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PARAMETERS EXTRACTION OF A SINGLE DIODE SOLAR CELL MODEL USING BAT ALGORITHM, FIREFLY ALGORITHM & CUCKOO SEARCH OPTIMIZATION

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Abstract: Estimation of a highly accurate model for photovoltaic (PV) modules and solar cells from experimental data is an important task for researchers for the simulation, evaluation and design of Photovoltaic systems. In this paper, we propose three optimization techniques for the portrayal of the comparable electrical model of photovoltaic cell. The models with three, four and parameters, separately are considered. The Bat Algorithm (BA), Cuckoo search optimization (CSO) and Firefly Algorithm (FA) are utilized as an optimization tool for the extraction of the model parameters by arriving at the worldwide least arrangement in a brief span with an excellent exactness dependent on the minimization of the quadratic error among exploratory and hypothetical attributes. The reproduction results show that the proposed methodology is compelling for displaying the single model RTC cell just as the module.
Keywords: Photovoltaic, PV module, Parameters extraction, BAT algorithm, Cuckoo search algorithm, Firefly algorithm

1. INTRODUCTION

Finding of option, inexhaustible and eco-accommodating vitality sources and innovations have become a urgent undertaking for people because of expanding use and the inadequacy of fossil based energizes, air contamination and nursery emanations related with it [1], [2]. Among various sustainable power sources, for example, solar, wind, wave, tidal, geothermal, biomass and so on, solar energy is considered as one of most potential sustainable power source because of its broad accessibility, effectiveness of utilization and neatness. A Solar based photovoltaic (PV) framework can straightforwardly change solar energy into electrical energy.

Photovoltaics is the field of innovation and research identified with the gadgets which legitimately convert solar energy into power. The solar cell made of semiconductor materials is the basic structure square of the photovoltaic innovation. Various solar based cells electrically associated with one another and mounted in a single structure or casing is known as a 'photovoltaic module'. Photovoltaic modules and exhibits produce direct-flow power. They can be associated in both series and parallel arrangement to create any necessary voltage and current flow [3]. To all the more promptly understand the acting physical parts inside the sunlight based cell a couple of procedures have been proposed for the unmistakable confirmation of the different parameters that impact their traits, for increase their introduction, yet furthermore to reenact their direct and advance their particular characteristics [4-10]. These techniques can be arranged in two classifications:

a) deterministic strategy and
b) heuristic strategies.

Metaheuristics are the one of the most renowned subclass improvement strategies where smoothing out structures are consistently pushed by physical wonders, animals' practices and transformative thoughts.

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Straightforwardness, versatility, derivation free framework and close by optima avoiding capacity are the basic purposes for reputation of metaheuristics. These traits make metaheuristics unimaginably appropriate for authentic improvement issues. Method is required to improve the model parameters to such an extent that exploratory bend fits best with the mimicked target output.

Distinctive meta-heuristic optimization or their adjustment have been utilized to take care of the issue of parameters estimation of PV cells/modules. Genetic Algorithm [11] Particle Swarm Optimizer [12], Differential Evolution [13] Artificial Bee Colony calculation [14] Artificial Bee Swarm Optimization calculation [15], Shuffled Frog Leaping calculation [16], Hybrid Flower Pollination Algorithm [17], [18] and adjusted elephant swarm water search algorithm [19],[29] were utilized to optimize the photovoltaic cell parameters by the researchers. A considerable lot of these meta-heuristic calculations have been performed incredibly for this present issue. In any case, concurring No Free Lunch hypothesis [20], there is no single metaheuristics which is appropriate for tackling a wide range of issues. Thusly, examining for centered particular metaheuristics to deal with the issue of parameters estimation of PV cells/modules is up 'til now a critical and open issue in this field of research.

In this paper, we propose the relative examination between three metaheuristic improvement system: Bat algorithm, Cuckoo search optimization and Firefly Algorithm for the extraction of electrical parameters (the photo generated current, reverse saturation current, series resistance, shunt resistance & ideality factor). The models with three, four and five parameters of a solar based cell separately are considered. All the improvement optimization technique increment the likelihood of arriving at the global search least arrangements in a brief span with an excellent exactness dependent on the minimization of the quadratic error among test and hypothetical attributes. The recreation results show that the exactness of the heuristic methodology is viable for displaying on account of solar modules.

The rest of the paper is composed as pursues. In Section 2, the issue of photovoltaic cell demonstrating is characterized. Area 3 portrays the BA (Bat Algorithm), CSO (Cuckoo Search optimization) and FA (Firefly algorithm) just as the issue of solar cell recognizable proof meant an improvement task utilizing this method. Section 4 displays the result analysis where the optimization techniques output contrasted with trial ones. In Section 5 ends with conclusion.

2. PV CELL MODELLING

Undoubtly comprehended and extensively used Shockley diode models [21] operated in two major conditions: the ideal model (the three parameters model) and the single-diode model (the five parameters model). The most notable variations of these models are shown underneath: if there should arise an occurrence of three parameters model it involves a consistent current source, in parallel with a diode, which fuses an ideality factor to speak to the recombination in the space-charge region [22].

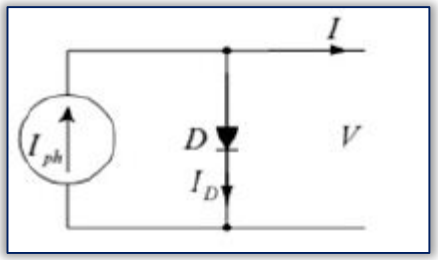

Figure 1. Single diode with three parameter model

—**Three parameter model:**

The structure of the single diode model with three parameter model shown in Figure 1.

Three parameter model of a single diode is given by

$$I_C = I_{ph} - I_{sd}\left[\exp\left(\frac{V_C}{\eta V_t}\right) - 1\right] \quad (1)$$

where I_C is the cell output current, I_{ph} is the photo generated current, I_{sd} is the reverse saturation current of the diode, V_C is the cell output voltage, η is the diode ideality factor, K is the Boltzmann constant (1.3806503×10^{-23} J/K), T is the temperature of the junction in Kelvin, and q is the electron charge (1.60217646×10^{-19} C). Let $V_t = KT/q$.

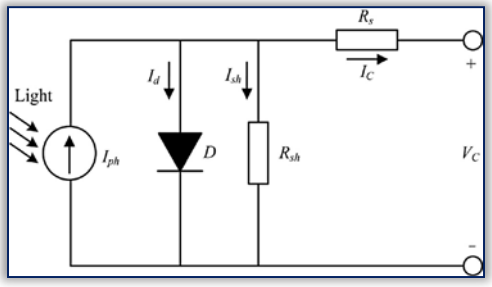

Figure 2. Single Diode Model with five parameter

—**Five Parameter Model:**

The structure of the single diode model with three parameter model shown in Figure 2.

In this model, the output current of the solar cell can be formulated as

$$I_C = I_{ph} - I_d - I_{sh} \quad (2)$$

where I_C is the cell output current, I_{ph} is the photo generated current, I_d is the diode current, and I_{sh} is the shunt resistor current. According to the Shockley equation, I_d can be calculated as:

$$I_d = I_{sd}\left[\exp\left(\frac{q(V_C+I_CR_s)}{\eta KT}\right) - 1\right] \quad (3)$$

After replacing $V_t = KT/q$, then Eq. (3) can be simplified as Eq. (4).

$$I_d = I_{sd}\left[\exp\left(\frac{V_C+I_CR_s}{\eta V_t}\right) - 1\right] \quad (4)$$

The shunt resistor Current I_{sh} is formulated as:

$$I_{sh} = \frac{V_C+I_CR_s}{R_{sh}} \quad (5)$$

Substituting Eqs. (4) and (5) into Eq. (2), the current-voltage relationship of the single diode model can be expressed as:

$$I_C = I_{ph} - I_{sd}\left[\exp\left(\frac{V_C+I_CR_s}{\eta V_t}\right) - 1\right] - \frac{V_C+I_CR_s}{R_{sh}} \quad (6)$$

This model totally contains five parameters to be estimated (I_{ph}, I_{sd}, R_s, R_{sh}, η).

—Objective function

Normally, metaheuristics are utilized to fit the determined current-voltage characteristics for a PV framework to the trial one. The estimation task plans to look for the most ideal qualities for the obscure parameters in order to limit the error between the deliberate and simulated current. The root mean square of the mistake (RMSE) characterized as Eq. (7) can be utilized as the target work [23].

$$RMSE(X) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} f(V_{Ci}, I_{Ci}, X)^2} \quad (7)$$

where N is the number of the experimental data, X is the set of the estimated parameters. For the five parameter single diode model, $f(V_C, I_C, X)$ and X can be respectively expressed as Eqs. (8) and (9).

$$f(V_C, I_C, X) = I_{ph} - I_{sd}\left[\exp\left(\frac{V_C+I_CR_s}{\eta V_t}\right) - 1\right] - \frac{V_C+I_CR_s}{R_{sh}} - I_C \quad (8)$$

$$X=\{I_{ph}, I_{sd}, R_s, R_{sh}, \eta\} \quad (9)$$

For the four parameter single diode model, $f(V_C, I_C, X)$ and X can be respectively expressed as Eqs. (10) and (11).

$$f(V_C, I_C, X) = I_{ph} - I_{sd}\left[\exp\left(\frac{V_C+I_CR_s}{\eta V_t}\right) - 1\right] - I_C \quad (10)$$

$$X=\{I_{ph}, I_{sd}, R_s, \eta\} \quad (11)$$

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$$f(V_C, I_C, X) = I_{ph} - I_{sd}\left[\exp\left(\frac{V_C}{\eta V_t}\right) - 1\right] - I_C \quad (12)$$

$$X=\{I_{ph}, I_{sd}, \eta\} \quad (13)$$

Obviously, smaller objective function value corresponds to better estimated parameters. Because of the objective function is nonlinear and transcendental, this problem is difficult to solve.

3. PROPOSED METHODOLOGY

—Bat Algorithm

In light of the conduct of the bats, created by Yang [24] is an intriguing advancement procedure called Bat Algorithm, which is an enhancement calculation, motivated from the echolocation of microbats. Echolocation of bats fills in as sonar in bats, radiates an uproarious and short heartbeat sound, and it hits an article after a small amount of time, the reverberation returns back to their bats ears. What's more, this makes bats having the option to recognize the contrast between a deterrent and a prey, enable them to chase even in complete obscurity. Bat algorithm is a considered as another metaheuristic calculation dependent on Bat conduct. This bat calculation has great assembly and preferable nature of arrangement over PSO and IWD. The primary bit of leeway of this system is simple is execute and fit for finding doable worldwide ideal arrangement. BA (Bat Algorithm) has convent of precision and better productivity contrasted with different calculations. For straightforwardness, we are presently considering the accompanying principles are:

All bats use echolocation to detect and they likewise know the distinction between nourishment/prey. Bats fly haphazardly with speed (Vi) and position (Xi) and recurrence (fmin) with wavelength (λ) and commotion (Ao) to search prey and ready to translate the sign and sees the prey is huge or little.

—**Firefly Algorithm**

Firefly calculation (FA), created by Xin-She Yang [25] for Solving ideal power stream issue and to accomplish better worldwide ideal arrangements. It dependent on the glorified conduct of the blazing attributes of fireflies, including the light outflow, ingestion and the shared fascination. The calculation has less number of administrators and can be effectively actualized for any advancement issues. The stream outline for Firefly Algorithm for minimization of Real power misfortune.

The accompanying guidelines are given,

≡ A firefly will be pulled in by different fireflies paying little heed to their sex.

≡ Allure is corresponding to their splendor and diminishes as the separation among them increments

≡ The scene of the target work decides the brilliance of a firefly.

—**Cuckoo Search Calculation**

Cuckoo search is the most recent group of metaheuristic search calculations, which is propelled by the life of a fledgling, has been created by Yang and Deb (2009). It is appropriate for nonlinear improvement issue. It depends on the commit brood parasitic nature of certain cuckoos and it is joined with the Levy flight conduct of different winged animals [26]. Cuckoo search (CSO) is a populace based streamlining procedure and the same number of other heuristic calculations it begins with arbitrary starting populace. So as to rearrange Cuckoo search calculation three admired guidelines can be utilized [27]:

≡ A solitary cuckoo lays each egg in turn and dumps it arbitrarily picked host home.

≡ Choices of the greatest eggs from the best homes are to complete to the people to come.

≡ The quantity of accessible host homes is fixed and likelihood is that an Egg laid by a cuckoo winged animal can be found by the host flying creature.

4. RESULTS AND DISCUSSION

Here, the calculation is tried against single instances of solar cell relating to the single diode model. Next, to check the reasonable application ability, the proposed three calculations has been applied for solar cell modules to test with the trial information from producer's information sheets.4.1. Test with the experimental data from Ref. [18]

At first, the test I–V dataset of the of the photovoltaic cell are estimated from a 57 mm measurement RTC France silicon sun oriented cell at an irradiance of (1000 W/m2) and a temperature of (33˚C) and thoroughly contains 26 sets of current and voltage values [19]. In this segment, we present the numerical analysis consequences of Bat Algorithm (BA), Cuckoo Search optimization (CSO) and Firefly Algorithm (FA) on the three previously mentioned benchmark issues. Besides, we perform correlation among some notable streamlining techniques in particular Bat Algorithm, Cuckoo search and Firefly calculation and give measurable examination of the assessed outcomes.

The parameters setting for every calculation in the examination is portrayed as pursues:

—For BA, loudness decreasing factor (α) 0.9 , pulse rate decreasing factor (γ) 0.9 , minimum and maximum frequency are set to 0 and 1 respectively indicated by the prior work.

—For CSO, number of cuckoos 25 and abandoned probability (Pa) is 0.25.

—For FA, randomness 0.5, minimum value of beta 0.2 and Absorption co efficient 1 according to the earlier work.

For all the algorithms we choose maximum iteration number 5000 and population 100 respectively. For a single diode model, search space is confined to 5, 4 & 3 dimensional function optimization problems to look through ideal estimations of $\{I_{ph}, I_{sd}, R_s, R_{sh}, \eta\}$, $\{I_{ph}, I_{sd}, R_s, \eta\}$& $\{I_{ph}, I_{sd}, \eta\}$. The search range [28] for the optimization of diode based model of RTC solar cell is shown in table 1.

Table 1: Parameters search ranges [18] of RTC France solar cell.

PV System	RTC Solar Cell	
Parameter	Lower Limit	Upper Limit
I_{ph} (A)	0	1
I_{sd} (μA)	0	1
R_s (Ω)	0	0.5
R_{sh} (Ω)	0	100
η	1	2

Because of stochastic nature of metaheuristics, they may give distinctive yield depending diverse arbitrary instatement. In this way, every calculation is executed for multiple times for every case and the measurable examination has been completed from the gotten reenacted results. Every one of the methods were recreated utilizing Matlab 2013b in a PC with 4 GB RAM, Intel(R) Core(TM) i3 processor and Windows7 working System. During these numerical experimentations, we have tried and looked at the productivity of the proposed calculation based on certain standards such computational effectiveness test, exactness test, dependability test and combination test which are depicted in following subsection individually.

—Computational Efficiency Test

Computational time is likewise a main consideration for assessing the betterment of a metaheuristic. For this reason, we have watched normal execution time taken by every calculation for every one of the issues of Solar Cell which thus means the computational proficiency of the calculation after 5000 cycle. Table 2 shows a near report dependent by and large execution time. From Table 2 it is seen that for all the parameter extraction in single diode solar cell BAT algorithm takes least average computational time& Firefly algorithm takes maximum average computational time.

Table 2: Comparative study based on computational time for RTC singleDiode

Case	Method	Average Computational Time
Five parameter	BA	344.333 seconds
	CSO	450.084 seconds
	FA	784.948 seconds
Four parameter	BA	338.002 seconds.
	CSO	778.110 seconds
	FA	1398.539 seconds.
Three Parameter	BA	415.704 seconds.
	CSO	429.952 seconds.
	FA	857.244 seconds.

—Accuracy Test

Next, the exactness test has been led to watch current forecast ability under various exploratory voltages. Two records separately named as individual absolute error (IAE) and relative error (RE) and separately characterized as Eq. (14) and (15) are received to show the blunder esteems between the exploratory and the recreated current information.

$$IAE = |I_{measured} - I_{calculated}| \quad (14)$$

$$RE = \frac{I_{measured} - I_{calculated}}{I_{measured}} \quad (15)$$

Moreover, Total Absolute Error (TAE) can be defined as:

$$TAE = \sum_{i=1}^{n} IAE_i \quad (16)$$

where n is the quantity of voltage estimation in the test dataset, $I_{measured}$ and $I_{calculated}$ are the exploratory and assessed estimation of current for a specific voltage. In any case, to compute or gauge the estimations of current for various test voltages, the best instance of metaheuristics has been viewed as where RMSE is littlest among every single diverse run. Table 3, 4, and 5 depict the distinctive best ideal parameters esteems for five, four and three parameters of a solitary diode displaying of RTC sun oriented cell. Utilizing these parameters, estimations of current for the PV frameworks are determined for various cases.

Table 3: Estimated optimal parameters for five parameter single diode RTC solar cell

Method	I_{ph}	I_{sd}	R_s	R_{sh}	η
BA	1	0.2	0.0377	37.072	1.443
CSO	1	0.3	0.0364	53.718	1.482
FA	1	0.9	0.0311	38.728	1.593

Table 4: Estimated optimal parameters for four parameter single diode RTC solar cell

Method	I_{ph}	I_{sd}	R_s	η
BA	0.7587	0.9095	0.0324	1.5935
CSO	0.7581	0.6665	0.034	1.5579
FA	0.758	0.06296	0.0342	1.5516

Table 5: Estimated optimal parameters for three parameter single diode RTC solar cell

Method	I_{ph}	I_{sd}	H
BA	0.7316	1	1.6139
CSO	0.7316	1	1.6139
FA	0.7316	1	1.6139

In actuality, utilization of RTC solar cell for single-diode model, the estimation of idealist factor, η, is lies in the middle of 1 and 2. From Table 3, 4 and 5, it very well may be seen that estimations of idealist factors are consistently stay somewhere in the range of 1 and 2. It approves outcomes as well as proposed methodology.

Table 6 describes a comparative study based on total absolute error. From Table 6, it can be clearly seen that proposed BAT algorithm has the best performances in term of total absolute error for four &three parameter single diode sun oriented cell model. Be that as it may, in five parameter sunlight based cell demonstrating Firefly Algorithm (FA) have least complete total mistake. It implies that the proposed both BAT and FA strategy can anticipate the estimations of flow all the more precisely

Table 6: Comparative study based on Total Absolute Error (TAE) of a RTC Single Diode

Case	Method	Total Absolute Error
Five Parameter	BA	1.093
	CSO	1.096
	FA	1.062
Four parameter	BA	1.0633
	CSO	1.0842
	FA	1.0845
Three Parameter	BA	1.254
	CSO	1.254
	FA	1.254

for all cases contrast with the others detail of workmanship procedures like Cuckoo search optimization (CSO). It is intriguing to see that for three parameter extraction of a solitary diode sun based cell model all the proposed model has same TAE because of same ideal parameter esteem previously appeared in Table 6.

Figure 3, 4, & 5 show the relative errors vs. different voltage measurement instances for five, four & three parameter extraction of a single diode modeling of RTC solar cell. It can be clearly seen that the proposed Bat Algorithm give superior results in term of relative error in all the parameter extraction single diode modeling of RTC Solar cell.

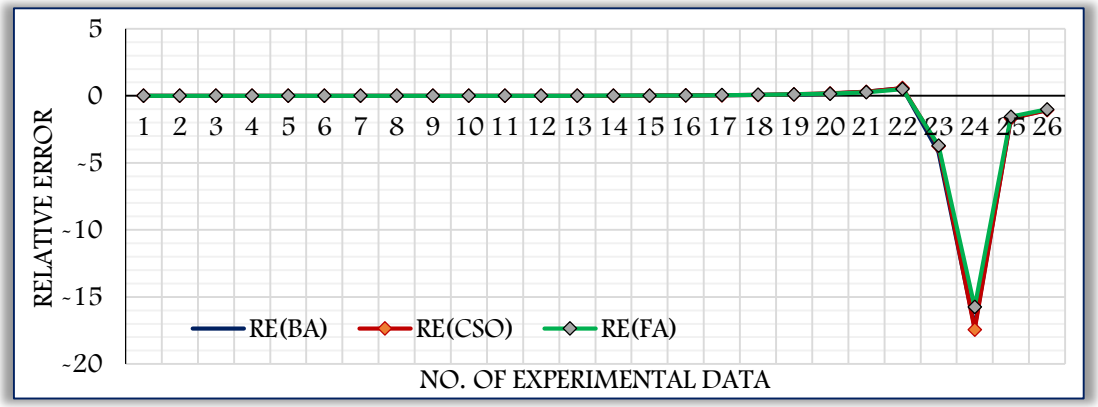

Figure 3: Relative errors for five parameter single diode modelling of RTC Solar cell using different metaheuristics

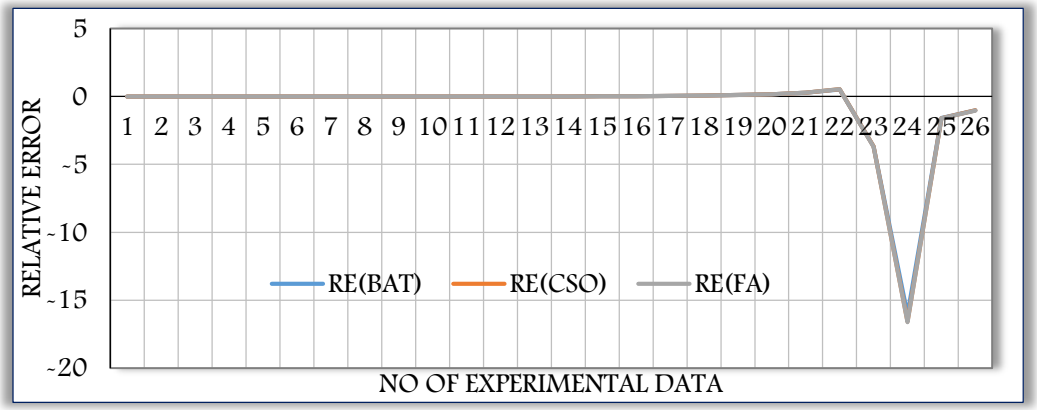

Figure 4: Relative errors for four parameter single diode modeling of RTC Solar cell using different metaheuristics

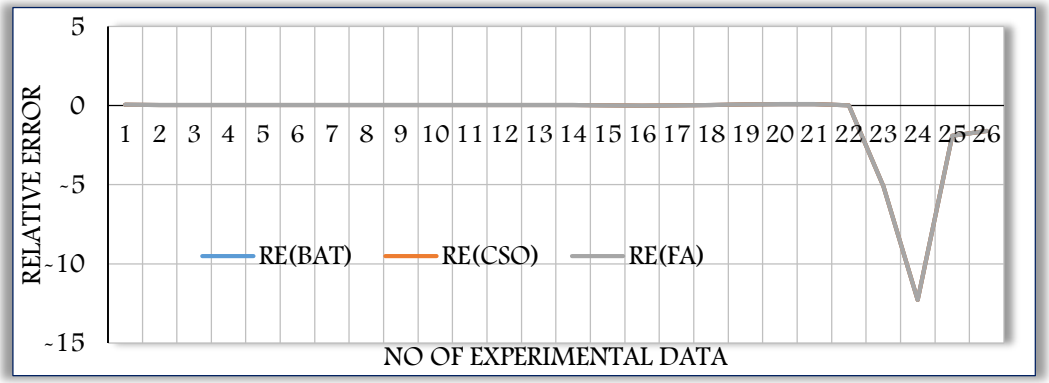

Figure 5: Relative errors for three parameter single diode modeling of RTC solar cell using different metaheuristics

— Reliability Test

It is constantly expected that a metaheuristic must ready to reach closer to the worldwide ideal point as close as conceivable in each and every run. In any case, because of stochastic nature of the metaheuristic, the last yield of the enhancement procedure fluctuates with various run. Anyway the best metaheuristic enhancement strategy the yield variety ought to be negligible. Along these lines, in this subsection, we have tried the unwavering quality of proposed calculations based on some measurable parameters to be specific Accuracy, RMSE and standard deviation. Examinations among themselves have been likewise appeared in Table 7. The standard deviation means fluctuation or consistency of the information. Along these lines, a progressively dependable calculation should have less estimation of standard deviation in the yield. It can be clearly shown that Firefly Algorithm get smallest values of standard deviation for five parameter model while four parameter extraction model Bat Algorithm has a least SD and three parameter extraction of a solar cell all the optimization technique have same SD.

Table 7. Comparative study based on RMSE &standard deviation

Case	Method	RMSE	Accuracy	Standard Deviation (SD)
Five parameter	BA	7.74	92.26	0.07749
	CSO	7.85	92.15	0.07855
	FA	7.30	92.70	0.07303
Four Parameter	BA	7.3608	92.63	0.073608
	CSO	7.5379	92.46	0.075379
	FA	7.5539	92.44	0.075539
Three Parameter	BA	8.7885	91.211	0.087885
	CSO	8.7885	91.211	0.087885
	FA	8.7885	91.211	0.087885

Firefly Algorithm is able to achieve highest accuracy (least RMSE) i.e. 92.70% for five parameter extraction model of a single solar cell modelling & four parameter modelling Bat algorithm achieve highest accuracy i.e. 92.63%. On the hand, all algorithms achieve the same accuracy i.e. 91.211% for three parameter extraction model.

— Convergence Test

The conclusive outcome correlation can't totally portray the looking through presentation of a calculation. So we further direct a combination test on the analyzed calculations on each PV frameworks. For this reason, we have picked the yield comparing to the run where we discovered least or best wellness (RMSE) among every one of the multiple times run and watch the wellness esteem at seven diverse emphasis record. At that point, we plot them for all calculations in five parameter extraction in single sunlight based cell frameworks which are appeared in following figures. In the figures, wellness esteems are appeared at 5000 emphasis just for better clearness and comprehension. It can be observed that proposed Firefly Algorithm converges slowly compare to the other existing metaheuristic methods. BA convergence faster than other for all of the cases but it has least convergence chances up to 1000 no. of iteration.

— Validation of the proposed approach

In any case, to approve the proposed strategy for displaying of fluid stream control process two kinds of approval have been considered. Initial one is 'cross approval' where ideal models are applied against preparing or starting exploratory information. Second one is 'test new situation' where enhanced models are applied against new arrangement of info information which are not utilized during the preparation or advancement.

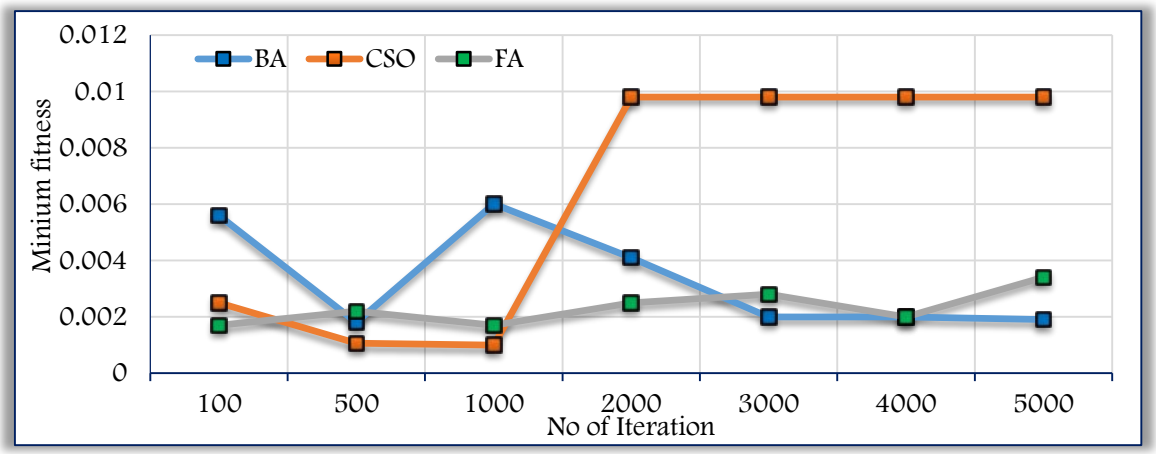

Figure 6. Minimum fitness for single diode modeling of RTC solar cell using different metaheuristics

Here we play out the cross approval where sun oriented cell ideal parameter (RMSE least) get from every one of the calculations and determined the yield current Comparing to all these ideal parameter. Figure 6, 7 and 8 shows of the exploratory information and evaluated current incentive for the five, four and three parameter extraction of a solitary sunlight based cell model. It very well may be seen that the proposed BAT calculation can foresee the single sunlight based cell current with more prominent precision or agreeably. Additionally, the expectation ability approves the effectiveness of the proposed calculations.

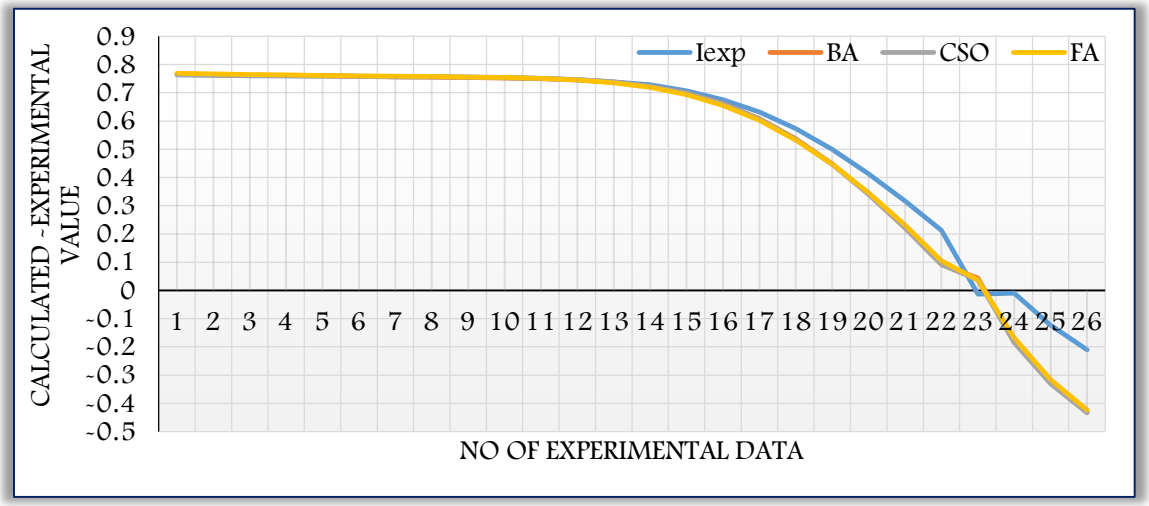

Figure7. Experimental v/s Calculated value for five parameter of single solar cell model

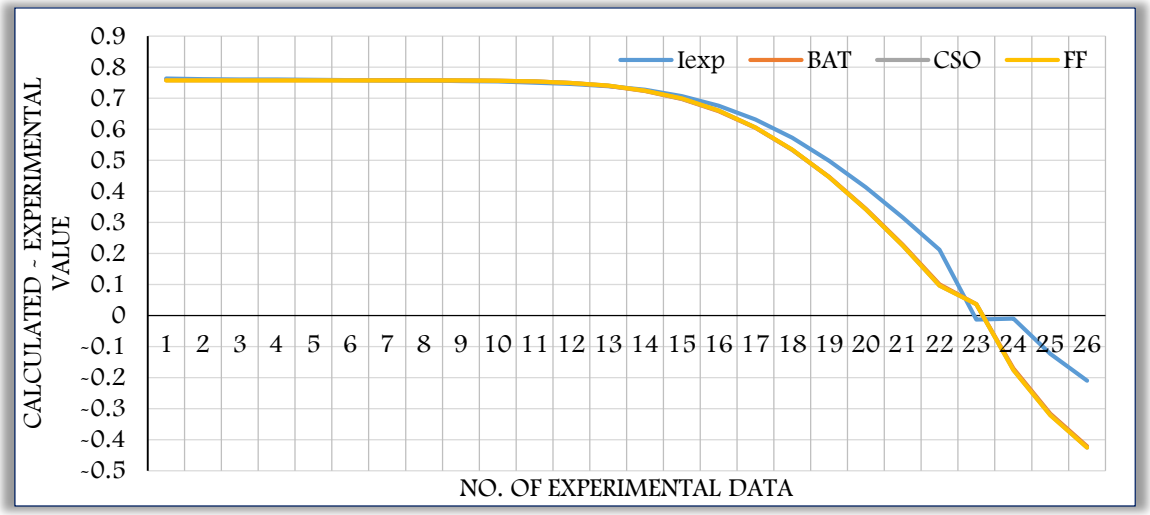

Figure 8. Experimental v/s Calculated value for four parameter of single solar cell model

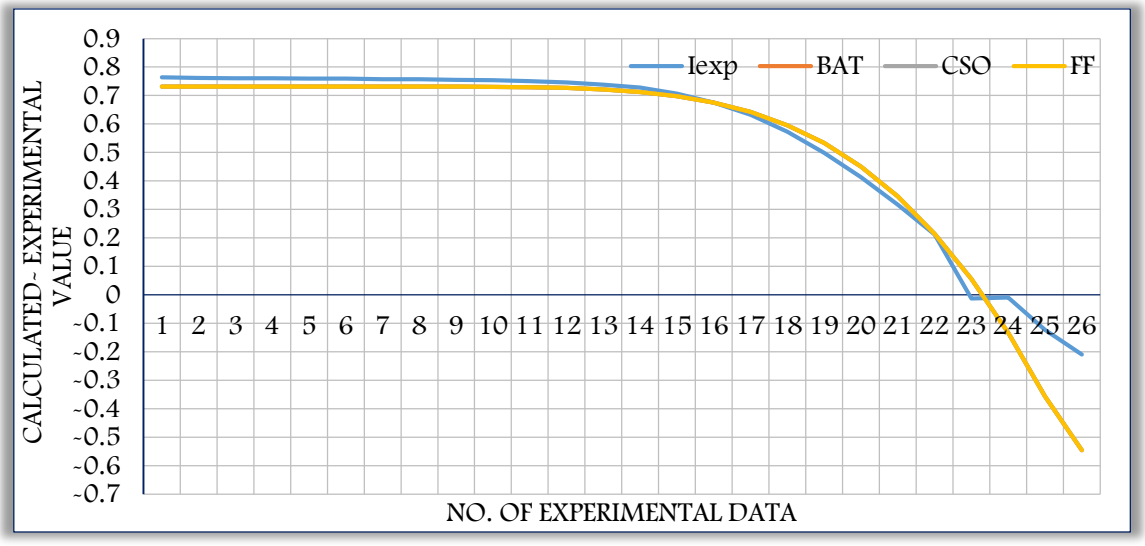

Figure 9. Experimental v/s Calculated value for three parameter of single solar cell model

5. CONCLUSIONS

In this examination we proposed three distinctive metaheuristics Algorithm: Bat algorithm (BA), Cuckoo search algorithm (CSO) and Firefly algorithm (FA) for assessing the parameters of solar cell models precisely. All the algorithm which are utilized in this exploration tend to expand the likelihood of arriving at the global minimum in terms of time & great precision dependent on minimization of quadratic error. In this research we utilized five, four and three parameter model of a single diode solar cell. The acquired outcomes were additionally contrasted by means of three metaheuristics optimization techniques: BA, CSO and FA. Different statistical analysis of these three algorithms are tested and relative outcomes justify that the proposed algorithms can extricate the parameters precisely and productively.

From the result analysis it has been seen that the exhibitions of the proposed BAT algorithm outperformed than the CSO and FA. But one of the significant disservices of BA is computational time is moderate compared to the other algorithms. In addition, the dependability and precision of the proposed algorithm ought to be additionally upgraded in future. Presenting distinctive introduction components and adjustments or hybridizations of the optimization might be a potential methodology mitigating these shortcomings.

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