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Photovoltaic (PV) Parameter Extraction using a Hybrid Algorithm based on Spotted Hyena-Ant Lion Optimization

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Abstract: The parameter extraction of Photovoltaic (PV) cell and module is a necessary to simulate and evaluate the performance of the PV system. The parameter extraction is a complex and challenging task due to its non-linear nature. Researchers are used several metaheuristic algorithms to solve the non-linear problem of parameter extraction. However, the demand for most accurate and reliable methods is increasing to get precise estimation of parameters. In this paper, a novel hybrid optimization algorithm is proposed based on the Spotted-Hyena optimization (SHO) and Ant Lion Optimization (ALO). The hybrid method is called as Spotted Hyena – Ant Lion (SH-AL) optimization. The optimization algorithm is applied in two stages. In stage 1, essential parameters are identified and extracted using SHO and passed to stage 2. In stage 2, identified parameters are optimized using ALO for accurate model of PV cell. Different type of PV cells such as thin film, mono and multi crystalline are examined under various irradiance conditions to extract the parameters. The proposed algorithm is validated by comparing the results with other algorithms and proposed algorithm is proved its superiority.

Keywords: PV cell, Parameter extraction, Optimization, Spotted Hyena Optimization (SHO), Ant-Lion Optimization (ALO).

1. Introduction

The use of solar energy is increasing due to environmental concerns and abundance of solar energy. Solar PV system are having lot of benefits such as pollution free, noise free, grid compatibility and easy installation [1]. The utility level contribution of PV system for energy production is increasing [2] and it is fastest growing renewable energy source [3]. The PV system integration with existing grid leads several issues in the grid operation because PV system output dynamical changes with weather conditions. Which enable to study the PV system performance in a virtual environment before actual integration to the grid. The PV cell has to be modelled accurately to simulate the PV cell. The PV cell will be represented as equivalent circuit and circuit parameters must be extracted for better analysis of the PV cell. The PV cell parameter extraction is a complex problem due to its non-linear nature. The non-linearity increases with the increase of PV cell and Modules which results the development of unknown parameters and impact the system efficiency. The non-linearity of the system is responsible for the increase in parasitic parameter content. These parasitic parameters greatly influence the IV and PV characteristics of PV module and system finally [4]. The parameter estimation problem is a non-linear problem and non-linear problems are effectively solved using metaheuristic optimization algorithms [5].

In the literature, researchers are used different methods to eliminate the parasitic parameters and extraction of required parameters. Among all the methods, use of metaheuristic techniques is gaining popularity due to their capacity to handle the non-linearity. An adaptive differential algorithm is used [6] to eliminate the parasitic parameters of the PV system. An advanced Either-or Teaching Learning based algorithm is used [7] for parasite parameter elimination and results are compared with experimental data. A new algorithm called gaining–sharing knowledge-based algorithm [8] is implemented to identify and extract the unknown parameters. A hybrid algorithm based on Grey Wolf Optimizer and Cuckoo Search [9] is used to extract the parameters for single diode and double diode model by considering the experimental data. Particle-Swarm

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optimization [10] used for parameter extraction of three diode lumped model of PV cell. Lambert W-function [11] is proposed for exact representation of PV cell. Parameters are extracted using Multi scale parallel chaos optimization algorithm [12] for different PV cell models. The parasitic parameters are eliminated effectively using Adaptive Particle Swarm Optimization Mutation [13] and evaluation is done based on the Root mean square Error elimination process. An Improved Shuffled Complex Evolution algorithm [14] for extraction of parameters from the different models of PV cell model. The parameters are extracted in a comprehensive manner in order to escape from local minima. The parameters are extracted for different types of PV modules under different solar irradiance and temperature conditions using application-oriented Supply-Demand-Based Optimization [15] and Hybrid Differential Evolution in associated with Wale Optimization [16]. Parameters are evaluated using Winner- Leading Comparative Swarm Optimizer with Dynamic Gaussian Mutation Algorithm [17] and compared with experimental data. In ref [18], improved ant lion optimization is used to estimate the unknown parameters of a solar cell. The parameters are extracted using modified swarm optimization [19] by considering least mean square error as objective function. Authors in [20] use Coyote Optimization Algorithm for extraction of parameters for different diode models and cell types. The weighted mean of vectors (INFO) algorithm [21] is statistically proved it's superiority to extracts unknown parameters. Forensic-Based Investigation Algorithm [22] is used to extract the 9 unknown parameters of triple diode model of PV cell. Hunter–Prey and Wild Horse Optimizers is used to extract the parameters of three diode model of PV cell and route mean square error (RMSE) is used as objective function [23]. An improved variant of Flower Pollination Algorithm (FPA) is used in [24], in this method, accuracy of the FPA algorithm is improved with the help of dynamic switch probability and a dynamic step size. Turbulent Flow of Water-Based Optimization is used [25] along with new objective function called sum of squared errors. Parameters are estimated under practical operating conditions [26] using Artificial Hummingbird Algorithm.

From the literature, it is observed that several metaheuristic methods are used for parameter extraction and elimination of parasitic parameters. The methods still have several issues such as accuracy, reliability, convergence and trapping into local optima etc. Hence, there is always a scope for improvements in those issues. In this paper, a hybrid algorithm is developed by combining the SHO and ALO algorithms as called as SH-AL Optimization algorithm. The parameter extraction done in two different stages that are handled by SHO and ALO separately. SHO is used to filter the essential parameters and passes to the ALO. ALO will optimize the parameters for accurate modeling of PV cell. Parameters are extracted for different types of PV cells such as thin film, mono and multi crystalline cells. Parameter extraction is examined under different irradiance conditions for different rated modules. The results are compared with the existing methods and synthetic data to validate the effectiveness of the proposed hybrid SH-AL optimization algorithm.

The major contributions in this paper are as follows:

- A novel hybrid method is developed based on SHO and ALO algorithms.
- Essential parameters are filtered using SHO and passes to ALO.
- ALO optimizes the parameters and provides accurate PV cell modelling.
- The robustness of the proposed algorithm is tested by extracting the parameters of different types of PV cells and power rating.
- The results are validated by comparing the IV curves of both experimentation and PV cell model using extracted parameters.

2. PV Modelling

Single diode (SDM) and double diode (DDM) models are commonly used cell models [19], [20], [21], [27]. SDM and DDM are having five and seven parameters respectively. DDM is very complex but provides more accurate cell model. In this paper, DDM is used to validate the performance of the proposed algorithm and other algorithms for the purpose of comparison. The equivalent circuits of both SDM and DDM are shown in Fig. 1.

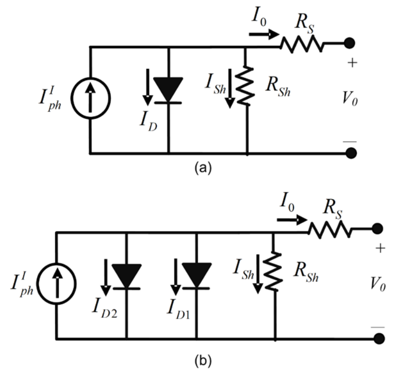

Figure 1. Equivalent circuit of PV cell a) SDM b) DDM

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A. Single Diode Model

As shown in Fig. 1(a), SDM has a diode and a resistance (R_{Sh}) in parallel with ideal current source. Cell also has a series resistance (R_S) due to the mental contacts. Kirchhoff's current law is applied to Fig. 1(a) to get the output current (I_0).

$$I_0 = I^I_{ph} - I_D - I_{Sh} \tag{1}$$

The diode current (I_D) and current through shunt resistance (I_{Sh}) is expressed by

$$I_D = I_{rs}\left[\exp\left(\frac{q(V_0 + I_0 R_S}{n \cdot k \cdot T}\right) - 1\right] \tag{2}$$

$$I_{Sh} = \frac{V + I_0 \cdot R_S}{R_{Sh}} \tag{3}$$

Where I_{rs} is the reverse saturation current for diode, n is the ideality factor, k is the Boltzmann's constant and value of k is 1.380×10^{-23} *J/K*, q denotes the charge of an electron (1.602×10^{-19} C) and T denotes the cell absolute temperature.

By substituting Eq. (2) and Eq. (3) into Eq. (1), the solar cell output current is expressed as

$$I_0 = I^I_{ph} - I_{rs}\left[\exp\left(\frac{q(V + I_0 \cdot R_S)}{n \cdot k \cdot T}\right) - 1\right] - \frac{V + I_0 \cdot R_S}{R_{Sh}} \tag{4}$$

B. Double Diode Model

The DDM consists of seven unknown parameters, i.e., Photo current (I^I_{Ph}), diodes reverse saturation currents (I_{rs1} and I_{rs2}), ideality factors (n_1 and n_2), R_s and R_{Sh}.

The output current equation is calculated by

$$I_0 = I^I_{ph} - I_{rs1}\left[\alpha_1\right] - I_{rs2}[\alpha_2] - \frac{V_0 + I_0 \cdot R_S}{R_{Sh}} \tag{5}$$

where,

$$\left.\begin{aligned} \alpha_1 &= \exp\left(\frac{q(V_0 + I_0 \cdot R_S)}{n_1 \cdot k \cdot T}\right) - 1 \\ \alpha_2 &= \exp\left(\frac{q(V_0 + I_0 \cdot R_S)}{n_2 \cdot k \cdot T}\right) - 1 \end{aligned}\right\} \tag{6}$$

B. Objective Function

Parameter extraction problem is solved by using Root Mean Square Error (RMSE) as an objective function. The error is obtained in between the experimental data and estimated values.

The RMSE is formulated as

$$RMSE = \sqrt{\frac{1}{N^I}\sum_{i=1}^{N^I} F(V_E, I_E, \lambda)^2} \tag{7}$$

Where, $F(V_E, I_E, \lambda)$ is the error function, V_E, I_E are the experimental values of voltage and current. N^I is the set of parasitic parameters data, and λ represents the unknown vector parasitic parameters such as for SDM λ consist of $I^I_{Ph}, I_{rs}, n, R_s,$ *and* R_{sh} and for DDM the λ consist of $I^I_{Ph}, I_{rs1}, I_{rs2}, n_1, n_2, R_s,$ *and* R_{sh}.

3. Proposed Hybrid SH-AL Algorithm

The proposed SH-AL technique is the interlinked process of optimization with Spotted Hyena Optimization (SHO) algorithm and Ant-Lion Optimization (ALO) algorithm.

A. Spotted hyena optimization (SHO)

The SHO algorithm is developed based on the behavior of Spotted Hyena [28]. Searching, encircling, haunting, and attacking are the important steps in SHO algorithm. In the same manner the extraction of solar parameters is eliminated from the PV module i.e., the nonlinear parasitic parameters are identified and selected. After selection, they are filtered in the priority order and finally the evaluation takes places after several iterations. In order to select the extracted parameters (encircling) of spotted hyena is calculated as

$$\left.\begin{aligned} \vec{D}_H &= \left| \vec{B}\cdot \vec{P}_P(x) - (\vec{P}(x)) \right| \\ \vec{P}(x+1) &= \vec{P}_P(x) - \vec{E}\cdot \vec{D}_H \end{aligned}\right\} \tag{8}$$

The distance between prey (extracted parameter) and spotted hyena (computation) is denoted as $\overrightarrow{D_{H.x}}$ indicates the current iteration. The position vector of prey and computation is represented as $\overrightarrow{P_p}$ and $\vec{P}$, $\vec{B}$, and $\vec{E}$ are the coefficient vectors. Further computation of $\vec{B}$ and $\vec{E}$ are represented in Eq. (9).

$$\left.\begin{aligned} \vec{B} &= 2\cdot r\,\vec{D}_1 \\ \vec{E} &= 2\,\vec{H}\cdot r\,\vec{D}_2 - \vec{H} \\ \vec{H} &= 5 - (i^I \times \frac{5}{i_{Max}}) \end{aligned}\right\} \tag{9}$$

$\vec{H}$ is the linearly decreased variable and value changes from 5 to 0. Random extracted parameters $r\vec{D}_1$ and $r\vec{D}_2$ are in the range of [0, 1]. The effective searching space equations are represented in terms of iterations (N) are depicted in Eq. (10).

$$\left.\begin{aligned} \vec{D}_H &= \left|\vec{B}\cdot\vec{P}_H - \vec{P}_K\right| \\ \vec{C}_H &= \vec{P}_K + \vec{P}_{K+1} + \ldots\ldots\ldots\ldots\vec{P}_{K+N} \\ \vec{P}_K &= \vec{P}_H - \vec{E}\cdot\vec{D}_H \end{aligned}\right\} \tag{10}$$

The number of iterations is computed by using Eq.

$$\left.\begin{aligned} N &= Count_{n^l}(\vec{P}_H, \vec{P}_{K+1}, \ldots\ldots(\vec{P}_H + \vec{M})) \\ \vec{P}(x+1) &= \frac{\vec{C}_H}{N} \end{aligned}\right\} \tag{11}$$

In given search space the number of parasitic parameters extracted (n^l) is similar to best optimal solution. $\overrightarrow{C_H}$ is the group of optimal solutions. $\vec{M}$ is the movement of extracted parameters in the range of [0.5, 1]. During haunting process, the spotted hyena searches for prey, similarly in solar extraction process the parasitic parameters are searched by fitness parameters which are important for obtaining the optimization solution. Fig. 2 (a), depicts about the searching mechanism of extraction parameters in the PV module. The suitable fitness values are implemented for eliminating the above-mentioned issues in solar panel which is shown in Fig. 2 (b) i.e., in the form of the spotted hyena is attacking on the prey.

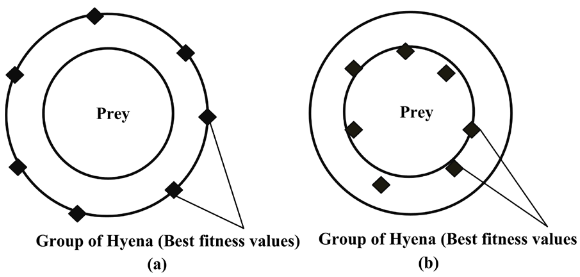

Figure 2. The behavior of Spotted Hyena during (a) Searching for prey, (b) Attacking on prey.

The complex bridge system is formed during the computation process using SHO algorithm. The fitness value is mainly responsible for the formation of bridge. The purpose of bridge is to search for non-linear parasitic parameters and suitable evaluations are used to eliminate the unknown parameters from the PV module. The working of SHO algorithm is shown in Fig. 3 as a flow chart.

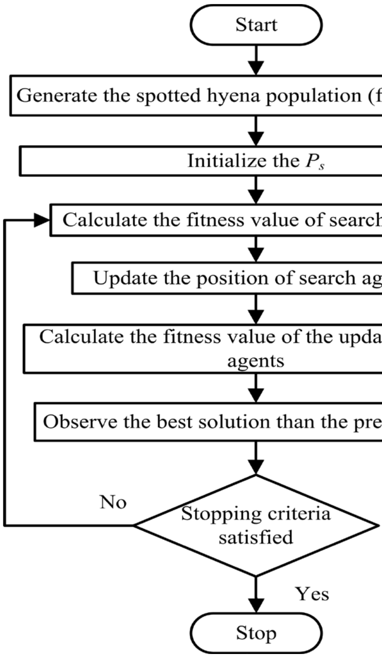

Figure 3. Flowchart of the Spotted Hyena Optimization (SHO) algorithm.

B. Ant lion optimization (ALO)

The ALO algorithm is inspired from the haunting behavior of ant lion larvae [29]. IThe strategy of the ant lion is to build the traps, casual walk of ants, rebuild the traps for effective result, attracting the ants and catches the prey. Similarly, in the same manner the parasitic parameters (I^{I}_{Ph}, R_S, R_{Sh}, n_1, n_2, I_{rs1}, and I_{rs2}) are eliminated from PV module. The ALO is suitable for solving non-linear parameters like solar extracted parameters (ants) in a limited search space, also useful for determining the unknown parameter data. Random selection of extracted parameter data, i.e., random walk of ants is mathematically represented as

$$X(t) = 0, \text{culsum}(2r(t_1)-1), \text{culsum}(2r(t_2)-1), \ldots\ldots\ldots\ldots\ldots \text{culsum}(2r(t_n)-1) \quad (12)$$

here, culsum= cumulative sum
n= maximum iterations
t= step of random walk (extracted data)
The random function has the limits of

$$r(t) = \begin{cases} 1 & \text{if } rand > 0.5 \\ 0 & \text{if } rand < 0.5 \end{cases} \quad (13)$$

rand= random generator (0, 1)

In order to maintain the extracted parameters within the boundaries of search space, the random function should be normalized using the following equation [18].

$$X_i^t = \frac{(X_i^t - a_i) \times (D_i^t - a_i)}{(b_i - a_i)} + C_i^t \quad (14)$$

The Eq. (14), consists of C_i^t, D_i^t which means minimum and maximum of i^{th} variable at t^{th} iteration. The trapping of ants (extracted parameters) changed at every instant of time within the eliminating zones. They are represented in following equation.

$$\left.\begin{aligned} C_i^t &= Antlion_j^t + C^t \\ D_i^t &= Antlion_j^t + D^t \end{aligned}\right\} \tag{15}$$

$Antlion_j^t$ denotes the selection of j^{th} antlion at t^{th} iteration. Based on their fitness value, ALO uses the roulette operator. The concept of using this operator is attracting the more extracted data using filtration process. The filtration is calculated as [18].

$$\left.\begin{aligned} D^t &= \frac{D^t}{I} \\ C^t &= \frac{C^t}{I} \end{aligned}\right\} \tag{16}$$

Where, I is calculated as shown in Eq. (17).

$$I = 10^{\tau \frac{t}{M}} \tag{17}$$

As number of iterations are changed at every interval of time, the value of τ also changes i.e., when $t/M > 0.75$ and $t/M > 0.9$ the τ values are 4 and 5. The updated solution of antlion process is represented as

$$\left.\begin{aligned} Antlion_j^t &= Ant_i^t \\ Ant_i^t &= \frac{R_A^t + R_E^t}{2} \end{aligned}\right\} \tag{18}$$

R^t_A and R^t_E are the random walk (solar parameters extraction) around the roulette wheel and elite at t^{th} iteration. The step-by-step process of ALO algorithm is depicted in Fig. 4.

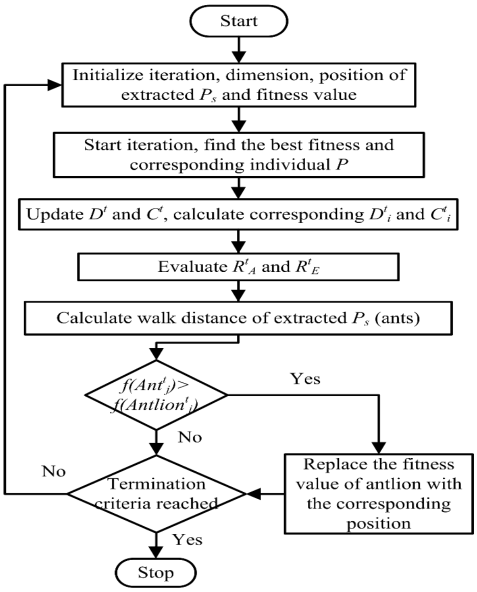

Figure 4. Flowchart of the Ant Lion Optimization algorithm.

C. Hybrid SH-AL algorithm

In SHO algorithm the computation process is easier for less than five variables beyond that the computation process is complex. Whereas in ALO algorithm the searching agents finds minimum number of extracted parameters which is not suitable for the effective PV module performance. Therefore, proposed SH-AL technique is introduced to obtain the effective performance of extracted parameters. The operation of hybrid algorithm is simply explained as the searching strategy of spotted Hyena and the hunting behavior of ant lions together obtain the required output i.e., initially, the suitable extracted parameters are searched by the proper fitness values, after that these values are updated in the form of random walks (remaining extracted parameters). Finally, these parameters are hunted (computed) by suitable ant lions (proper fitness values). Therefore, the maximum parasitic solar parameters are extracted from the PV module. The behavior of proposed SH-AL technique is depicted in Fig. 5.

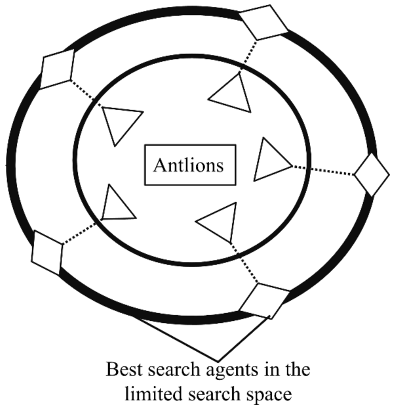

Figure 5. Searching and hunting strategy of SH-AL algorithm.

The flow chart describes about the step-by-step process of proposed SH-AL technique is shown in Fig.6.

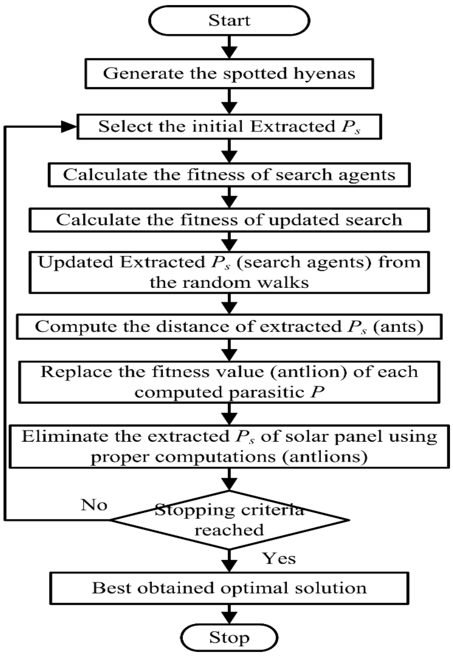

Figure 6. Flow chart of proposed Hybrid SH-AL optimization algorithm.

4. Results and Discussions

The proposed SH-AL optimization algorithm is used to extract the parameters of four DDM PV modules which are having the rating of 80W, 275W, 300W and 410W respectively. The parasitic parameters are extraction process is executed via MATLAB/Simulink platform using 1.7 GHz Intel core i5 processor, 8 GB RAM Laptop. The algorithm parameter values used for simulation is given in Table 1.

Table 1. Algorithm parameters for optimization

	Parameters
SHO	Population size = 30 Maximum iterations = 800 $\vec{H}$ = [5, 0] $\vec{M}$ = [0.5 1]
ALO	Population size = 30 Maximum iterations = 800 Dimension = 10

The performance of proposed algorithm is compared with other existing algorithms like Adaptive Guided Differential Evolution (AGDE) [30], Simulated Annealing (SA) [31], Bacterial Foraging Algorithm (BFA) [32], Coyote Optimization Algorithm (COA) [20], Artificial Bee Colony (ABC) [33], and Social Learning Particle Swarm Optimization (SLPSO). The results are also compared with synthetic data (SD). The Root Mean Square Error (RMSE) is used to measure the error in quantitative data. The convergence characteristics for different algorithms along with proposed algorithm is shown in Fig. 7 for DDM solar panel. SH-AL has better starting and achieved global optima with lesser computations compared to other algorithms.

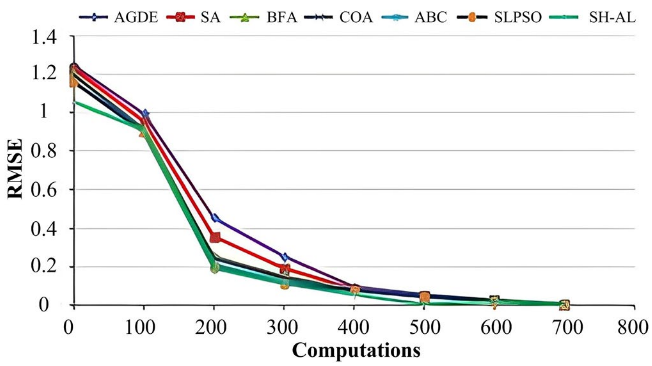

Figure 7. The convergence curve for the DDM solar panel.

The extracted parameter values for DDM for different algorithms for 80W solar panel is given in Table 2. From the Table 2, it is clear that proposed algorithm is giving better parameter extraction and parameter values which are nearer to the SD values. Other algorithms estimated some of the parameters near to synthetic data like ideality factors but in overall SH-AL is dominated the other algorithms by estimating the parameter values near to synthetic data. The deviation of parameter values with SH-AL is very less compared to other existing methods. The SLPSO algorithm has closer to the proposed algorithm for few parameters but never has better than the proposed algorithm. The proposed algorithm has better performance in terms of simulation time i.e., it has lesser simulation time.

Table 2. Extracted parameters for 80W panel

Algorithm	Parameter (P)							
	I^{l}_{Ph} (A)	I_{rs1}(μA)	I_{rs2}(μA)	R_S (Ω)	R_{Sh} (Ω)	n_1	n_2	Time (S)
SD	0.7845	0.3887	0.4236	0.0386	65.674	1.53	1.91	-----
AGDE	1.8427	1.6578	2.3214	0.4589	125.67	1.77	2.47	287
SA	1.6832	1.4789	1.9873	0.3678	108.98	1.71	2.18	225
BFA	1.4532	1.2595	1.5432	0.1837	97.274	1.68	2.06	197
COA	1.3893	0.9865	1.3794	0.0986	85.392	1.62	1.99	175
ABC	1.2487	0.6897	0.9491	0.0765	72.989	1.59	1.97	154
SLPSO	0.9832	0.4632	0.7525	0.0572	69.275	1.57	1.95	137
SH-AL	0.7867	0.3901	0.4290	0.0384	65.786	1.55	1.92	115

Table 3. Extracted parameters for 220W Solar panel

Algorithm	Parameter (P)							
	I^{l}_{Ph} (A)	I_{rs1}(μA)	I_{rs2}(μA)	R_S (Ω)	R_{Sh} (Ω)	n_1	n_2	Time (S)
SD	4.54	1.8754	2.4679	1.6785	435.982	1.74	1.88	-----
AGDE	5.85	3.6587	5.8793	3.7639	668.946	1.99	2.43	367
SA	5.23	2.9851	4.6582	2.9462	586.468	1.95	1.95	332
BFA	4.87	2.7643	4.2476	2.5765	554.864	1.94	1.96	298
COA	4.76	2.4298	3.8743	2.1579	516.872	1.89	1.99	265
ABC	4.61	2.2683	3.7643	1.9643	498.381	1.82	1.97	247
SLPSO	4.58	2.1843	3.3691	1.7439	474.916	1.77	1.96	229
SH-AL	4.51	1.7654	2.4472	1.6717	442.359	1.71	1.93	207

The parameter extraction results for 220W panel are given in Table 3 for different algorithms. From the observations, it is clear that the proposed SH-AL algorithm has shown its superiority over other existing algorithms for extraction of cell parameters. It gave less deviation from the SD values than other methods. However, I^{l}_{Ph}, n_1 and n_2 are having same deviation for SLPSO as compared to SH-AL but it is limited to only these three parameters and other parameters are having larger deviation comparatively.

The parameter extraction results for 300W panel are given in Table 4 for different algorithms. From the observations, it is clear that exiting algorithms estimated one or two parameters better than proposed algorithm. For example, n_1 has better estimation with all existing algorithms compared to proposed algorithm. However, their other parameter estimations highly deviated from the SD values. Hence, we can conclude that proposed SH-AL algorithm has better compromised parameter extraction compared to other existing algorithms.

Table 4. Extracted parameters for 300W Solar panel

Algorithm	Parameters (P)							
	I^{l}_{Ph} (A)	I_{rs1}(μA)	I_{rs2}(μA)	R_S (Ω)	R_{Sh} (Ω)	n_1	n_2	Time (S)
SD	7.65	3.1578	5.6578	4.3677	874.867	1.86	1.97	-----
AGDE	8.54	6.3785	9.1495	7.1479	1114.57 2	1.98	2.49	479
SA	7.97	5.8752	8.7274	6.8624	1086.32 9	1.91	2.28	416
BFA	7.95	5.2183	8.2579	6.4379	992.914	1.86	2.17	395
COA	7.91	4.8529	7.8516	5.9542	976.482	1.82	2.06	382
ABC	7.80	4.6494	6.9264	5.2632	912.752	1.79	1.99	347
SLPSO	7.71	4.2197	5.9472	4.7632	884.235	1.76	1.98	304
SH-AL	7.59	3.1271	5.5495	4.2482	864.621	1.74	1.93	286

The parameter extraction results for 410W panel are given in Table 5 for different algorithms. From the observations, proposed algorithm has shown its superiority in parameter extraction. The SLPSO algorithm has competed with proposed algorithm in some parameters but always ended with more deviations from SD values. The SLPSO algorithm predicted I^{l}_{Ph} better than proposed SH-AL algorithm.

Table 5. Extracted parameters for 410W Solar panel

Algorithm	Parameters (P)							
	I^l_{Ph} (A)	I_{rs1}(μA)	I_{rs2}(μA)	R_S (Ω)	R_{Sh} (Ω)	n_1	n_2	Time (S)
SD	8.57	5.7837	7.8472	6.5381	1045.741	1.93	1.99	----
AGDE	9.67	8.9269	11.7659	12.4371	1289.765	2.54	2.84	528
SA	9.32	7.3259	10.8582	11.8392	1176.847	2.11	2.66	486
BFA	9.16	6.8942	9.8638	10.5478	1105.752	2.07	2.54	463
COA	8.95	6.5219	9.1484	9.3281	1095.672	2.01	2.37	432
ABC	8.74	6.1823	8.4581	8.6383	993.762	1.99	2.19	396
SLPSO	8.62	5.9621	7.9369	7.9582	975.238	1.96	2.01	381
SH-AL	8.43	5.8328	7.7634	6.6428	941.365	1.91	1.98	374

From Table 2, Table 3, Table 4 and Table 5, it is observed that the existing algorithms are performed better than proposed SH-AL algorithm occasionally by estimating one or two parameters better than proposed algorithm. However, the proposed algorithm dominated other algorithms by better estimation of all parameters for different rated panels. The data provided in Table 2, Table 3, Table 4 and Table 5 supports superiority of the proposed SH-AL algorithm.
The proposed HS-AL technique is aslo used to estimate the parameters of different types of PV cells such as Poly Crystalline (SEP-300W, TSM 410W), Thin-film (SN-H 300W, FS-6430A), and Mono Crystalline (BBSM-300W, CS1U-410MS). The estimated parameters are given in Table 6 for all types of PV cells for different solar irradiance values. Mono crystalline PV cells take lessor time for parameter estimation.

Table 6. Estimated parameters for different types of PV cells under different irradiance conditions.

Parameters	Poly Crystalline		Thin-film		Mono Crystalline	
	SEP-300W	TSM 410W	SN-H 300W	FS-6430A	BBSM-300W	CS1U-410MS
G=1000W/m²						
I^l_{Ph} (A)	8.02	9.46	8.86	9.12	6.26	7.14
I_{rs1} (A)	7.97×10^{-6}	10.87×10^{-6}	5.68×10^{-6}	7.47×10^{-6}	4.42×10^{-6}	6.34×10^{-6}
I_{rs2} (A)	5.29×10^{-7}	6.47×10^{-7}	2.87×10^{-7}	4.05×10^{-7}	3.52×10^{-7}	5.72×10^{-7}
R_s (Ω)	6.81	8.77	5.48	7.93	4.32	6.19
R_p (kΩ)	816.25	734.2	698.62	745.10	598.18	495.08
n_1	1.85	1.63	1.18	1.36	1.08	1.16
n_2	1.93	1.87	1.65	1.54	1.46	1.41
Time *(Sec)*	0.5	0.43	0.41	0.39	0.31	0.29
G=800W/m²						
I^l_{Ph} (A)	7.55	5.621	6.75	5.49	5.57	4.85
I_{rs1} (A)	6.12×10^{-6}	8.91×10^{-6}	4.53×10^{-6}	5.47×10^{-6}	3.97×10^{-6}	5.17×10^{-6}
I_{rs2} (A)	7.29×10^{-7}	8.07×10^{-7}	6.78×10^{-7}	5.91×10^{-7}	5.22×10^{-7}	4.18×10^{-7}
R_s (Ω)	4.738	5.718	4.762	6.716	5.72	3.82
R_p (kΩ)	716.73	654.72	548.58	615.38	648.22	518.12
n_1	1.21	1.32	1.25	1.42	1.82	1.78
n_2	1.24	1.32	1.46	1.57	1.43	1.37
Time *(Sec)*	0.53	0.42	0.40	0.39	0.31	0.30
G=600W/m²						
I^l_{Ph} (A)	5.920	4.512	5.742	4.651	3.732	2.292
I_{rs1} (A)	5.97×10^{-6}	6.87×10^{-6}	4.98×10^{-6}	5.47×10^{-6}	4.17×10^{-6}	5.07×10^{-6}
I_{rs2} (A)	6.19×10^{-7}	5.67×10^{-7}	4.48×10^{-7}	5.049×10^{-7}	4.12×10^{-7}	3.98×10^{-7}
R_s (Ω)	4.006	3.162	3.73	2.812	2.894	2.227
R_p (kΩ)	596.21	464.83	628.83	545.12	727.34	508.46
n_1	1.15	1.21	1.26	1.31	1.35	1.52
n_2	1.21	1.25	1.36	1.51	1.46	1.51
Time *(Sec)*	0.36	0.40	0.33	0.31	0.26	0.24

The PV cell characteristics are simulated by using estimated parameters. The accuracy of the estimated parameters is validated by plotting the I-V curves with the help of estimated values and experimental values of the parameters. The I-V curves for different irradiance and temperature are shown in Fig. 8 for BBSM-300, CS1U-410MS, SEP-300W, TSM 410W, SN-H 300W, and FS-6430A respectively. The voltage and current values are measured by simulating the PV cell using estimated parameters and compared with experimental values i.e., measuring directly from the PV cell. The current and voltage values from simulation is called as simulation data. Three different irradiance values i.e., 1000 w/m^2, 800 w/m^2 and 600 w/m^2 are used for I-V curves while keeping the PV cell temperature constant at 25 ºC. The I-V curves are plotted for three different PV cell temperatures such as 25 ºC. 50 ºC and 75 ºC while keeping the solar irradiance constant at 1000 w/m^2. These two scenarios are applied for all six types of PV modules (constant temperature for BBSM-300, SEP-300W, and SN-H 300W, constant irradiance for CS1U-410MS, TSM 410W and FS-6430A). From the Fig. 8, it is very clear that measured values are in line with experimental data for all types of PV modules for different irradiance values and temperature as well.

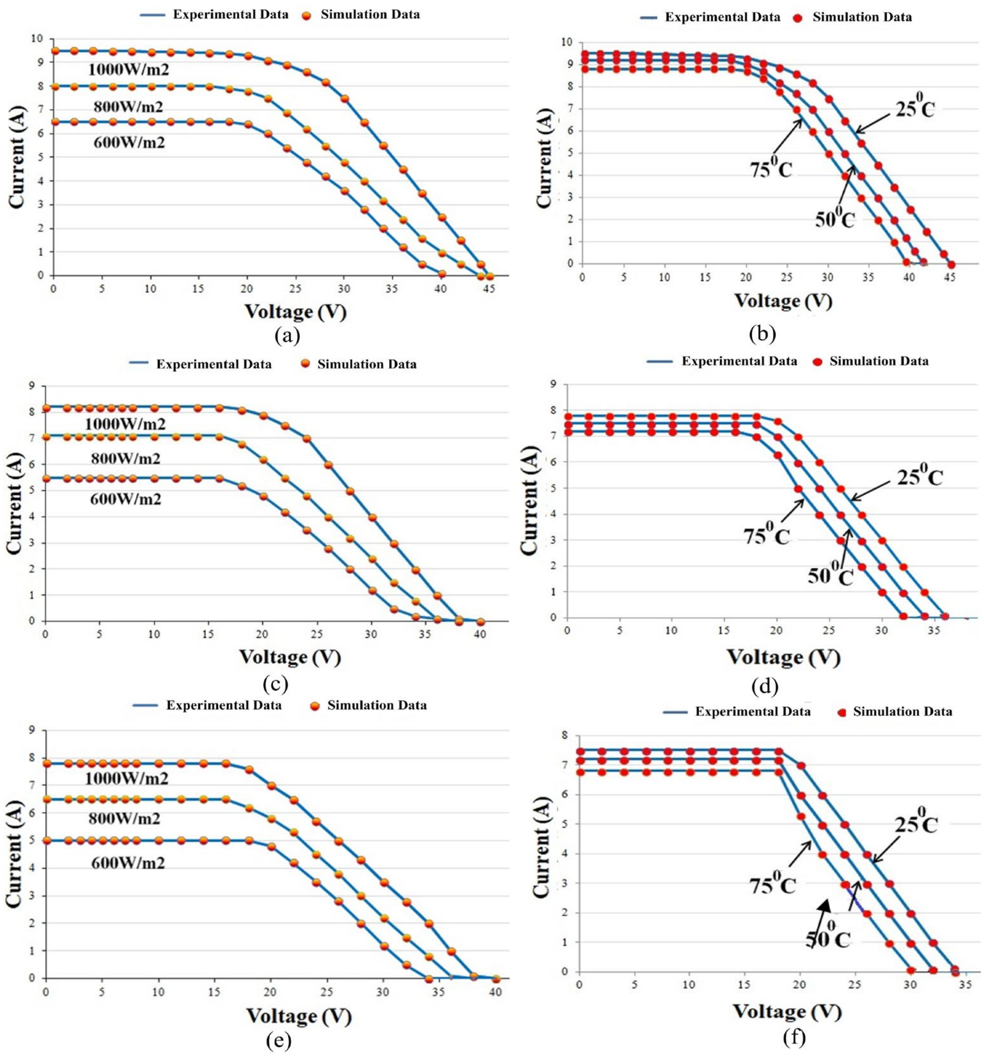

Figure 8. Estimated and measured (I-V) characteristics for Mono crystalline (a) BBSM-300, (b) CS1U-410MS, Poly crystalline (c) SEP-300W, (d) TSM 410W, and Thin-film (e) SN-H 300W, (f) FS-6430A for DDM solar panel.

The fitness factor decides the effectiveness of extraction process, so the amount of feasibility is present in proposed HS-AL technique. The term feasibility means the parameters are easily managed towards the computation process without any complexity. Therefore, the convenient extraction process is obtained using proper computations. The non-feasible parameters are filtered out initially during the data extraction process. Fig. 9, depicts the feasible parameters are in green color and non-feasible parameters are represented in red color.

Figure 9. Convergence of extracted parameters in terms of fitness factor and ab
solute error.

5. Conclusion

This paper proposes a novel algorithm based on Hybrid Spotted Hyena Optimization with Ant-Lion Optimization (HS-AL) technique for extracting the unknown (parasitic) parameters from various PV modules under different irradiance conditions. The seven parameters of the DDM of PV cell are properly extracted and are compared with synthetic data. It is found that proposed method extracted the parameters very precise compared to other methods. The parameters of different types of solar cells such as thin film, mono crystalline and multi crystalline are extracted with lessor absolute error. Different rated PV modules (80W, 220W, 300W, and 410W) studied for parameter extraction using different algorithms. The IV curves for 6 different PV modules are plotted by using experimental data and measured data from simulated model developed by extracted parameters. It's proved that the proposed algorithm is very effective in parameter prediction. The SH-AL algorithm converges faster and reaches to better fitness value compared to other presented algorithms. The absolute errors for different PV modules and irradiance conditions proves that SH-AL algorithm is optimally evaluated the cell parameters.

6. References

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