A Robust Metaheuristic Approach for Parameter Extraction of Complex Solar Cell Models: Validation on Industrial PV Panels

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Abstract

The Estimating the performance of solar panels (PV systems) requires highly accurate modelling. Standard optimization methods often fail to find the best settings (parameters) for complex models like the three-diode (3D) and four-diode (4D) equivalent circuits, getting stuck in wrong answers (local minima). To fix this, we developed a new, improved optimization algorithm. This new method proved superior and faster than existing ones like Particle Swarm Optimization (PSO), Reptile Search Algorithm (RSA), and Crow Search Algorithm (CSA), achieving remarkably low error rates: an RMSE of 3.47E-16 and for the 3D model and 5.06E-16 for the 4D model.

Keywords. Photovoltaic Systems, Parameter Estimation, Three-Diode Model, Four-Diode Model, Metaheuristic Optimization, Crow Search Algorithm.

1. INTRODUCTION

The global transition to renewable energy sources has caused solar photovoltaic (PV) technology to become a fundamental part of the future energy mix. The assessment of PV systems requires accurate simulation and modelling, which in turn requires a well-defined solar cell standard [1]. The working of a solar cell from an electrical perspective is exclusively influenced by the internal values which are referred to as parameters. The most important parameters include photocurrent, saturation currents, series and shunt resistances (which characterize internal losses), and idealization factors. If these values are very accurately known, one can predict the exact performance of the cell under various real-world conditions [2]. On the other hand, the parameter values listed in the manufacturer's datasheet are generally insufficient for the construction of high-fidelity models, which leads to a considerable number of difficulties since the output of the simulated system will not be the same as that of the actual one [3].

2. ALGEBRAIC MODELLING OF SOLAR PV CELLS

The three-diode model illustrated in Figure 1 introduces a third diode to more accurately capture recombination losses occurring at grain boundaries within semiconductor materials, a phenomenon that is not fully accounted for by simpler models [4]. The governing equation for the output current (I_O) in the 3D model is given in Figure 1, which extends the DD model by adding a third diode current term.

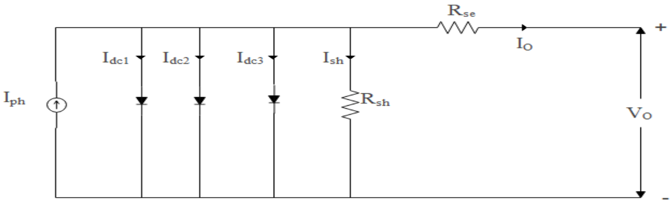

Figure 1. Simplified 3-Diode PV Circuit.

3. PROPOSED ALGORITHM: ENHANCED CROW SEARCH ALGORITHM (ECSA)

The new optimization method we are proposing is built upon an improved version of the. The CSA is a metaheuristic technique that draws inspiration from the clever food-finding (foraging) strategies of crows. Crows are renowned for their extraordinary cognitive abilities, including self-awareness, tool making, and sophisticated social strategies such as hiding food and stealing other birds' stores while protecting their own. Although the standard CSA is efficient, it might face the challenge of unequal exploration and exploitation.

4. EXPERIMENT AND RESULTS

The proposed metaheuristic algorithm was subjected to a rigorous evaluation in this trial phase against the already existing algorithms PSO, Reptile Search Algorithm (RSA) and CSA by means of five selected benchmark test functions (CEC1-CEC5) of CEC 2019 which all had 20 parameters. To avoid any favouritism in the comparison all algorithms were limited to 1000 feature estimations per test task. Programming was carried out in MATLAB 2018b, each algorithm run independently for 30 iterations to obtain reliable arithmetical outcomes as shown in Table 1 and 2 and Fig. 2 and 3.

Table 1. Unknown Parameters of Three Diode Model.

Parameter/Algorithms	Proposed Algorithm	CSA	PSO	RSA
I_{pv}	5.8587	6.9159	5.2835	5.8224

n_3	1.261	0.947	0.58	1.135
R_{sh}	158.2	155.13	97.451	273.09
I_{o2}	3.80E-07	4.51E-07	1.16E-07	2.78E-07
n_1	1.081	0.714	0.5	1.65
n_2	1.161	0.701	0.668	1.213
I_{o1}	2.69E-07	2.91E-08	0	7.31E-08
R_s	0.077	0.017	0.001	0.096
I_{o3}	6.28E-07	2.82E-09	7.70E-09	6.28E-08
RMSE	3.47E-16	3.31E-04	1.57E-02	4.33E-06

Table 2. Unknown Parameters of Four Diode Model.

Parameter/ Algorithms	**Proposed Algorithm**	**CSA**	**RSA**	**PSO**
n_1	1.085	1.567	0.76	0.538
n_2	1.214	1.072	1.026	0.584
R_s	0.087	0.02	0.023	0.024
I_{o1}	2.55E-07	2.10E-07	5.24E-07	4.86E-09
I_{o2}	4.87E-07	0	3.12E-07	2.48E-08
n_3	1.089	0.612	1.286	0.5
n_4	1.053	0.849	1.598	0.545
I_{pv}	7.8285	6.8896	3.8102	6.1342
R_{sh}	220.96	153.43	301.84	222.8
I_{o3}	3.72E-07	6.60E-07	3.97E-07	0
I_{o4}	2.65E-07	0	4.21E-07	3.58E-08
RMSE	5.06E-16	2.97E-04	5.97E-06	2.25E-01

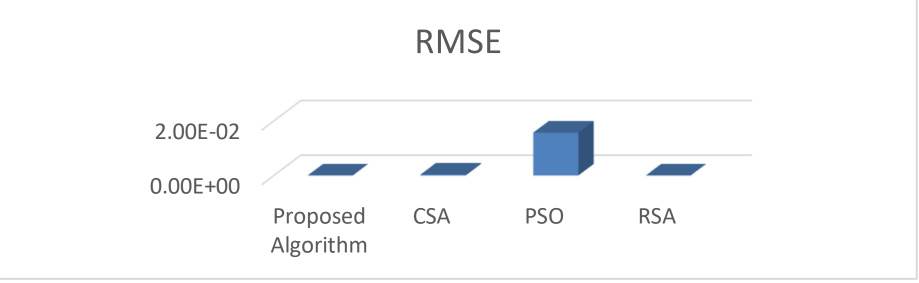

Figure 4.1. RMSE of Three Diode Model.

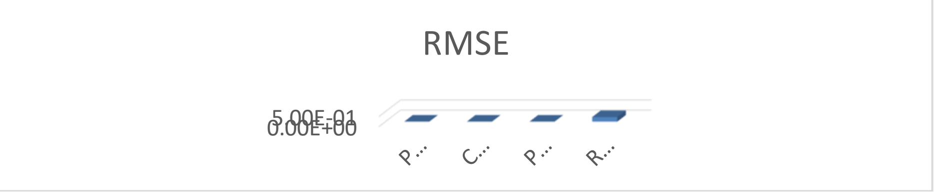

Figure 4.2. RMSE of Four Diode Model.

5. Conclusion

This research study introduces a brand-new algorithm created specifically to solve the challenging problem of global optimization when determining the operating parameters of a solar cell. The core innovation of this algorithm is the ability to interpret temperature variations, which increases the diversity of the solution. Moreover, it features an opposition-based learning approach, which is a technique for considering and filtering all possible solutions from a wide range.

6. References

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