International Journal of Electrical Engineering and Intelligent Computing (IJEEIC) EISSN 3031-5255
https://ejournal.unkhair.ac.id/index.php/ijeeic/index

Symbiotic Organism Search Based on Sensitivity Factor for Optimal Location and Sizing of Distributed Generation

Iswan[1], Umar[1], M Natsir Rahman[1], Suparman[1], Muhammad Said[1], Faris Syamsuddin[1], Dharmawan[1], Andi Syarifuddin[2]
[1]Department of Electrical Engineering, Universitas Khairun
Kampus Gambesi, Ternate, Indonesia
*is.one.wan@gmail.com
[2]Department of Electrical Engineering, Universitas Muslim Indonesia
Makassar, Indonesia

Article history : Received April 13, 2025 | Revised August 8, 2025 | Accepted Sept 9, 2025

The technology of Distributed Generations (DGs) has attracted the focus of researchers and engineers over the past two decades as an effective solution to address power quality and supply issues for customers. Determining the optimal locations and sizes for DGs remains a significant challenge. This study explores the optimization of DG placement and sizing to reduce power losses in radial distribution systems. The Loss Sensitivity Factor (LSF) is used to identify suitable locations for DGs, while Symbiotic Organisms Search (SOS) is utilized to determine their capacities. Simulation results using three DGs on the IEEE 33-bus distribution system indicate that this approach can reduce active power losses by 67.66%.

Keywords: Power Losses, Symbiotic Organism Search, Sensitivity Factor, Distributed Generation, Power Quality

This is an open access article under the (CC BY-NC-SA 4.0)

1. INTRODUCTION

In electrical systems, ensuring the supply of electrical energy to loads in sufficient quantities and with good quality is a priority. The largest reserves of fossil energy and the necessity to reduce greenhouse gas emissions promote the shift to renewable energy. The United States, China, and Brazil are leading countries in the development of renewable energy potential. According to IRENA's *Renewable Capacity Statistics 2025*, global renewable power capacity reached 4,448 GW in 2024. The 585 GW added in 2024 accounted for 92.5% of total capacity expansion, marking a record annual growth rate of 15.1% [1]. The demand for affordable and high-quality electricity encourages the adoption of electricity based on Distributed Generations (DGs), which are small-scale electricity networks and distributed energy resources [2].

Research indicates that approximately 13% of the generated power is lost as distribution network losses [3]. Increased load on the distribution network results in significant voltage drops. To reduce power losses and improve voltage profiles, the planning of the electrical system, which includes the integration of Distributed Generation (DG) into the network, must be carefully executed. Placing DG in suboptimal locations can lead to increased power losses and decreased voltage levels in the power system.

Determining the location and capacity of DG simultaneously is a challenging task due to the involvement of numerous variables. To address this issue, various methods have been developed. The optimal location of DG based on the Voltage Sensitivity Index (VSI) was developed by Nweke et al [4]. The DG location determination is based on the bus with the lowest VSI. Kirmani et al [5] used an exhaustive search approach based on the direct load flow method to find the optimal location and size for multiple DGs. Moughal et al [6] and Patwa et al [7] developed analytical methods based on the Voltage Stability Index to determine the location and capacity of DG. Analytical methods based on exact loss formula were developed by Singhal et al [8] and Sakulphaisan et al [9]. These methods are based on the ratio of power losses generated before and after the placement of DG in the distribution system. The location of the DG is based on the bus with the greatest reduction in power loss. As systems grow larger and problems become more complex, index-based optimization methods for DG placement encounter difficulties in solving these issues.

The development of intelligent computing methods has driven the use of artificial intelligence (AI) in optimizing DG placement. Various intelligent algorithms have been developed, such as Genetic Algorithm (GA) [10], Particle Swarm Optimization (PSO) [11], Harmony Search (HS) [12], Grey Wolf Optimizer (GWO) [13], Whale Optimizer Algorithm (WOA) [14], Multi Verse Optimizer (MVO) [15], and others. To address complex problems in optimizing DG capacity and location, researchers typically use a combination of sensitivity factors (SF) and AI-based algorithms. SF is used to determine the location, while AI is used to determine the DG capacity. For example, the loss sensitivity factor (LSF) and improved analytical method are proposed in [16]. Hybrid analytical method and PSO are developed in [17]. Sujono et al. [18] employed the sensitivity index and an adaptively modified firefly algorithm (AMFA). One heuristic method that has attracted researchers' interest is SOS [19]. This method is known for its simplicity, ease of application, and robustness, making it applicable in several applications [19-21]. In this study, SOS is used to determine the DG capacity, while the DG location is determined using the loss sensitivity factor (LSF). The rest of this paper is organized as follows: SOS, objectiv function and constrain are explained in section 2. Section 3 presents data test system, result and discussion. Finally, section 3 proposes the research conclusions.

2. PROBLEM FORMULATION

2.1. Symbiotic organism search algorithm

SOS is an algorithm that emulates the symbiotic relationships found among living organisms in an ecosystem [19]. The most common types of these relationships are mutualism, commensalism, and parasitism. The mutualism phase illustrates the interaction between two organisms (X_i and X_j) in the ecosystem, where both parties benefit. This mutualistic relationship can be expressed as follows:

$$X_{i\_N} = X_i + rand(0,1) \times (X_b - M \times BF_1) \quad (1)$$

$$X_{i\_N} = X_i + rand(0,1) \times (X_b - M \times BF_1) \quad (2)$$

i and j are integers, where $i \neq j$. X_b is the organism with the highest fitness in the ecosystem. M is a mutual vector. Mutual vector is defined as:

$$M = (X_i + X_j)/2 \quad (3)$$

Benefit factors are defined as:

$$BF_1 = 1 + round[rand(0,1)] \quad (4)$$

$$BF_2 = 1 + round[rand(0,1)] \quad (5)$$

During the commensalism phase, the new organism resulting from the interaction between X_i and X_j is represented as:

$$X_{i_N} = X_i + rand(-1,1) \times (X_b - X_j) \quad (6)$$

The parasitism phase describes the interaction between two organisms, where one benefits at the expense of the other. A parasitic vector (P_v) is created by cloning the Xi organism, which acts as the parasite. The X_j organism is randomly chosen to serve as the host for the parasitic vector. If the fitness of P_v is higher than that of X_j, then X_j is replaced by the P_v; otherwise, X_j remains unchanged. The flowchart for symbiotic organism search is shown in Figure 1.

2.2. Objective and Constrain

In distribution systems, active power loss is influenced by the resistance and line current. High line resistance leads to significant power loss and voltage deviations. The goal of DG optimization is to minimize active power loss, so the objective function of this work can be expressed as:

$$F = min\left(\sum_{i=1}^{n} \sum_{j=2}^{n} i_{ij}^2 R_{ij}\right) \quad (7)$$

The objective function in Eq. 7 must meet the following constraints:

a. In distribution systems, the voltage constraint specifies the permissible voltage range that must be maintained at each bus to ensure reliable and stable operation. Adherence to this constraint prevents equipment malfunction, reduces excessive power losses, and mitigates the risk of potential network instability. Mathematically, the voltage at each bus i (V_i) is constrained by its minimum (V_i^{min}) and maximum (V_i^{max}) limits as formulated below:

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (8)$$

b. The total active power supplied by the primary generation sources (Pg) and DG units (PDG) must be sufficient to meet the total load demand (Pd) while also compensating for the real power losses (Ploss) that occur in the network. This balance ensures stable operation and optimal utilization of generation resources. Mathematically, this relationship can be expressed as follows:

$$P_g + PDG = P_d + P_{loss} \quad (9)$$

c. The number of DG units (ηDG) to be integrated into the system must not exceed the maximum allowable limit (ηDG_{max}) as defined by technical, operational, and regulatory constraints. This limitation is imposed to maintain system reliability, avoid excessive penetration levels that may cause voltage fluctuations or reverse power flow, and ensure compliance with grid integration standards. Mathematically, this constraint can be expressed as:

$$\eta DG \leq \eta DG_{max} \quad (10)$$

d. The active power output of a DG unit (P_{DG}) must operate within its specified capability range to ensure safe, efficient, and reliable performance. This range is bounded by the minimum permissible output (P_{DGmin}), which may be determined by technical constraints such as generator stability and minimum loading requirements, and the maximum permissible output (P_{DGmax}), which is dictated by equipment ratings, thermal limits, and operational safety margins. Mathematically, this constraint is expressed as:

$$P_{DGmax} \leq P_{DG} \leq P_{DGmin} \quad (11)$$

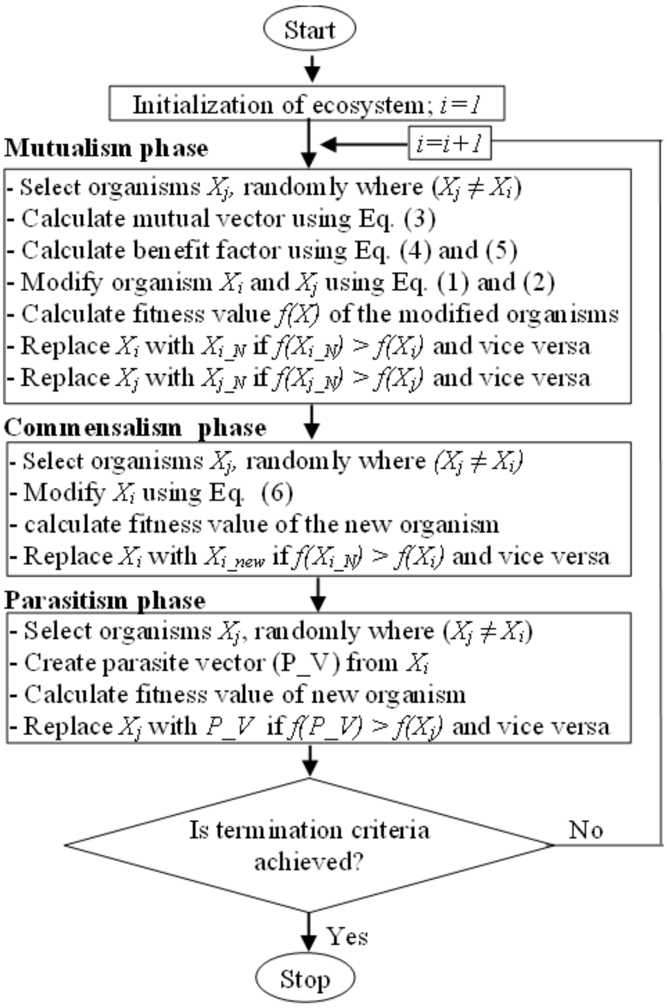

Figure 1. Flowchart for symbiotic organism search

3. TEST SYSTEMS AND RESULT

3.1. Data Test System

The IEEE 33-bus system consists of 32 lines and 33 buses. The loads connected to this system include active power loads of 3.715 MW and reactive power loads of 2.3 MVar. These loads are supplied through bus 1 at a supply voltage of 12.66 kV. The load and bus data for the IEEE 33-bus system in this paper are adopted from [16]. The single-line diagram of the IEEE 33-bus radial distribution system is shown in Figure 2.

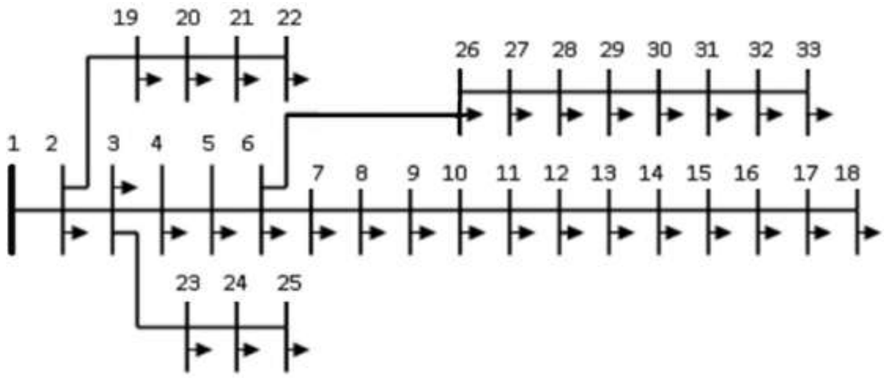

Figure 2. Single line diagram of IEEE 33 bus system

3.2. DG location Identification

The most challenging part of optimizing DG placement is determining the appropriate DG locations to ensure the objective function is optimal. For a single DG, the possible combinations of DG locations are the same as the number of buses in the system, making it easy to determine. However, as the number of DGs increases, the number of location combinations also increases, complicating the optimization problem further. To address this issue, the Loss Sensitivity Factor (LSF) is used in this paper to identify DG locations. The LSF value due to DG injection at a specific bus is formulated as follows:

$$LSF_i = \frac{P^i - P^b}{P^{inj}} \quad (12)$$

P^i and P^b are the network loss due to DG injection and the system loss prior to DG injection respectively, while P^{inj} is the power injected by DG. The steps to determine the DG location based on LSF are as follows:

1. Identify the number, size, and capacity of DG units.
2. Inject a single DG into the distribution system, gradually increasing its capacity while recording the LSF value for each bus until the desired DG capacity is reached.
3. Select the optimal DG location based on the smallest LSF value from step 2.
4. Install the DG unit at the optimal location which is identified in step 3.
5. Repeat steps 2 to 4 for each additional DG unit until all optimal DG locations are determined.

Based on the above steps, the minimum LSF value and the DG location for each optimization scheme for the IEEE 33 bus system are presented in Table 1.

Table 1. The minimum LSF value and DG location for IEEE 33 bus System

Scheme	DG Location (Bus)	Size (MW)	LRSF
1 DG	6	2.550	-0.03855
2 DG	13	0.850	-0.02649
	30	0.850	-0.04386
3 DG	13	0.850	-0.02648
	30	0.850	-0.04387
	24	0.850	-0.04987

3.3. DG Capacity Identification

Using LSF, optimal sizing of DG is performed using back-forward load flow and SOS. The type of DG used is DG which is only capable of injecting real power. The optimization of DG placement in this study consists of three schemes, which are adjusted according to the number of DGs connected to the network. The optimization results are compared with hybrid methode, PSO, enhanced analytical (EA) [16], and SOS. SOS parameter settings are: Ecosystem number (n) = 50, Number fitness evaluation (NFE) = 3000. The algorithm is run 10 times per scheme to ensure the optimal point is reached. PSO and hybrid parameter settings are adopted from [17], while EA parameters follow [16]. Tables 2 show the results of DG optimization for the IEEE 33 bus system.

Table 2. Optimal location and size of DG on IEEE 33 bus System

Scheme	Method	Objective	Bus Location	Size (MW)	Capacity (MW)	Power Loss(kW)	Loss Reduction (%)	NFE
No DG	Initial condition	-	-	-	0.000	211.000	0.000	-
1 DG	Hybrid [17]	Min (P_{loss})	6	2.490	2.490	111.700	50.356	NA
	Enhanced Analitical [16]	Min (P_{loss})	6	2.600	2.600	111.100	50.622	NA
	PSO [17]	Min (P_{loss})	6	2.590	2.590	111.030	50.653	NA
	Proposed	Min (P_{loss})	6	2.590	2.590	111.023	50.659	215.210
2 DG	Hybrid [17]	Min (P_{loss})	13 30	0.830 1.110	1.940	87.280	61.209	NA
	Enhanced Analitical [16]	Min (P_{loss})	6 14	1.800 0.720	2.520	91.630	59.276	NA
	PSO [17]	Min (P_{loss})	13 30	0.850 1.160	2.010	87.170	61.258	NA
	Proposed	Min (P_{loss})	13 30	0.852 1.158	2.010	87.162	61.262	1095.052
3 DG	Hybrid [17]	Min (P_{loss})	13 24 30	0.790 1.070 1.010	2.870	72.890	67.604	NA
	Enhanced Analitical [16]	Min (P_{loss})	6 12 31	0.900 0.900 0.720	2.520	81.050	63.978	NA
	PSO [17]	Min (P_{loss})	13 24 30	0.770 1.090 1.070	2.930	72.790	67.649	NA
	Proposed	Min (P_{loss})	13 24 30	0.802 1.091 1.054	2.947	72.782	67.655	685.174

NA=Not Available

As shown in Table 2, the proposed method performs better compared to the Hybrid, PSO, and EA methods for all schemes. For the single DG optimization case, all methods produce almost identical results. However, as the number of DGs increases, significant differences emerge between the analytical method (EA) and AI-based methods. EA is an analytical method that uses mathematical expressions to integrate the DG model into the load flow. However, analytical methods are limited in their ability to accurately model non-differential or complex problems, leading to inaccurate results. The hybrid method combines analytical and PSO methods: PSO is used to determine the optimal DG location, while the analytical method determines the DG size. Although PSO accurately identifies the optimal DG location, the analytical method struggles with accurately determining the DG size. PSO also faces challenges due to the numerous parameters that need adjustment to ensure a global optimum is reached. The balance between exploration and exploitation phases depends on the appropriate parameter settings in PSO, and improper settings can affect its accuracy. In contrast, SOS does not require special control parameters, making it robust with good convergence speed.

DG placement optimization significantly improves the bus system voltage. Before DG placement, most of the bus voltages in the system were below 0.95 pu, with a minimum voltage of 0.9133 pu at bus 18 and an average voltage of 0.9486 pu. Injecting a single DG of 2.59 MW at bus 6 improved the bus system voltage, raising all bus voltages above 0.95 pu and increasing the average voltage from 0.9486 pu to 0.9750 pu. Adding more DG units to the system significantly impacts bus system voltage. Placing three DG units in the system not only reduces power losses but also enhances system voltage. In the three-DG placement scheme, the average bus voltage increased to 0.9824 pu with a minimum voltage of 0.9686 pu at bus 33. The bus system voltages before and after the addition of DG are shown in Figure 3.

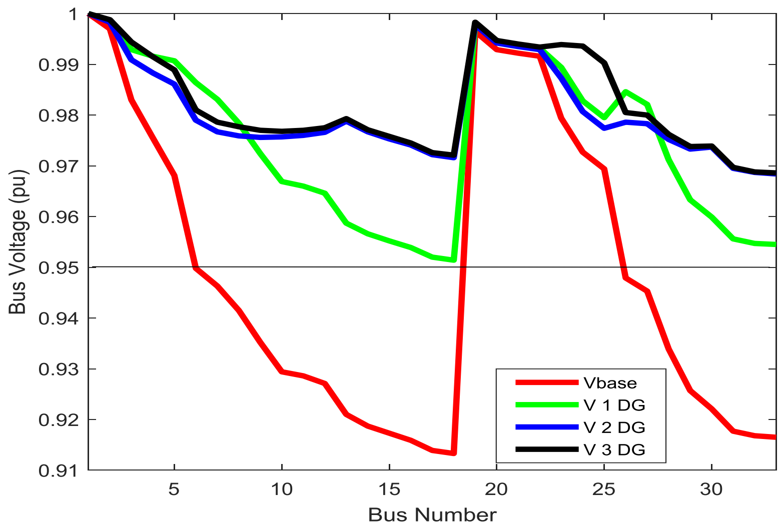

Figure.3 Bus voltages before and after DG placement on the IEEE 33 bus system

4. CONCLUSION

From the above discussion, it can be concluded that the addition of DGs to the distribution system effectively reduces active power losses. The reduction in active power losses increases with the capacity and number of DGs added to the distribution system. Among the three optimization schemes conducted, the proposed method performs better than the others in terms of compensating for active power losses. The SOS-based loss sensitivity factor method, in the scheme using 3 DGs, was able to reduce power losses by 67.66%. Adding DGs to the power system not only reduces active power losses but also significantly improves bus voltage. Bus voltage increases as more and larger DGs are connected to the system.

REFERENCES

[1] International Renewable Energy Agency (IRENA), *Renewable Capacity Statistics 2025*. Abu Dhabi, United Arab Emirates: IRENA, 2025. [Online]. Available: https://www.irena.org/publications.

[2] M. Gonçalves-Leite, E. Carreño-Franco, and J. López-Lezama, "Impact of distributed generation on the effectiveness of electric distribution system reconfiguration," *Energies*, vol. 16, no. 17, p. 6154, 2023, doi: 10.3390/en16176154.

[3] O. Penangsang, "Simultaneously placement and sizing of multiple DGs and shunt capacitor banks in unbalanced distribution systems using real coded GA," in *2016 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, 2016: IEEE, pp. 487-492.

[4] J. N. Nweke, A. O. Salau, and U. C. Ogbuefi, "Bus Voltage Sensitivity Index Based Approach Against Voltage Collapse in Distribution Systems," in *Proc. 2021 Int. Conf. Decision Aid Sci. Appl. (DASA)*, Sakheer, Bahrain, 2021, pp. 1062–1066, doi: 10.1109/DASA53625.2021.9682359..

[5] S. Kirmani, A. Kumar, and A. K. Pandey, "DG placements in distribution network using exhaustive search approach," in *2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, 2019: IEEE, pp. 1-6.

[6] M. U. A. Moughal and S. A. A. Kazmi, "An upgraded Voltage Stability Index based Approach for Multiple DG Placement in Mesh Distribution System across Multiple Horizons," in *Proc. 2021 16th Int. Conf. Emerging Technol. (ICET)*, Islamabad, Pakistan, 2021, pp. 1–6, doi: 10.1109/ICET54505.2021.9689906.

[7] A. Patwa, T. Thakur, and S. Gupta, "Voltage stability index based optimal sizing and placement of DG," in *2020 IEEE Students Conference on Engineering & Systems (SCES)*, 2020: IEEE, pp. 1-6.

[8] G. A. S. Gandhi, R. Prakash and S. Sivasubramani, "Optimal Allocation of DG for Minimization of Power Loss and Total Investment Cost using an Analytical Approach," *2020 21st National Power Systems Conference (NPSC)*, Gandhinagar, India, 2020, pp. 1-6, doi: 10.1109/NPSC49263.2020.9331891.

[9] G. Sakulphaisan, N. Junhuathon, and K. Chayakulkheeree, "Minimizing power loss in a DC distribution system through an analysis of the loss sensitivity factor and distributed generator loss characteristics," in *2022 International Electrical Engineering Congress (iEECON)*, 2022: IEEE, pp. 1-4.

[10] U. Umar *et al.*, "Single-phase distributed generations for power balanced using adaptive real coded genetic algorithm," *International Journal of Applied*, vol. 13, no. 1, pp. 11-19, 2024.

[11] G. He *et al.*, "Optimal Location and Sizing of Distributed Generator via Improved Multi-Objective Particle Swarm Optimization in Active Distribution Network Considering Multi-Resource," *Energy Engineering*, vol. 120, no. 9, 2023.

[12] X. Shi, T. Liu, W. Mu, and J. Zhao, "Implementing an optimal energy management system for a set of microgrids using the harmony search algorithm," *Energy Engineering*, vol. 119, no. 5, pp. 1843-1860, 2022.

[13] A. Lakum and V. Mahajan, "A novel approach for optimal placement and sizing of active power filters in radial distribution system with nonlinear distributed generation using adaptive grey wolf optimizer," *Engineering Science and Technology, an International Journal*, vol. 24, no. 4, pp. 911-924, 2021.

[14] K. Subbaramaiah and P. Sujatha, "Optimal DG unit placement in distribution networks by multi-objective whale optimization algorithm & its techno-economic analysis," *Electric Power Systems Research*, vol. 214, p. 108869, 2023.

[15] F. M. Behbahani, B. Ahmadi, and R. Caglar, "Multi-objective multiverse optimization for optimal allocation of distributed energy resources: The optimal parallel processing schemes," *Electric Power Systems Research*, vol. 231, p. 110298, 2024.

[16] D. Q. Hung and N. Mithulananthan, "Multiple distributed generator placement in primary distribution networks for loss reduction," *IEEE Transactions on industrial electronics*, vol. 60, no. 4, pp. 1700-1708, 2011.

[17] S. Kansal, V. Kumar, and B. Tyagi, "Hybrid approach for optimal placement of multiple DGs of multiple types in distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 75, pp. 226-235, 2016.

[18] A. Priyadi, M. Pujiantara, and M. H. Purnomo, "A Hybrid Adaptively Modified Firefly and Differential Evolution in DG Integration Optimization for Improving the Radial Power Distribution Networks," *International Journal of Intelligent Engineering & Systems*, vol. 16, no. 5, 2023.

[19] M.-Y. Cheng and D. Prayogo, "Symbiotic organisms search: a new metaheuristic optimization algorithm," *Computers & Structures*, vol. 139, pp. 98-112, 2014.

[20] U. Umar, F. Faanzir, I. Iswan, M. Said, and H. Haryati, "Improved Symbiotic Organism Search (I-SOS) for global numerical optimization," *Engineering and Applied Science Research*, vol. 50, no. 5, pp. 499-505, 2023.

[21] A. E. Ezugwu and D. Prayogo, "Symbiotic organisms search algorithm: theory, recent advances and applications," *Expert systems with Applications*, vol. 119, pp. 184-209, 2019.

BIOGRAPHIES OF AUTHORS

Iswan received a Bachelor of Engineering Degree From the Department of Electrical Engineering from the Muslim University of Indonesia Makassar in 2000, While the Master of Engineering Degree from the Department of Electrical Engineering, Hasanuddin University, Makassar, in 2005. Completing a Doctoral Program at Electrical Engineering Department, Faculty of Engineering, Universitas Indonesia, in 2021. Iswan, is Lecture, Faculty of Engineering, Khairun University, Ternate - Indonesia. Researching about being in Energy Management, Distributed Energy Resources, and Renewable Energy. He can be contacted at email: is.one.wan@gmail.com.

U. Umar is currently works as an associate professor in the electrical engineering department of Universitas Khairun, Indonesia. He completed his undergraduate program in electrical engineering at Universitas Hasanuddin in 2000. He obtained his master's and Doctoral degrees from the electrical engineering department of Institut Teknologi Sepuluh Nopember, Indonesia in 2008 and 2022 respectively. His main research areas include artificial intelligence, renewable energy, distribution automation, and power quality. He can be reached via email at umarmadjid94@gmail.com.

Muhammad Natsir Rahman received his Bachelor and Master Engineering from Hasanuddin University in 1999 and Bandung Institute of Technology in 2004, respectively. He is currently pursue his PhD in Kyushu University, Japan. He is alecturer in the Electrical Engineering Department, Khairun University, North Maluku, Indonesia. His interests are energy system optimization, agriculture control and intelligent systems. Email: mnr4hm4n@yandex.com.

Dharmawan obtained his Master of Engineering degree from Universitas Brawijaya. Since 2024, he has been serving as a lecturer in the Department of Electrical Engineering, Universitas Khairun. His research focuses on the field of mechatronics. He can be reached at dharmawan@unkhair.ac.id.

Andi Syarifuddin received a bachelor's degree from Universitas Muslim Indonesia Makassar, Indonesia, in 1997, a master's degree from Institut Teknologi Sepuluh Nopember, Indonesia, in 2008, all in electrical engineering, and a Doctoral degree from Universitas Negeri Makassar in the field of vocational engineering, in 2024. He is currently working for the Electrical Power Engineering Program, Electrical Engineering Department, Universitas Muslim Indonesia, Makassar, Indonesia. His main research interests include power systems, renewable energy, and smart grids. andisyarifuddin@umi.ac.id