Firefly Algorithm and Particle Swarm Optimization for photovoltaic parameters identification based on single model

Murat Erhan ÇİMEN
Electric Electronic Engineering
Electric Electronic Engineering Dep,
Sakarya University of Applied Sciences
Sakarya, Turkey
muratcimen@sakarya.edu.tr

Zeynep GARİP
Mechatronic Engineering
Institute of Natural Sciences,
Sakarya University of Applied Sciences
Sakarya, Turkey
zbatik@sakarya.edu.tr

Ali Fuat BOZ
Electric Electronic Engineering
Electric Electronic Engineering Dept.,
Sakarya University of Applied Sciences
Sakarya, Turkey
afboz@sakarya.edu.tr

Durmuş KARAYEL
Mechatronic Engineering
Mechatronic Engineering Dept.,
Sakarya University of Applied Sciences
Sakarya, Turkey
dkarayel@sakarya.edu.tr

***Abstract*— In this study, solar cell parameters, the most basic material of solar energy that has become increasingly widespread in recent years, are determined by Particle Swarm Optimization and Firefly and algorithms. The previously proposed single-diode solar cell model was used as a base for solar cells used in series connection and then in parallel connection with each other. Integral Absolute Error (IAE) was chosen as error criterion in heuristic algorithm for the parameters of a single diode solar cell. With this work, the parameters of the solar cell are brought closer to the reality, which is important because it will change the maximum power and efficiency to be drawn from the panes by designing a more accurate controller. In this study, it has been seen that the firefly algorithm gives more successful results when firefly and particle swarm optimization algorithms compared to the previous studies. (*Abstract*)**

***Keywords*— firefly algorithm; particle swarm optimization; integral absolute error; single diode; optimal parameters (*key words*)**

I. INTRODUCTION

Energy is one of the foundations of civilization that we have today. In recent times, our energy sources that cannot be replaced have been consumed with energy production and consumption methods and as a result irreversible destruction is caused on the nature and environmental pollution is brought to the scene with this.

The solar cell is a very useful and promising device for the production of clean energy. Also performance of solar cell is constantly improved thanks to the intensive research in this area [1]. The clean and environmentally friendly solar cell is known as an alternative solution to today's problems in global measurement, as it directly converts sunlight into electricity.

There are many studies in the literature about modeling single and double diodes. In these studies, parameter extraction of solar cells can be done by using least squares method, linear / nonlinear iterative optimization algorithms or recently developed heuristic algorithms. In 2009, the work by Ye et al. was to determine the solar cell parameters by fitting the experimental voltage-current (V-I) data given using the Particle Swarm Optimization (PSO). The results were also compared with the data obtained by the Genetic Algorithm (GA). The V-I characteristics of the proposed method has shown that it gave better results than the GA with respect to the conformance function value, computation time and parameter accuracy criterion for both single and double diode models. In addition to these results, they showed that the PSO method does not require close approximation to the solutions when compared to traditional gradient (derivative) based methods, but only requires wide range values for each parameter. They indicated that solar cells are easily applicable technique, an accurate and fast for parameter deduction based on the V-I characteristics of the proposed PSO technique [2]. In 2011, Ishaque et al. predicted the factors of photocurrent, saturation currents, series resistances, parallel circuit resistances and ideality generated by Genetic Algorithm (GA), PSO, boundary-based and penalty-based evolutionary algorithms and current-voltage characteristics of photovoltaic cells in their study. With these methods, they compared the performances according to the correctness of solution, solution consistency, convergence speed, calculation efficiency and required control parameter numbers. According to the comparison result, the applicability of the penalty-based evolutionary algorithm was confirmed by the I-V data set obtained from the experiments [3]. In 2013 Khanna et al. optimized the above parameters produced based on the voltage-current characteristics of PSO photovoltaic cells. They verified the approach using industrial photovoltaic cells [4]. In another study they did in 2015, they developed a new equivalent circuit model, which is three diodes to model industrial crystalline silicon solar cells in large areas. The PSO algorithm was used to estimate parameters of solar cell which are the two-diode model and the proposed three-diode model by V-I characteristics measured using a solar simulator. Finally, they compared the proposed three-diode model with the two-diode model [5]. In the year 2017, Amokrane et al. developed the PSO algorithm to determine the unknown parameters of solar cell and photovoltaic models in their study. They produced adjustment parameters corresponding to the weight factors in the position equation

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of the PSO algorithm. The IPSO algorithm proposed by them provides better convergence and local minimum avoidance when compared to other algorithms [6]. In the study done by Abed in 2016, firefly algorithm was developed with local search and used to determine the parameters of the photovoltaic model. They showed that the local search enhanced method gives the best result by comparing the electromagnetism (EMW) with different algorithms without standard FA, electromagnetism-like (EM) algorithm and local search algorithm [7]. In 2018, Louzazni et al. used the FA algorithm to provide a proper model of solar cells that are single, double and photovoltaic modules. The data required to test the effectiveness and success of the FA optimization technique is based on the results in the previous literature, on the experimental data and on the nonlinear function of the photovoltaic and solar cell properties. From the obtained results and statistical analysis, it can be observed that the proposed FA obtains the sum of square errors comparing and estimated and experimental data obtained square root (RMSE), sum of squared errors (SSE) and mean absolute error (MAE). From the obtained results and statistical analysis, it can be observed that the proposed FA obtains the sum of root mean square errors (RMSE), sum of squared errors (SSE) and mean absolute error (MAE) [8-9]. According to the results obtained from the literature, FA and PSO algorithms were found to be suitable for predicting the parameters of solar cells as they gave stable results.

In this study, the parameters of the single diode solar cell model are determined by Firefly and Particle Swarm Optimization algorithms. In this study, it was seen that the Firefly Algorithm gave more successful results than Particle Swarm Optimization and previous studies.

MODELLING AND ESTIMATION BY FIREFLY ALGORITHM AND PARTICLE SWARM OPTIMIZATION

A. *Single Diode Model*

Even though the recombination currents and diffusion are linearly independent, both currents are brought together by the incorporation of the nonphysical diode ideality factor (n) [10]. The single diode solar cell model is represented using the equivalent electrical circuit shown in Figure 1. This model is known as the single-diode solar cell model and is widely used to represent the behavior of the solar cell. The voltage-current (V- I) characteristic of this model was measured by using experimental data and the parameters were determined by matching the model to experimental data.

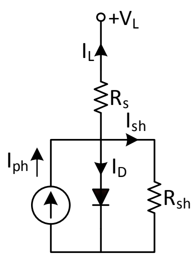

Figure 1. Equivalent circuit of a single diode model

The single diode solar cell model has been reduced to the following equation (1) :

$$I_L = I_{ph} - I_{sd}\left[\exp\left(\frac{q(V_L + I_L R_S)}{nkT}\right) - 1\right] - \left(\frac{V_L + I_L R_S}{R_{sh}}\right) \quad (1)$$

As a result, there are unknown parameters as Isd, Rsh, Rs, Iph, n. In this equation, parameters of the model such as Isd saturation current, Iph photo current, Rsh parallel circuit resistance (shunt), Rs series resistance, and n ideality factor are determined. Here VL is the solar cell output voltage, q is the electronic charge (1.60217646 x 10-19 C), k is the Boltzmann constant (1.381 x 10– 23 J/K), Vt (q/nkT) is the thermal voltage and T is the temperature in the Standard Test Conditions (STC = 25 ° C, 1000 W / m2 and A.M 1.5).

Before running the optimization algorithms, an objective function or performance criterion must be defined. The objective function determined in this study is determined by the objective functions of the Absolute Errors Total (IAE) in Eq (2). This objective function problem is being tried to be minimized.

$$IAE = \int |e(t)| dt = \int |y(t) - r(t)| \, dt \quad (2)$$

To create the objective function of the single-diode solar cell model, the function is rewritten in the following homogeneous equations using the current-voltage relationships given in Eq (1):

$$f_i(V_L, I_L, R_s, R_{sh}, I_{ph}, I_{sd}, n) = 0 \quad (3)$$

For a new objective function for a measurement group, the IAE sum is defined as:

$$\sum_{i=1}^{N} \left| f_i(V_L, I_L, R_s, R_{sh}, I_{ph}, I_{sd}, n) \right| \quad (4)$$

In Eq. (4) N is the value, V_L and I_L are the measured current and voltage values. The FA and PSO algorithms and the objective function during the optimization process are minimized according to the parameter set. Theoretically, the exact values of the parameters are obtained when the objective function has a value of zero.

B. *Parameter estimation by Firefly Algorithm*

The firefly method is an algorithm originally developed by Xin-She in 2008. Firefly method, a population based meta-heuristic algorithm, is used to optimize multiple model functions. This method has been developed based on observing social behaviors of fireflies.

This method has been chosen to obtain local maximum / minimum points. The most important difference between the use of firefly swarm optimization and other optimization algorithms in multimodal function optimizations is to efficiently place maximum / minimum points and dynamic decision making of the individuals in the swarm.

When the behavior of fireflies is regulated, the following conclusions arise [11];

• Fireflies can attract other fireflies using regardless of their sex.

• The attractiveness of fireflies is proportional to their light, their brightness. Those who are too bright according to their light, move the less bright ones towards themselves.

• The value is determined by the fitness function to be used to solve the problem that will be optimized depending on the brightness of fireflies.

There are two main issues in the FA. The first is to change the intensity of light and form the attractiveness. The other is the attractiveness of fireflies is determined by their brightness. The aim function is associated with the acquired appeal.

The light intensity (I) of fireflies is given in equation (5). This value depends on the initial light intensity (I_0), the gamma (γ) and the distance (r).

$$I = I_0 e^{-\gamma r} \tag{5}$$

In Equation (6), the initial value β_0=0) that gives the attractiveness of fireflies (β) is the value at which the distance between two fireflies is zero. Attractiveness depends on square of the distance, gamma and initial value.

$$\beta = \beta_0 e^{(-\gamma r^2)} \tag{6}$$

Equation (6) can be used to simplify operations, since calculation of attractiveness using Equation (7) can sometimes be difficult [12].

$$\beta = \frac{\beta_0}{1+\gamma r^2} \tag{7}$$

The distances of the fireflies to each other are important, because both light intensity and attractiveness vary with distance. So these changes will determine the movement of fireflies. The distance can be calculated using equation (8).

$$r_{ij} = x_i - x_j = \sqrt{\sum_{k=1}^{d}(x_{ik} - x_{jk})^2} \tag{8}$$

Fireflies move towards fireflies, which are brighter and more attractive. This motion can be expressed by equation (9). The second expression in equality comes from the attractiveness formula. That is, it is expressed by the multiplication of the distance and the attractiveness between two fireflies. In the third expression, α is the random parameter and ε is a vector from the Gaussian distribution [11]. The α random parameter is usually generated randomly between [0,1].

$$x_i^{t+1} = x_i + \beta_0 e^{-\gamma r^2 ij}\left(x_j - x_i\right) + \alpha\varepsilon_i^t \tag{9}$$

When β_0=0, the motion is only dependent on the random walk. On the other hand, γ parameter has a very important effect on convergence speed. The value of this parameter can theoretically take any value from the range of $\gamma \in [0,\infty)$. Optimization varies depending on the problem. It is usually between 0.1 and 10. In Fig. 2., the pseudo code of FA is given.

```
The objective function is determined. f(x), x = (x1, ..., xd)T .
n number firefly initial population values are produced.
Light intensity in xi is calculated by (Ii) (Ii) f(xi)
Light absorption is determined by ( γ )
while (stopping criterion),
for i = 1 : n
    for j = 1 : n
        if (Ii < Ij)
            Fireflies move from i to j.
        end if
    The attractiveness changes through r and exp[−γr2] .
    New solutions are calculated and light intensity is updated.
    end for j
end for i
Fireflies are sorted and the global best (g *) is found.
end while
```

Fig. 2. Pseduo code of FA

C. Parameter estimation by Particle Swarm Algorithm

Particle Swarm Optimization is an algorithm developed by Kennedy and Eberhart, inspired by the ability of birds, fish and herbs to adapt to their environments, to find rich food sources, and to escape from hunters [13].

In each iteration, the direction in which the particle will travel and at which speed it will travel in the solution space is the combination of the best coordinates of other particles (positions) and best personal coordinates of the particle. As the particle reaches the optimum, it adjusts the next step to both the best position for it (closest to the optimum) and the position of the particle with the best fitness value in the swarm.

Each individual in the swarm is called particle, and each particle has information about position (p) and velocity (v) in the swarm. This position and velocity information is updated in every iteration according to the best position (pbest) of the particle in the iteration, the best position in the swarm (gbest) and the velocity information at that moment. At each iteration, as the speed of the individuals is updated with equation (10), their positions are updated according to equation (11) [14, 15].

$$v_{t+1} = v w_t + c_1 r_1 \left(p_{best} - p_t\right) + c_2 r_2 \left(g_{best} - p_t\right) \tag{10}$$

$$p_{t+1} = p_t + v_{t+1} \tag{11}$$

```
        Assign initial parameters
        Create initial population
        For each particle;
        Calculate fitness value
        Find pBest, find gBest
Do
 For each particle;
 Calculate the particle velocity according to equation (1)
Calculate the particle position according to equation (2)
            Calculate fitness value
Update pBest, update gBest, Update v value
```

Fig.3. Pseudo code of PSO

II. SIMULATONS RESULTS

In this study, optimization of R_S, R_{sh}, I_{ph}, I_{SD}, n parameters of the single diode solar cell model were determined by FA and PSO algorithms. The measured voltage and current values are selected as the limit intervals of the optimization. It was also compared with FA, PSO and the results in the literature.

of optimization, parameters of PSO and FA algorithms are first determined from the "Design method" section. Then, if "Design" button is pressed, parameters of R_S, R_{sh}, I_{ph}, I_{SD}, n are displayed in the "Estimated parameters" fields. In addition, the I-V characteristics of the single-diode solar cell are plotted.

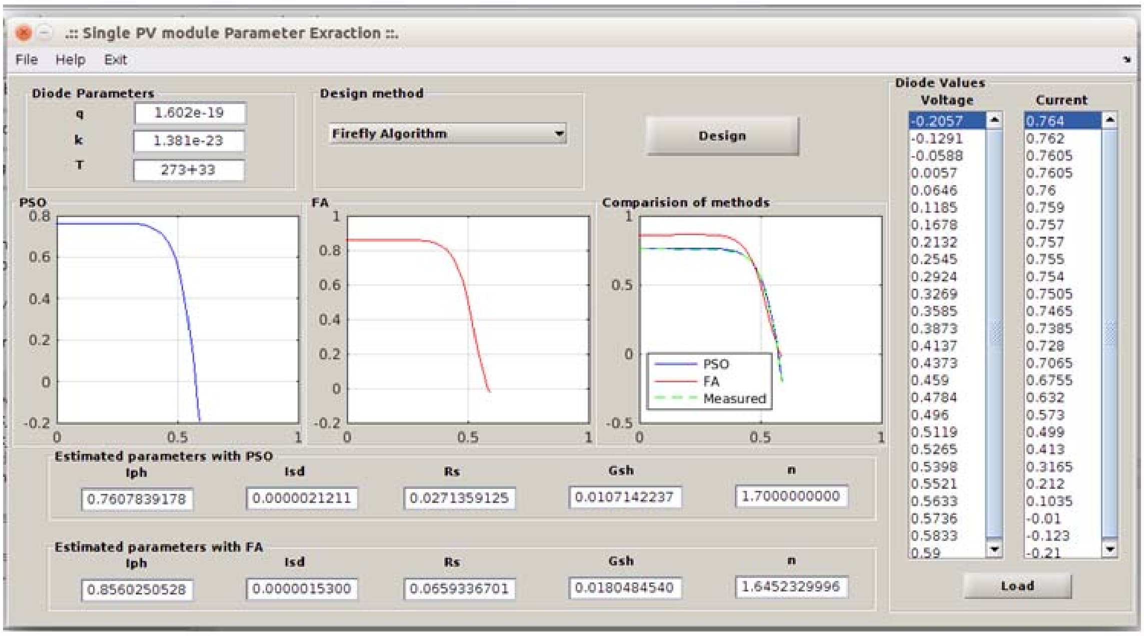

Fig. 4. Determination of the parameters of the single-diode solar cell

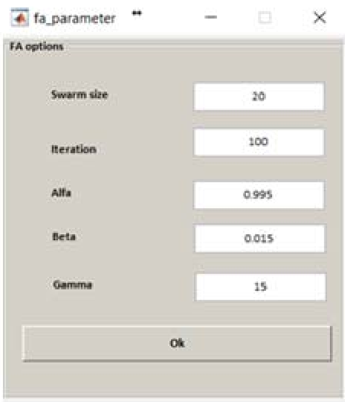

Fig. 5a. Parameters of FA

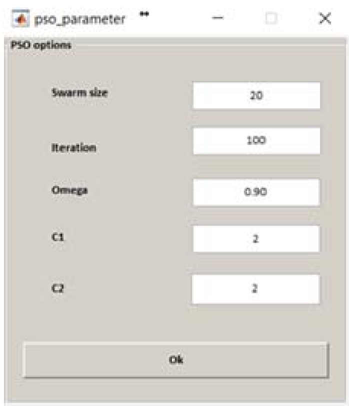

Fig. 5b. Parameters of PSO

Simulation studies are run on Ubuntu 14.04.5 LTS operating system on a computer with Intel (R) Core (TM) i5-5200U CPU @ 2.70 Ghz, 64 Bit, 4GB RAM. A graphical interface based on user friendly MATLAB-GUI (Graphical User Interface) was created to show the effectiveness of the developed method.

As shown in Fig. 4., diode values and parameter values are determined firstly when a single diode solar cell model is developed. In this simulation, the true measured current-voltage data of the solar cell is used [16]. If the "Load" button is pressed, the actual measured current-voltage data is loaded to the design. In addition, the algorithm to optimize the system to be designed is selected. For the start

Figure 4 shows the determination of the parameters of the single-diode solar cell according to the function given in the Equation 1.

Control parameters are entered through the window created by the interface in Figures 5a and 5b to determine the parameters of the FA and PSO algorithms. In order to compare the algorithms, 20 population sizes and 100 iteration numbers are taken as the same. Here, the FA algorithm's alpha parameter is 0.995, beta parameter is 0.015, and gamma is 15. The inertia parameter of the PSO algorithm is determined as 0.9, and the correlation coefficients are determined as 2. The results of the PSO and FA algorithms already made in the literature and made in this study for the parameters of the PV panel are given in Table 1. The FA algorithm shows the best result in comparison with the others, depending on the determined IAE criterion.

TABLE 1. ESTIMATED PARAMETERS FOR THE SINGLE DIODE MODEL

Parameter	Ref. Easwarakhanthan et al. (1986)	Ref. Bouzidi et al. (2007)	Ref. AlRashidi et al. (2011)	PSO	FA
I_{ph}	0.7617	0.7607	0.7620	0.7613	0.7609
I_{sd} (μA)	0.9980	0.3267	0.4798	0.1860	0.5103
R_s(ohm)	0.0313	0.0364	0.0345	0.0388	0.0344
R_{sh} (S)	0.0156	0.0166	0.0232	0.0245	0.0158
n	1.6	1.4816	1.5172	1.4270	1.5289
IAE	0.05599	0.21222	0.03712	0.0291	0.0270

In order to measure the consistency of the FA and PSO parameters, each algorithm was run 20 times to look at the average of the errors and the standard deviations. According to the simulation results given in Table 2, it is seen that the error rate of the FA algorithm is smaller, it can also be understood from the standard deviation that it gives the closest results to the average.

TABLE 2. SIMULATION RESULTS OF FA AND PSO ALGORITHMS

Algorithm	Error Rate	Standard deviation of the error
PSO	0.095811	0.0573
FA	0.080717	0.0400

III. CONCLUSIONS

In this study, PSO and FA algorithms are used to estimate solar cell parameters. Solution space is tested using real recorded data. The correctness, consistency, convergence speed, computational efficiency and performance of the PSO and FA algorithms developed according to Table 1 are seen to be improved.

As a result, it was seen that the results obtained by using the FA algorithm to determine the parameters of the PV panel are better when compared to the results of PSO and other studies in the literature.

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