{out}R_s}{R_p}\right) - I_{out} \tag{9}$$

$$ff = \{I_o, R_s, R_p, a\} \tag{10}$$

Where N denotes the number of experimental data.

IV. Improved Firefly Algorithm

A. Overview

Fireflies are glow worms that flare during bioluminescence [17]. It depends on the group dashing conduct of fireflies, or lighting bugs, in the summer sky in the tropical temperature areas [18]. FA is based on the swarm conduct like bird-schooling, fish, and insects [19]. FA has some similarity with a bacterial foraging algorithm (BFA). The attractiveness between the bacteria in BFA depends on partially the fitness, and partially the distance [11]. Firefly algorithm 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, optimization method depends on the presumption that solution of the problem of an optimization can be seen as firefly which flares according to its goodness. FA is considered as simple algorithm in terms of the idea and construction. Three idealized rules have been supposed for FA:

1) The sex of fireflies in the population is unisex and the fireflies will attract each other, regardless of their sex.

2) Attractiveness is proportional to their brightness, where the most shining firefly will attract the less shining. Increasing the distance will cause that the brightness and attractiveness to decrease. The fireflies change their position randomly, when no firefly has a better brightness than the others.

3) The brightness of a firefly is influenced or evaluated by the backdrop of the objective function. For the minimization problem, there is an inversely relationship between the objective function and the brightness.

The essential procedures of standard firefly algorithm can be illustrated in Fig. 4 [21].

State the β_o , γ , α , and $Maxgeneration$
Random population of n fireflies
State objective function $Obj(ff)$
The intensity of light I_i at ff_i is by $Obj(ff_i)$
$Loop = 0$
While ($Loop < Maxgeneration$)
For $i = 1: n$
  For $j = 1: i$
    If ($I_j > I_i$)
    The movement of firefly i towards j
    end if
   The variation of attractiveness with distance r
   New solutions calculation and intensity of light updating
  End for j
End for i
Rank the fireflies and find the current best solution
End while

Fig. 4 The algorithm of firefly

Also, the chart of the firefly procedures is shown in Fig. (5).

B. The initialization

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

$$ff = rand * (upper\ limit - lower\ limit) + lower\ limit \tag{11}$$

Where ff is the firefly initial population. The upper limit and the lower limit are the upper and the lower of the firefly ff .

C. Attractiveness

The light intensity variation and the attractiveness formulation are two effective issues. There is a relationship between the objective function and the brightness of a firefly which in turn can find the attractiveness. At any specific position ff , the firefly brightness is selected as:

$$I(ff) \propto Obj(ff) \tag{12}$$

Therefore , the attractiveness β is relative to the light intensity which should be seen by the other fireflies. Subsequently, when the distance r_{ij} which is between firefly i and firefly j changes, then the attractiveness will be changed.

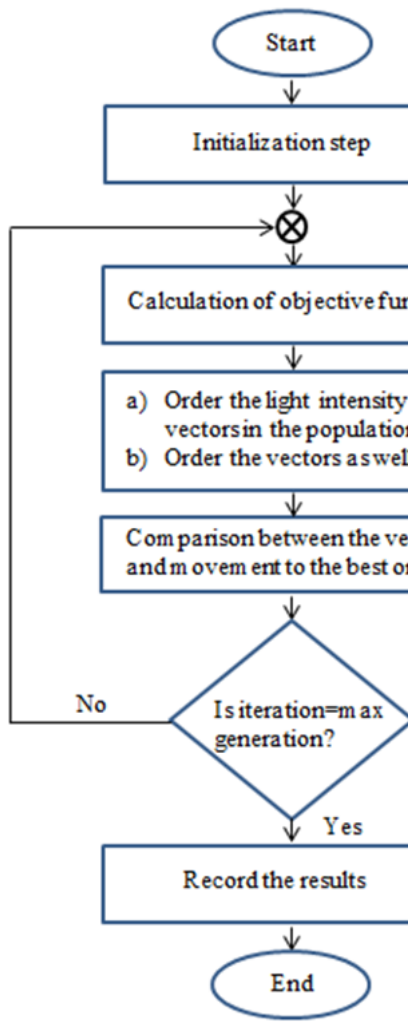

Fig. 5 Firefly flowchart

Then the light intensity will decrease as the distance from the source increase. Because of the media can absorp the light, the value of attractiveness will alter with the absorption.

Intensity of light $I(r)$ changes by inverse square law with the distance.

$$I(r) = I_s/r^2 \qquad (13)$$

Where the source intensity is I_s. Then

$$I(r) = I_{original}e^{-\gamma r} \qquad (14)$$

Where γ is the coefficient of absorbtion and the original intensity of light is $I_{original}$. Equation (15) presents the collective effect of inverse square law and absorption as follows [20]:

$$I(r) = I_{original}e^{-\gamma r^2} \qquad (15)$$

The primary structure of attractiveness function $\beta(r)$ can be any monotonically decreasing functions such as:

$$\beta(r) = \beta_o e^{-\gamma r^m} \qquad (16)$$

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

D. Distance

Here, the Euclidean or Cartesian distance is defined as the distance between any two fireflies i and j at positions ff_i and ff_j, respectively, as follows:

$$r_{ij} = \|ff_i - ff_j\| = \sqrt{\sum_{k=1}^{d}(ff_{i,k} - ff_{j,k})^2} \qquad (17)$$

Where $ff_{i,k}$ is the kth component of the ff_i of ith firefly. In $2-D$ case, i.e. for $d = 2$, then [20]

$$r_{ij} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2} \qquad (18)$$

E. Movement

According to the formula of (19), the firefly i will be attracted to firefly j, if the j is brighter than i as follows:

$$ff_i = ff_i + \beta_o e^{-\gamma r_{ij}^2}(ff_j - ff_i) + \alpha(rand - 0.5) \qquad (19)$$

Three parts in (19), the current location of firefly i is appeared in the first part, then the attractiveness is in the second part, and finally the third part is the randomization with parameter α. Rand $\in$ [0,1] is a random number which is uniformly distributed. Then the $\gamma \in [0, \infty)$, $\beta_o = 1$ and $\alpha \in [0,1]$.

F. Local Search

Local search is applied to promote the exploration and search capabilities of the algorithm and ensure rapid algorithm convergence. Firefly algorithm is permitted to search for the global optima for a proposed goal function [23]. Therefore, the firefly overwhelmingly traps into local optima. In order to modify the FA, Fig. 6 shows the flow chart of improved firefly algorithm (IFA).

V. RESULTS AND DISCUSSION

In this paper the boundary of the PV parameters are limited between the lower and the upper where $I_o(\mu A)$ (0-50), R_s (Ω) (0-2), $R_p(\Omega)$ (0-2000), a (1-50), and the other specifications are from [24]. The comparison has been done between the electromagnetism-like without local search (EMW), electromagnetism-like (EM), FA, and IFA. All the methods have been tested to calculate the parameters of PV system as in table 1. Also, this table presents the root mean square error , standard deviation (SD), and the error after a specific time period. In Fig. 7 EM algorithm and IFA are comparable but any way EM always has better speed and accuracy. To examine the validity of the proposed algorithms, the methods have been tested at the earlier generations as illustrated in Figs 8-11, where the extracted data is estimated for the current after the use of extraction parameters. The experimental data is as in [24].

I-V characteristic curves are introduced in Figs 12-15 which show that the EM algorithm and IFA do better estimation for the parameters.

VI.Conclusion

Firefly algorithm has been updated to avoid premature convergence of original FA by embedded a local search method. The contribution of the suggested method is basically the incorporation of a local search with a firefly algorithm. The test is applied on the electric circuit which its impact turns out to be extremely obvious in a photovoltaic module that comprises of numerous cells which are connected in series, and the value of resistance is multiplied by number of cells. The network also contains of parallel resistor which its impact is a great deal less obvious if the comparison has been done with the series resistance. On the other hand, this effect will be recognizable for the parallel connected photovoltaic modules in a bigger framework. The results cement that the IFA is outperformed the standard firefly. Future work, is the hybridization of firefly with other evolutionary algorithms.

TABLE I
COMPARISON AMONG DIFFERENT ALGORITHMS FOR THE PV MODULE

Parameter	EMW	EM	FA	IFA
$I_o(\mu A)$	45.9	7.6	50	0.775
$R_s(\Omega)$	0.631972249	1.108339015	0.724	1.362
$R_p(\Omega)$	1012.756245	1723.511786	679.952	664.2
a	1.706838125	1.440594675	1.724	1.2077
RMSE	0.022588104	0.003506203	0.023769406	0.005683712
SD	0.008431902	0.000909831	0.016593033	0.00363196
Error for 10 iterations	0.155200859	0.008034863	0.355126113	0.04532621

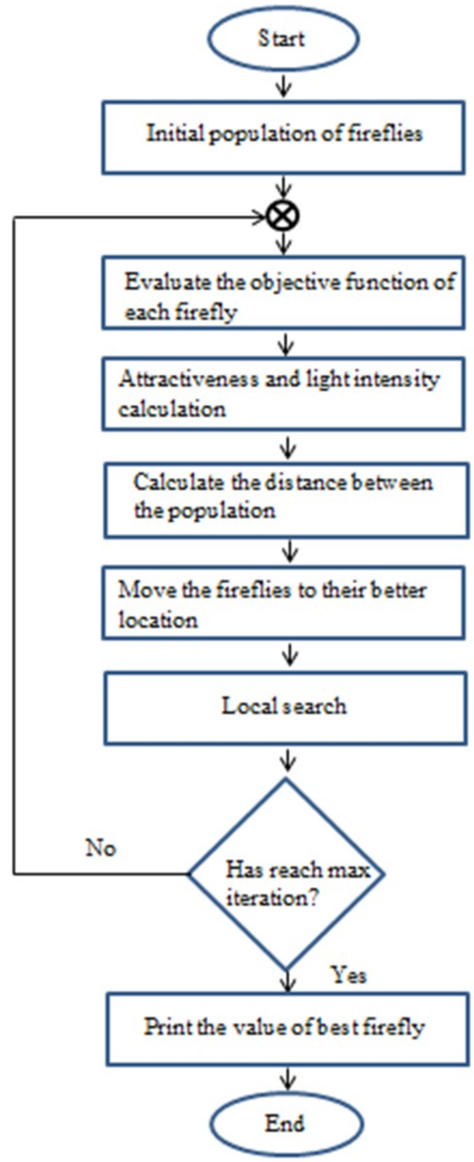

Fig. 6 Improved firefly algorithm

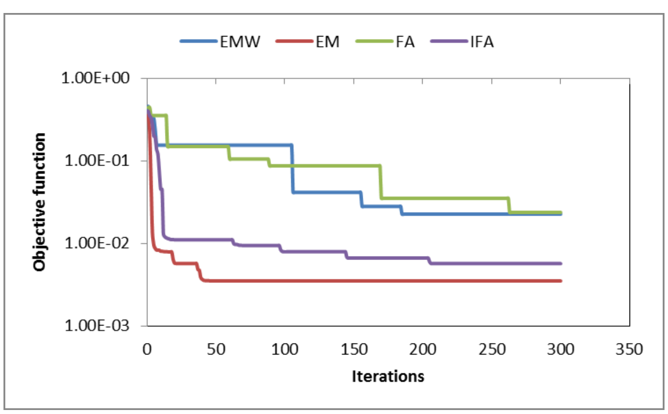

Fig. 7 Objective function comparison

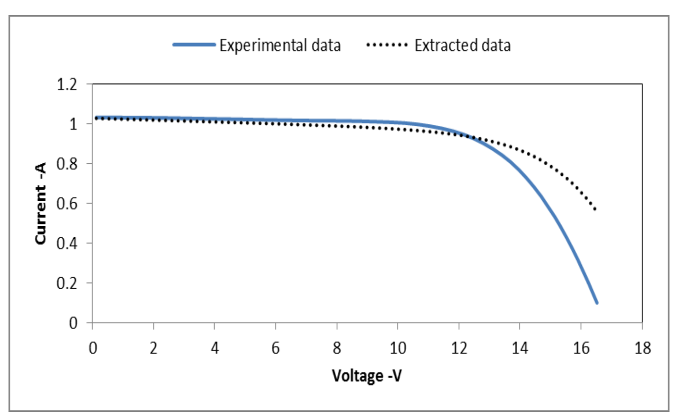

Fig. 8 Current-voltage curve using EMW algorithm for two iterations

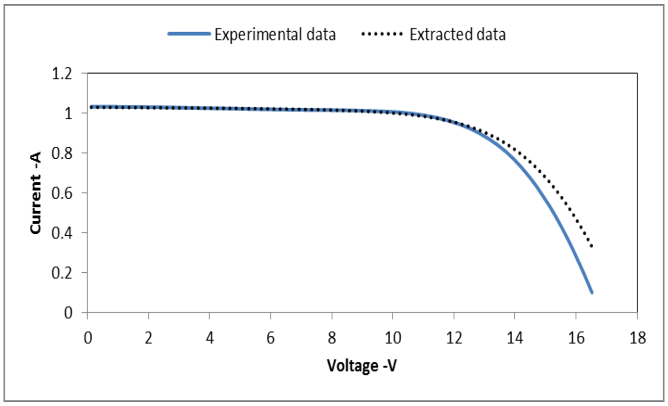

Fig. 9 Current-voltage curve using EM algorithm for two iterations

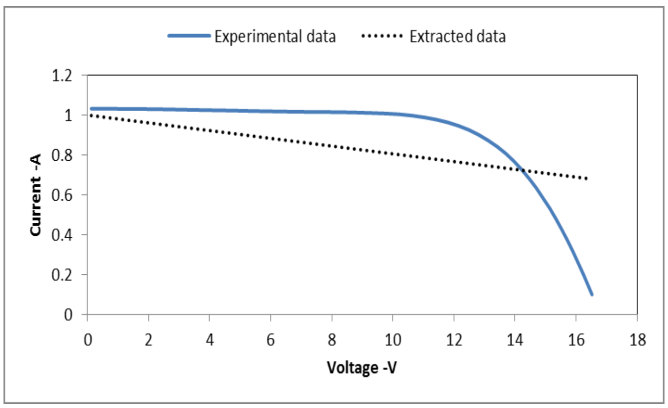

Fig. 10 Current-voltage curve using FA for two iterations

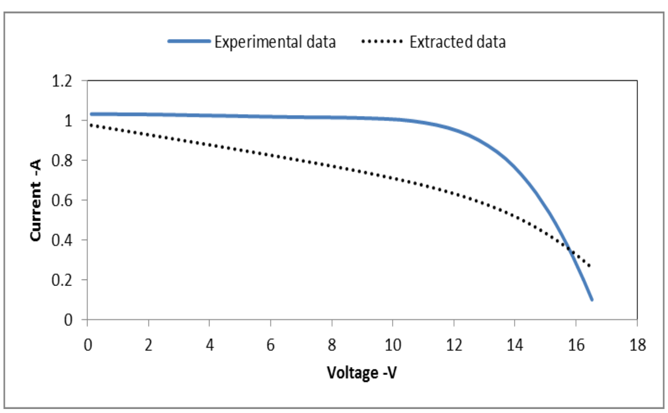

Fig. 11 Current-voltage curve using IFA for two iterations

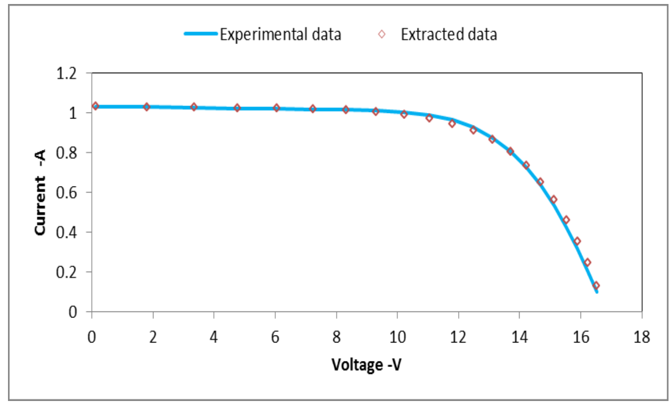

Fig. 12 Optimized Current-voltage curve using EMW algorithm

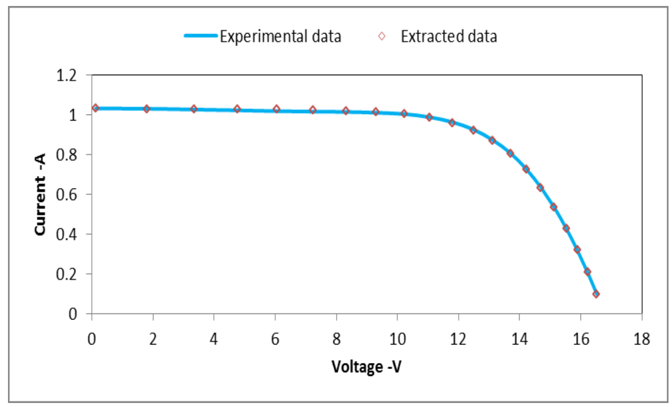

Fig. 13 Optimized Current-voltage curve using EM algorithm

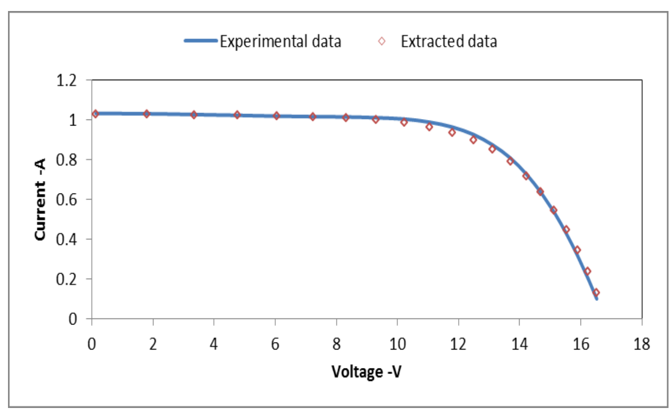

Fig. 14 Optimized Current-voltage curve using FA

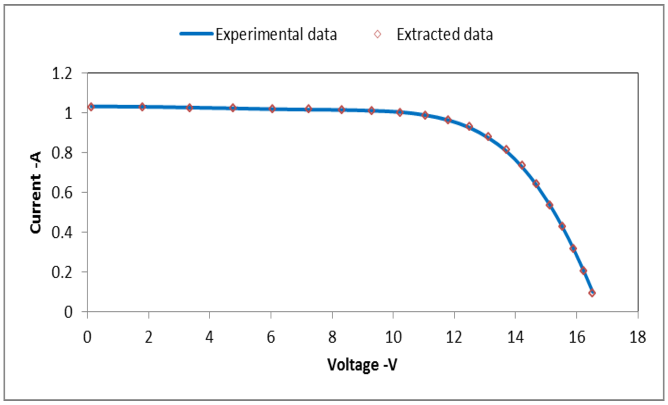

Fig. 15 Optimized Current-voltage curve using IFA

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