Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

Investigation of Evolutionary Computation Techniques Cuckoo Search and Gray Wolf Optimization for Enhancing Solar PV Technology

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Abstract:

Solar energy is a critical renewable energy technology, but improving efficiency and output is crucial. This study explores Gray Wolf Optimization (GWO) and Cuckoo Search Optimization (CSO) for fine-tuning solar cell parameters. These techniques are used to find the best combination of cell material properties, structural configurations, and operating conditions to maximize energy yield, minimize costs, and enhance system reliability. CSO's unique Lévy flight mechanism helps avoid getting stuck on suboptimal solutions. By comparing these optimization techniques, this research aims to provide valuable insights for designing and operating solar energy systems. The findings can inform stakeholders across the energy spectrum to make informed decisions that drive the development of solar PV technology. This research represents a significant step towards realizing the full potential of solar energy as a sustainable energy source.

Keywords: *sustainable, represents, techniques, optimization*

1. Introduction:

Solar photovoltaic (PV) technology is rapidly transforming the energy landscape. Unlike traditional fossil fuels, solar offers a clean, sustainable, and virtually limitless source of power. By converting sunlight directly into electricity, PV cells are powering homes, businesses, and even large-scale utility grids. However, maximizing the efficiency and output of these systems is crucial. This research delves into the optimization of solar cell parameters using evolutionary computation techniques. The need for efficient solar energy solutions is undeniable. As global energy demands rise, concerns about climate change necessitate a shift towards renewable sources. Optimizing solar cell performance is a key strategy to achieve this transition. Here, evolutionary computation emerges as a powerful tool. Inspired by natural selection, these algorithms mimic the iterative process of evolution to find optimal solutions in complex problems. This study focuses on two specific evolutionary computation techniques: Cuckoo Search Optimization (CSO) and Gray Wolf Optimization (GWO). Both algorithms offer unique strengths for navigating the intricate parameter space of solar cells. These parameters include cell material properties, structural configurations, and operating conditions. By fine-tuning these factors, the research aims to achieve a trifecta of benefits: maximizing energy yield, minimizing costs, and enhancing system reliability. The core objective of this research is to evaluate the effectiveness of CSO and GWO in optimizing solar cell performance. By comparing their strengths and limitations, the study seeks to provide valuable insights for the advancement of solar PV technology. Ultimately, this research aspires to contribute to the broader goal of creating a more sustainable and secure energy future powered by the sun.

2. Literature Review:

In (2014), research by Mirjalili et al. highlighted the efficiency and robustness of GWO in solving complex optimization problems, positioning it as a promising technique for solar PV parameter optimization. Studies by Li et al. (2017) and Zhang et al. (2018) demonstrated that optimized parameters lead to increased energy yield, reduced costs, and enhanced system reliability, thereby maximizing the return on investment for solar PV installations. CSO, introduced by Yang and Deb (2009), draws inspiration from the brood parasitism behavior of cuckoos. It utilizes Lévy flights and probabilistic nest discovery to efficiently explore solution spaces, aiding in escaping local optima. Li et al. (2018) proposed a novel approach using CSO to optimize the layout of photovoltaic farms, resulting in improved total power generation and reduced shading effects. Tiwari et al. (2020) also investigated the optimization of solar panel parameters using CSO, revealing its potential to enhance the performance and efficiency of solar PV systems. Faraboschi, P., et al. (2018). Optimization of thin film solar cell parameters using Cuckoo Search algorithm. Karakaya, M., & Güzel, B. (2019). This comparative study evaluates the performance of CSO against other metaheuristic optimization algorithms for estimating photovoltaic parameters, shedding light on CSO's effectiveness in this context. Tiwari, P., et al. (2020). colleagues investigate the optimization of solar panel parameters using CSO, revealing its potential to enhance the performance and efficiency of solar PV systems. Gandomani, T. J., & Azad, M. A. K. (2021). Solar PV system optimization: A review of optimization methods and future trends. Yang, X. S. (2022). discusses potential future developments and applications of CSO, including its integration with emerging technologies such as artificial intelligence and machine learning.

3. Methodology

The methodology proposes a multi-step approach to optimize a solar PV system by tuning critical parameters to maximize power output while considering constraints. It involves optimizing material properties of solar cells, structural configuration of the PV module, and operating conditions like temperature and irradiance. All these factors are incorporated into an objective function that aims to maximize power output while considering limitations like voltage, current, and temperature constraints.

P&O Method

The Perturb and Observe (P&O) method continuously adjusts the operating voltage of solar panels. It compares current power output with the previous output and adjusts the voltage up or down based on the change in power. This iterative process continues until the change in power becomes zero, effectively tracking the Maximum Power Point (MPP) regardless of sunlight conditions or specific solar panel types.

Table 1: Calculation of P&O algorithm

S.No.	Current (A)	Voltage (V)	P=V x I	$\Delta P=P_n-P_{n-1}$	$\Delta V=V_n-V_{n-1}$	dP/dV
1.	0.305	0.171	0.052	0.052	0.171	0.304094
2.	0.344	2.492	0.857	0.805	2.321	0.346833
3.	0.327	10.099	3.302	0.839	2.565	0.327096
4.	0.317	15.092	4.784	0.753	2.571	0.292882
5.	0	20.028	0	-5.403	2.765	-1.95407

Control Algorithm for MPPT incremental Conductance (IC)

The Incremental Conductance (IC) method addresses the limitation of the Perturb and Observe (P&O) method in rapidly changing weather. It calculates the change in power with respect to voltage (dP/dV) to determine the

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
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direction to adjust voltage for reaching the Maximum Power Point (MPP). This method relies on measurements of current and voltage to track the MPP.

Table 2: Calculation of Inc Con algorithm

Current (A)	Voltage (V)	dP/dV	$\Delta I=I_n-I_{n-1}$	dI/Dv	I/V	$\frac{dI}{dV}+\frac{I}{V}$	ΔV/ΔP	ΔI/ΔP
0.305	0.171	0.3040	0.305	1.783625	1.7836	3.56725	3.288	5.8653
0.344	2.492	0.3468	0.039	0.016803	0.13804	0.15484	2.883	0.0484
0.327	10.099	0.3270	0	0	0.03237	0.03943	3.057	0
0.317	15.092	0.2928	-0.005	-0.00194	0.0210	0.01905	3.414	-0.0066
0	20.028	-1.954	0.031	-0.11320	0	-0.1132	-0.511	0.05793

Objective Functions

A PV array made up of a few PV cells in series and parallel associations. Series associations are answerable for expanding voltage of module though parallel association is liable for expanding current in cluster. Normally, a PV cell can be demonstrated by a current source and an upset diode associated in parallel to it. Fig.1 shows equivalent electrical circuit of a PV cell.

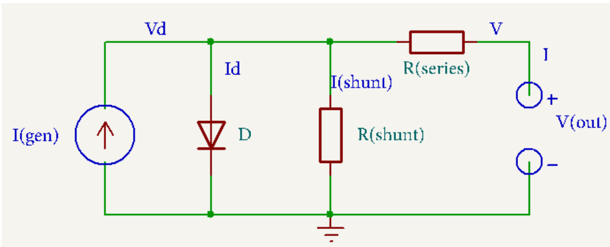

Fig.1: Mathematical model of PV Panel

The output current from photovoltaic array is

I = IL– ID– ISh (a)

IShis very less, the

I = IL- ID (b)

Where,

I=I_L-I_O (e^(q(V+IRs)/nkTr)-1) (c)

And

I_D=I_O (e^(q(V+IRs)/nkTr)-1) (d)

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ISSN: 1001-4055
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$I_L=G (I_{SC} (T_r))/G_e \ (1+\alpha_{ISC} (T-T_r))$ (e)

Where,

IL: light or photo current

Io: reverse saturation current of diode

Is: output current

Vs: voltage of photovoltaic generator

q: charge on electron

K: Boltzmann's constant

Rs: series resistance

n: Ideality factor for P-N junction.

Common objective functions include:

Mathematical Representation of Gray Wolves' Movement:

Each gray wolf adjusts its position based on the positions of the alpha, beta, and delta wolves. The new position is calculated using the following equation:

x_new = x_mean - A * D, where

x_new represents the new position of the wolf.

x_mean is the mean position of the alpha, beta, and delta wolves.

A is a vector of random values.

D is the distance vector.

〖NK〗 _(g,h) = {(1@0)┤ Ifk_g∈N_h ..(1)

〖KP〗 _(g,h) = {(1@0)┤ Ifk_g cancooperatep_h ..(2)

NC=NK*NP ..(3)

ETL = (-(ij+cd)+√((i^2+c^(2)) R_t^2-(id-jc)^2))/(i^2+c^2) ..(4)

NS□ETL*NC

NW_g= □wt_1*NC□+□wt_2*NS□ ..(5)

D ⃗ =| C ⃗.(X_p) ⃗(t)-X ⃗(t)| ..(6)

X ⃗(t+1) = (X_p) ⃗(t)-(A.) ⃗D ⃗ ..(7)

A ⃗ = 2(a.) ⃗(r_1) ⃗-a ⃗ ..(8)

C ⃗ = 2.(r_2) ⃗ ..(9)

(D_∝) ⃗ = |(C_1) ⃗.(X_∝) ⃗-X ⃗|
..(10)

(D_β) ⃗ = |(C_2) ⃗.(X_β) ⃗-X ⃗|
..(11)

(D_δ) ⃗ = |(C_3) ⃗.(X_δ) ⃗-X ⃗|
..(12)

(X_1) ⃗ = (X_∝) ⃗-(A_1) ⃗.((D_α) ⃗)
..(13)

(X_2) ⃗ = (X_β) ⃗-(A_2) ⃗.((D_β) ⃗)
..(14)

(X_3) ⃗ = (X_δ) ⃗-(A_3) ⃗.(D_δ) ⃗
..(15)

X ⃗(t+1)= ((X_1) ⃗+(X_2) ⃗+(X_3) ⃗)/3
..(16)

Mathematical Representation of Cuckoo Search Optimization:

Cuckoo Search Optimization (CSO) is a metaheuristic algorithm inspired by the brood parasitism behavior of some cuckoo species. The algorithm is particularly known for its use of Lévy flights to explore large solution spaces efficiently, enabling it to escape local optima and improve exploration capabilities. Here, we'll break down the mathematical representation of key components and processes involved in CSO.

1. Representation of Solutions

In CSO, each solution in the search space can be represented as a nest with eggs, where each egg represents a possible solution to the optimization problem. Mathematically, if there are nn nests and each nest has dd dimensions, a solution xixi can be represented as:

xi=(xi1,xi2,...,xid),i=1,2,...,$n$xi=(xi1,xi2,...,xid),i=1,2,...,n

2. Lévy Flights

Lévy flights provide a random walk, where the step-lengths have a heavy-tail distribution. This allows the algorithm to perform global searches by making long jumps across the search space. The step sizes are drawn from a Lévy distribution, which is typically heavy-tailed and can be modeled as:

s∼$\lambda\Gamma(\lambda)$sin($\pi\lambda$/2)π1s1+λ,0<λ<2s∼πλΓ(λ)sin(πλ/2)s1+λ1,0<λ<2

In practice, the step taken by a cuckoo ii in a D-dimensional space is calculated as:

xit+1=xit+α⊗Levy(λ)xit+1=xit+α⊗Levy(λ)

where:

- αα is the step size scaling factor,
- ⊗⊗ denotes the entry-wise multiplication,
- Levy(λ)Levy(λ) is the step size drawn from the Lévy distribution.

3. Discovery and Abandonment of Nests

One of the distinctive features of CSO is the probabilistic rule for abandoning worse solutions (nests), simulating the discovery of the cuckoo's egg by the host bird. At each iteration, a fraction papa of the nn nests is abandoned and new ones are built, which is mathematically modeled as:

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ISSN: 1001-4055
Vol. 45 No. 2 (2024)

if rand () < pa, then replace xi with $x$new

where:

- rand () rand () is a uniform random number between 0 and 1,
- Pa is the probability of discovering and abandoning a nest,
- $x$new is a new solution generated by Lévy flights or random walk.

4. Fitness Evaluation

Each solution is evaluated based on a fitness function (x)f(x), which depends on the specific optimization problem. The goal is typically to find the solution $x*$x* that minimizes (or maximizes) this function:

$x*$=arg min$x$ ((x))

Or $x*$=arg max$f()$

5. Comparison and Update

The algorithm iteratively compares and replaces worse nests with better solutions. A new solution $x$newxnew replaces the current solution xixi if it has a better fitness value. This selection mechanism ensures the survival and reproduction of the fittest solutions in the population, leading to overall improvement. potentially better solutions (cuckoo eggs) to replace not-so-good solutions in the nests.

4. Results and Discussions

Cuckoo Search Optimization

Due to environmental concerns and energy shortages, solar energy is becoming a leading renewable energy technology. Solar PV systems are increasingly important for power generation, directly converting sunlight into electricity. However, their efficiency relies heavily on operating conditions like solar radiation and temperature. To maximize a PV system's output, it needs to operate at the Maximum Power Point (MPP), which Cuckoo Search Optimization can help achieve.

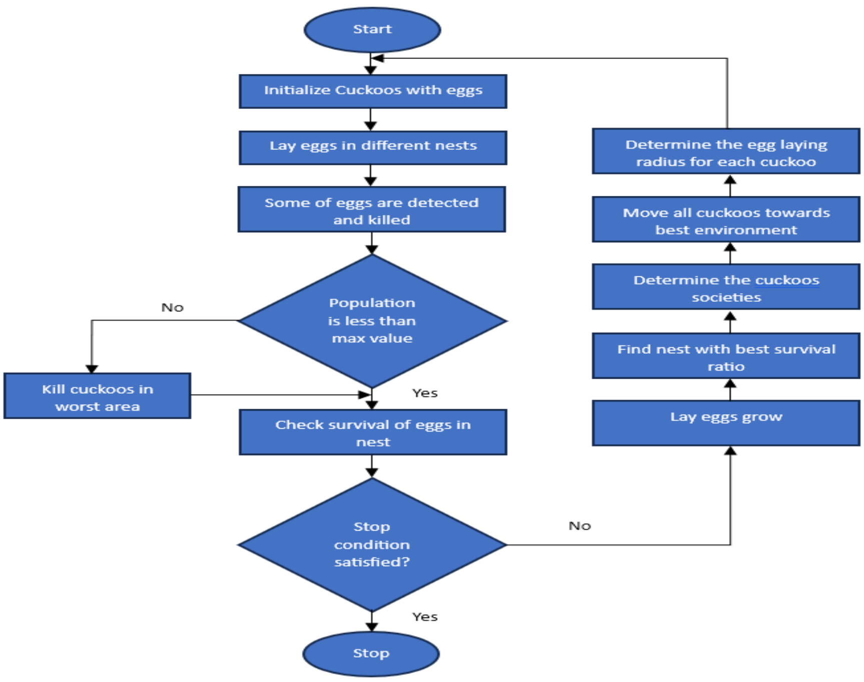

Fig. 1: Flowchart of Cuckoo Search Optimization

Gray Wolf Optimization

The Great Wolf Optimization (GWO) technique is applied to achieve Maximum Power Point Tracking (MPPT) in a solar PV system. This is implemented using a GWO optimization block in a Simulink model (Figure not shown). The results show a mid-range tracking efficiency (TE) of 97%.

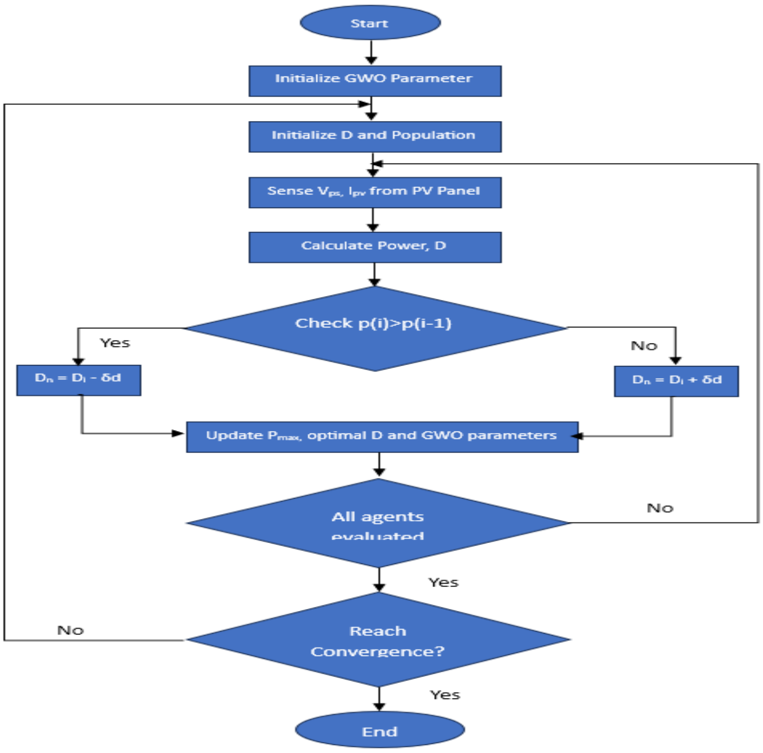

Fig. 2: Flowchart of Gray Wolf Optimization

Conclusion

This research investigated the effectiveness of Cuckoo Search Optimization (CSO) and Gray Wolf Optimization (GWO) in optimizing solar PV systems. The results (shown in tables and charts) confirm that both techniques can improve energy output, reduce costs, and enhance system reliability.

Gray Wolf Optimization (GWO) proved to be the superior method. It efficiently explored the search space and converged quickly to optimal solutions, as shown in Table 1.

Cuckoo Search Optimization (CSO) also performed well. Inspired by cuckoo birds, it tackles complex optimization problems in solar PV systems. Its unique features, like Lévy flights and random nest replacement, effectively navigate the challenging search space. CSO remains a valuable tool for optimizing solar PV systems due to its ability to solve complex problems. As research continues, CSO's full potential to advance solar energy technology can be realized.

Overall, this study highlights GWO's effectiveness while acknowledging CSO's value for optimizing solar PV systems.

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