EVOLUTION IN ELECTRICAL AND ELECTRONIC ENGINEERING
e-ISSN: 2756-8458

EEEE

Vol. 5 No. 1 (2024) 189-194
https://publisher.uthm.edu.my/periodicals/index.php/eeee

A Study of Stand-Alone Photovoltaic System Sizing Optimization Using Black Widow Optimization Algorithm

Muhamad Hariz Abdul Jalil[1], Muhammad Anas Razali[2]

[1] *Department of Electronic Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussien Onn Malaysia, 86400, Batu Pahat, Johor MALAYSIA*

*Corresponding Author: anas@uthm.edu.my
DOI: https://doi.org/10.30880/eeee.2024.05.01.024

Article Info

Received: 4 January 2024
Accepted: 31 January 2024
Available online: 30 April 2024

Keywords

Stand-alone Photovoltaic, Sizing Optimization, Black Widow Optimization Algorithm

Abstract

Optimization of SAPV systems is important to ensure cost effectiveness of the system assembly component combination which includes mainly photovoltaic panels, batteries, charge controllers and inverters. This work is aimed as a means of digitally optimizing the configuration of a stand-alone photovoltaic system by using a meta-heuristic approach through the application of a black widow optimization algorithm. The use of MATLAB software as a platform to compile algorithms of Iterative Sizing Algorithm (ISA) and Black Widow Optimization Algorithm (BWO) enables the production of minimal levelized cost of electricity at a fast rate without the need for manual individual component compatibility calculations.

1. Introduction

Solar and other renewables offer a promising solution for energy security and environmental sustainability [1]. However, it is important to note that solar energy resources exhibit intermittent and unpredictable behaviors factored by weather conditions throughout the year. Integrating a significant amount of solar PV power generation into the electricity grid may result in substantial supply-demand imbalances. These imbalances can lead to power supply unreliability, instability in the electricity network, and cost inefficiencies [2]. PV technology emerges as a highly promising solution in remote or off-grid areas, where the absence of access to the public power grid and the unavailability or high cost of traditional power sources like fossil fuels are common challenges. [3] To optimize PV systems for efficiency and cost-effectiveness, actively size the system by selecting components like PV modules, batteries, and charge controllers with optimal dimensions. Carefully determine the suitable size for each component to strike a balance between system availability and cost. This proactive approach enables the development of a high-efficiency PV system that remains economically viable. It ensures optimal operation, meeting performance requirements while minimizing overall costs [4]. In stand-alone PV systems, optimization is crucial for cost reduction and improved efficiency. Components like PV modules, batteries, and charge controllers can be fine-tuned, and researchers are turning to meta-heuristic algorithms, inspired by natural systems, to achieve this without structural modifications. These algorithms, particularly effective for tasks like system sizing and optimization, result in substantial time and cost savings, along with enhanced system quality and efficiency [5].

2. Materials and Method

This section discusses the basic processes of work including the chosen materials, software, and methods used as well as covers the detailed explanation of simulation developed using MATLAB for the Simulation study of swarm algorithms implemented for black widow optimization algorithm (BWOA).

2.1 Black Widow Optimization Algorithm Initial Population

Variable values create a framework for solving an optimization problem. In BWOA, each problem's solution is modelled as a Black widow spider. Each Black widow spider displays varied values. A widow is a 1 $Nvar$ array indicating the answer to an $Nvar$-dimensional optimization problem using the following equation (1). Array definition:

$$\text{Widow} = [x_1, x_2, \ldots, x_{Nvar}], \quad (1)$$

where ($x1$, $x2$, …, $xNvar$) are floating-point numbers. Evaluate fitness function f on a widow of ($x1$, $x2$, …, $xNvar$) by equation (2) to get widow's fitness.

$$\text{Fitness} = (\text{widow}) = (x_1, x_2, \ldots, x_{Nvar}) \quad (2)$$

Candidate widow matrix of size $Npop \times Nvar$ is produced with an initial population of spiders. At random, pairs of parents are chosen to conduct the procreating phase by mating, during or after which the male black widow is consumed by the female.

2.2 Procreate

Since the couples are independent, they mate in parallel to reproduce the next generation. In nature, each pair mates in their web, apart from the others. Each pairing produces 1000 eggs, but some stronger spider offspring survive. Now, in this process to reproduce, an array called alpha should also be constructed as long as widow array with random values, then offspring is generated by employing using the following equation (3) in which $\boldsymbol{x_1}$ and $\boldsymbol{x_2}$ are parents, $\boldsymbol{y_1}$ and $\boldsymbol{y_2}$ are offspring.

$$\begin{cases} y_1 = \alpha \times x_1 + (1 - \alpha) \times x_2 \\ y_2 = \alpha \times x_2 + (1 - \alpha) \times x_1 \end{cases} \quad (3)$$

This process is repeated for $N_{var}/2$ times, while randomly selected numbers should not beduplicated. Finally, the children and mom are added to an array and sorted by their fitnessvalue, now according to cannibalism rating, some of the best individuals are added to the newly generated population. These steps apply to all pairs.

2.3 Cannibalism

Three types of cannibalism are evident here. The first type is sexual cannibalism, where the female black widow actively consumes her male partner during or after mating. This program can distinguish between males and females based on their fitness scores. Another form of cannibalism is sibling cannibalism, where powerful spiderlings actively consume their weaker siblings. In this process, the calculation of the number of survivors is based on a cannibalism rating (CR). In rare instances, the third type of cannibalism occurs when spiderlings actively consume their mother. We use the fitness value to assess whether spiderlings are strong or weak.

2.4 Mutation

Mutepop number of people from the population in a random fashion is chosen. Each of the selected options involves making a haphazard swap of two items in the array. The mutation rate is used in the calculation of mutepop.

2.5 Convergence

Convergence in an algorithm is typically assessed by observing the improvement in the fitness values of the solution population across iterations. As the algorithm advances, the fitness values generally enhance, leading the solution population to converge to a stable and optimal solution. Several factors, such as population size, mutation rate, and selection criteria, influence the algorithm's convergence. For instance, a larger population size can increase solution diversity, aiding in finding the global optimum, but it may slow down convergence due to longer computational times. In the Black Widow Optimization Algorithm, convergence signifies the progress of the algorithm's search toward identifying the best solution for a given problem. It's evaluated by the improvement in fitness values across iterations and is influenced by factors tailored to the specific problem at hand.

2.6 Parameter Setting

To achieve superior outcomes with the proposed BWO algorithm, one must actively adjust crucial factors such as the mutation rate (MR), procreation rate (PR), and cannibalism rate (CR). Enhancing the algorithm's solution development requires the active modification of these parameters. The more factors actively modified, the higher the likelihood of escaping small optimums and actively exploring the search space globally. Consequently, determining the right balance between the exploitation and exploration phases actively depends on adjusting the controlling parameters—Mutation rate (MR), procreation rate (PR), and cannibalism rate (CR) of the BWO algorithm.

2.7 Flowchart

The black widow optimization algorithm has the same behavior of loading datasheets as the Iterative sizing algorithm while processing the output data is different. In Fig. 1, the lower data processing part of BWOA consists of generating the initial population, evaluating the fitness of black widow spiders, randomly selecting parents, procreate, cannibalism, mutation, and population update.

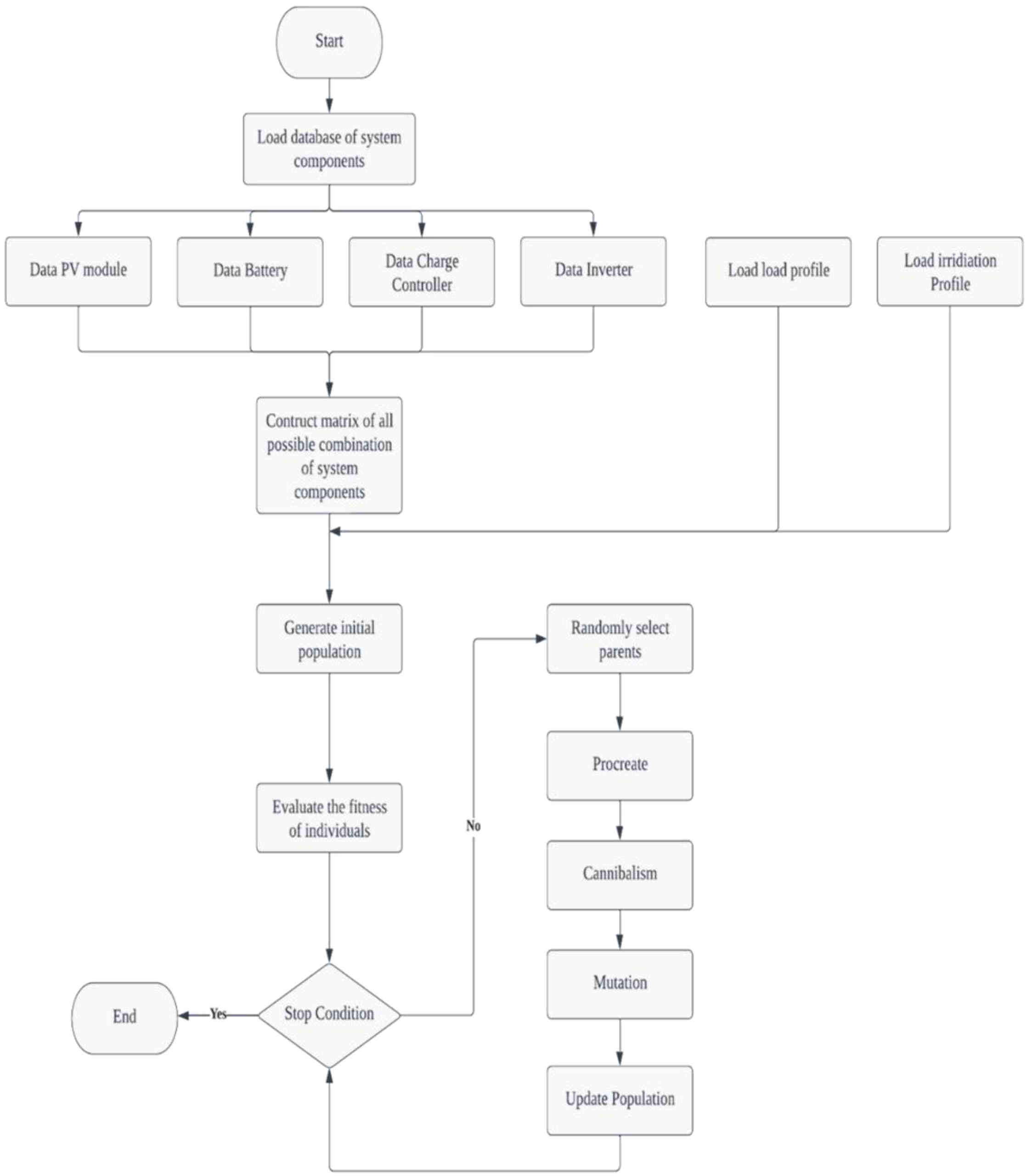


Fig. 1 *BWOA flowchart*

3. Equations

Finding the appropriate voltage and current ratings for each photovoltaic system component to meet the facility's electricity consumption and calculating the total system cost from the design phase to the final product is known as system sizing.

Step 1: Perform load assessment for the selected site and calculate the total required AC load required by applying equations (4) and (5). Required battery bank capacity determined by equation (6)

$$E_{req_{daily}} = E_{dc} + \frac{E_{ac}}{\eta_{inv}} \tag{4}$$

$$R_{IL} = \frac{H_{array_{plane_{daily}}}}{E_{req_{daily}}} \tag{5}$$

$$C_{required\_daily} = \frac{E_{required\_daily}}{f_{temp_{bat}}} \tag{6}$$

Step 2: Using equation (7), the number of batteries needed is determined.

$$C_{rev_{bank_{req}}} = \frac{C_{bank_{required}}}{SV} \, x \, \frac{T_{autonomy}}{DOD_{max}} \tag{7}$$

Step 3: Equation (8) is used to find the system's Performance Ratio (PR).

$$PR = \frac{(\frac{SY}{1000})}{PSH} \tag{8}$$

Step 4: The value of LCOE is determined using equation (9)

$$LCOE = \frac{LCC}{\sum_{t=1}^{n}(\, Y_f \, x \, \left(100\% - (\, t \, x \, g_{deg})\right))} \tag{9}$$

where,

LCC = Life cycle cost

Yf = System yield per year, in kWh

4. Result and Discussion

The results and discussion section presents the simulation result of the iterative sizing algorithm ISA and black widow optimization algorithm BWOA through MATLAB script. Comprehensive research is conducted to evaluate the potential of the proposed BWO algorithm in addressing the SAPV system in renewable energy. The study aims to optimize the SAPV system by employing both the ISA and Black Widow Optimization Algorithm to minimize the levelised cycle cost and maximize the performance ratio achievable by the photovoltaic system. To identify the optimal size of the SAPV system, a database consisting of 20 different types of each component is utilized. The sizing function then selected random combinations to generate LCOE and PR.

4.1 Performance ISA vs BWOA

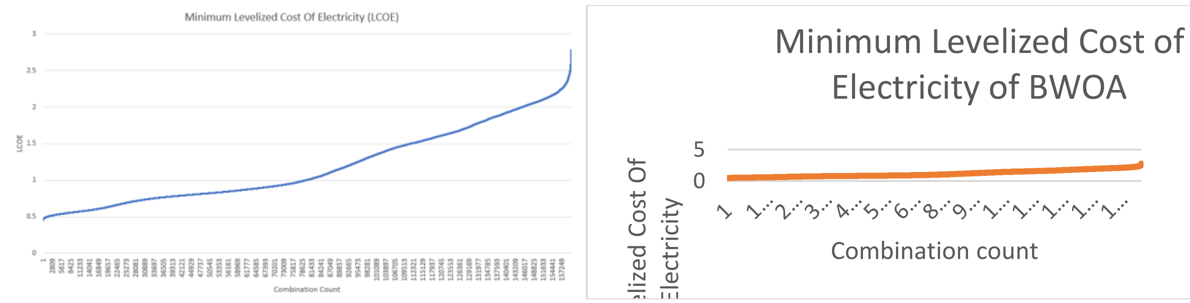
By optimizing SAPV using the Iterative Sizing Algorithm (ISA) and the Black Widow Optimization Algorithm (BWOA), the obtained system's levelised cost of energy (LCOE) and performance ratio (PR) are as presented in Table 1. Component codes are same between both optimization algorithms. 7 for solar panel (PV), 19 for battery, 11 for inverter and 14 for a charge controller producing the same levelised cost of energy (LCOE) and performance ratio (PR). The difference of performance can be seen through the MATLAB computational time of code simulation.

Table 1 Performance ISA vs BWOA

Parameter	ISA	BWOA
PV Code	7	7
BATT Code	19	19
INV Code	11	11
CC Code	14	14
LCOE (RM/kWh)	0.4493	0.4493
PR	0.8202	0.8202
Computational Time (sec)	497.148	192.716

4.2 Levelized Cost of Electricity (LCOE)

The results in Fig. 2 showed that both algorithms achieved a minimum LCOE of RM 0.4493 per kWh across "160,000" combination count.

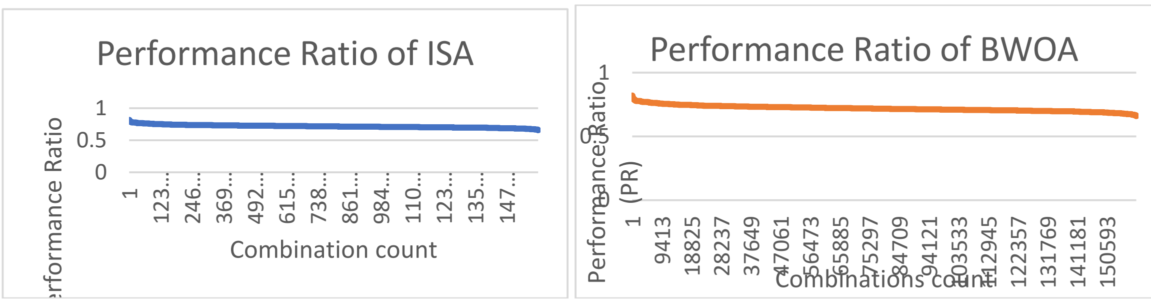


(a) **(b)**

Fig. 2 *Levelized cost of electricity LCOE (a) ISA; (b) BWOA*

4.3 Maximum Performance Ratio (PR)

The Performance Ratio (PR) is a crucial metric for evaluating photovoltaic (PV) system effectiveness, indicating the actual performance relative to its theoretical maximum. A higher PR reflects optimal efficiency, while a lower value suggests suboptimal performance. Commonly employed optimization methods, such as the Iterative Sizing Algorithm (ISA) and the Black Widow Optimization Algorithm (BWOA), actively enhance power reliability by identifying optimal sizes for key components like PV modules, batteries, inverters, and charge controllers. In Fig. 3 shows that the maximum performance ratio for both ISA and BWOA are similar for every combination of components simulated at the highest point, 0.8202 equivalent to 82.02%.



(a) **(b)**

Fig. 3 *Maximum performance ratio (a) ISA; (b) BWOA*

4.4 Computational Time

Five runs of simulations for each algorithm are documented in Fig. 4 which averaged 497.148 seconds for Iterative sizing algorithm and 192.716 seconds for Black widow optimization algorithm. Through BWOA simulation, a reduction of 61.23% simulation time compared to ISA proved that although BWOA code structure is high in complexity, overall time required to obtain the same optimized output data is reduced significantly.

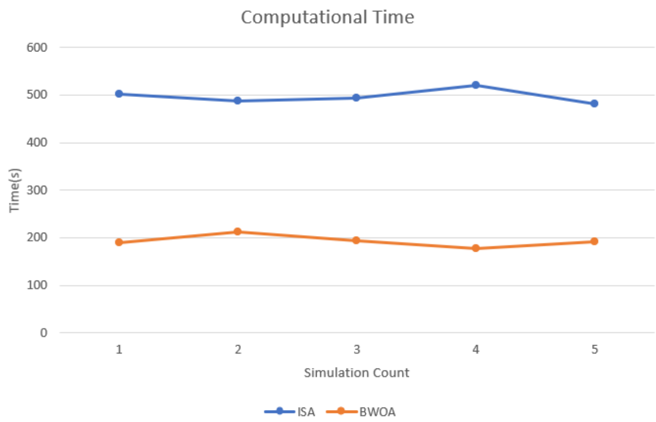


Fig. 4 *Computational time of ISA and BWOA*

5. Conclusion

The study utilized the BWO algorithm in MATLAB, incorporating principles from particle swarm optimization and binary coding. The algorithm explored diverse combinations of SAPV system components to identify the optimal configuration, resulting in reduced LCOE and increased PR. The BWO algorithm efficiently generated codes for the optimal configuration of each component, contributing to a more cost-effective and efficient system. Compared to the Iterative Sizing Algorithm (ISA), the BWO method proved more effective in generating an optimal code set and lowering the LCOE, requiring a smaller initial population. In conclusion, the study demonstrates the successful use of the BWO algorithm to optimize the SAPV system's size, achieving LCOE reduction and providing valuable insights for developing cost-effective and efficient renewable energy systems. This optimization can make renewable energy sources like SAPV more accessible and widespread, contributing to a sustainable future by decreasing energy production costs and enhancing system performance.

Acknowledgement

This research was fully supported by the Faculty of Electrical and Electronic Engineering (FKEE) and Universiti Tun Hussein Onn Malaysia (UTHM).

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

References

[1] J. Hu, et al., "Energy Big Data Analytics and Security: Challenges and Opportunities," IEEE Transactions on Smart Grid, vol. 7, pp. 2423-36, 2016.
[2] F. Cheng, et al., "Applying battery energy storage to enhance the benefits of photovoltaics," IEEE, Cleveland, OH, USA, 2012.
[3] L. A. Nguimdo, C. Kum, L. A. Nguimdo, and C. Kum, "Optimization and Sizing of a Stand-Alone Photovoltaic System and Assessment of Random Load Fluctuation on Power Supply," Energy Power Eng., vol. 12, no. 1, pp. 28–43, Dec. 2019, doi: 10.4236/EPE.2020.121003.
[4] V. K. Sharma, A. Colangelo, and G. Spagna, "Photovoltaic technology: Basic concepts, sizing of a stand-alone photovoltaic system for domestic applications and preliminary economic analysis," Energy Convers. Manag., vol. 36, no. 3, pp. 161–174, Mar. 1995, doi: 10.1016/0196-8904(94)00065-8.
[5] S. S. Alam, N. F. M. Nor, M. Ahmad, and N. H. N. Hashim, "A survey on renewable energy development in Malaysia: Current status, problems and prospects," Environ. Clim. Technol., vol. 17, no. 1, pp. 5–17, May 2016, doi: 10.1515/RTUECT-2016-0002.