International Journal of Information, Engineering & Technology
Volume 12, Issue 7, PP 22-30, ISSN: 2360-9194, July, 2024
DOI: 4272-1454-381-1274
Double Blind Peer Reviewed International Research Journal
Journal Series: Global Academic Research Consortium (garc)
arcnjournals@gmail.com
https://arcnjournals.org

Comparative Performance Evaluation of Distinct Distributed Generator Allocation and Sizing Methods: Crow Search Algorithm, Smell Agent Optimization, and Their Hybrid Variant in the IEEE 69-Bus Test System

Abdulsalam B. Muhammad[1*], M.M. Muhammad[1], Bukar U. Musa[1] & Lawan Dauda[1]
[1]Department of Electrical and Electronics Engineering, University of Maiduguri, Maiduguri, Borno State, Nigeria

Abstract: *This study compares the performance of the Crow Search Algorithm (CSA), Smell Agent Optimization (SAO), and Hybrid CSA-SAO for the optimal placement and sizing of Distributed Generator (DG) units in the IEEE-69-bus test system to improve power delivery. The objectives are to minimize total power losses and improve the voltage profile, considering a maximum of three DGs. The CSA method achieved a 50.74% reduction in system losses and a 10.73% improvement in the overall voltage profile. Similarly, the SAO method resulted in a 54.03% reduction in losses and a 34.39% improvement in the overall voltage profile. The hybrid CSA-SAO approach achieved a 57.12% reduction in losses and a 53.40% improvement in the overall voltage profile compared to the base case scenario. Convergence iterations were also evaluated, with both the CSA approach and the Hybrid Algorithm demonstrating efficiency by requiring fewer iterations compared to the SAO approach. CSA exhibited the fastest convergence due to its fewer parameters to adjust.*

Keywords: *Distributed Generation, Crow Search Algorithm, Smell Agent Optimization, Power Losses, Voltage Profile.*

1.0 INTRODUCTION

In recent decades, the integration of Distributed Generation (DG) into the power grid has seen substantial growth. DGs are attractive energy sources because they enhance the security and sustainability of the electricity system and promote the use of low-carbon technologies such as wind and solar power. Distributed Generation typically refers to small-scale electricity production (ranging from 1 kW to 50 MW) located closer to end-users than traditional central power plants [1]. Depending on the objectives, DGs can be strategically combined to alleviate line overloads and expand the system's operating range, allowing for more flexible operation. To maximize the benefits of DGs while minimizing costs, it is crucial to meet technical constraints and optimize economic goals [2, 3]. When integrating DGs into an Electric Distribution

System (EDS), their placement and capacity must be carefully considered. This ensures their optimal size is integrated into the grid, minimizing losses, attracting investment, ensuring reliable electricity supply, and achieving economic benefits. Therefore, determining the optimal location and capacity of DGs to reduce power loss is essential [4, 5].

Recently, several techniques and algorithms have been implemented to find solutions for the optimal integration of PV DG units in RDN, considering different objective functions. These include the Applied Biogeography-Based Optimization (BBO) algorithm [6], the Artificial Bee Colony algorithm (ABC) [7], invasive weed optimization [8], Cuckoo Search Algorithm (CSA) [9], Fireworks Algorithm (FWA) [10], Stochastic Fractal Search (SFS) [11], and Tabu search [12], among others, which have been used to determine the optimal location and size of distributed generators. The popularity of these techniques stems from their computational robustness.

Recent advancements include the Crow Search Algorithm [13] and Smell Agent Optimization [14]. The Crow Search Algorithm is noted for its ability to efficiently avoid local optima in dealing with multimodal optimization problems in complex search spaces. However, the exploitation phase of CSA is considered less effective {15]. A flowchart of hybrid CSA-SAO, which integrates the positive features of CSA and SAO, can be found in [16]

In this paper, a comparative performance analysis of the Crow Search Algorithm, Smell Agent Optimization, and a hybrid CSA-SAO was conducted. These algorithms were employed to determine the optimal size and location of DGs aimed at minimizing power losses and improving voltage on the IEEE 69 bus.

2.0 METHODOLOGY

This research focuses on the performance evaluation of three algorithms: the Crow Search Algorithm (CSA), Smell Agent Optimization (SAO), and their hybrid, for optimizing the placement and sizing of Distributed Generators (DGs) on the IEEE 69-bus system. The methodology comprises the following steps:

i. Formulation of optimization functions focusing on objectives to reduce power losses and improve voltage.

ii. Formulation of optimization constraints considering network control variables, voltage limits, generation limits, etc.

iii. Implementation of CSA, SAO, and their hybrid algorithm to optimize the formulated objective functions.

iv. Application of CSA, SAO, and their hybrid algorithm specifically on the IEEE 69-bus system using the MATLAB platform to identify optimal DG placements.

v. Comparison of results from CSA, SAO, and their hybrid with the base case scenario:

    a. Evaluate improvements in power loss reduction and voltage profile enhancement.

    b. Analyze convergence characteristics to assess effectiveness in optimizing DG locations and sizes on the IEEE 69-bus system.

3.0 PROBLEM FORMULATION

The problem formulation encompasses the objective function and constraints of the Crow Search Algorithm, Smell Agent Optimization Algorithm, and their hybrid to solve the optimization problem.

3.1 Objective Functions Formulation

The objective functions in this work aim to minimize power losses across the distribution line length.

To minimize a function comprising several parameters, the general function is expressed as a summation of those parameters.

$$f = f_1 + f_2 + \cdots + f_N = \sum_{i=1}^{N} f_i \tag{1}$$

3.1.1 The parameter of the DG size

It is vital that the optimal DG size be deployed on the network buses and is given by equation (2)

where;

$$f_1 = \sum_{i=1}^{N} P_{DG_i} \tag{2}$$

Where, P_{DG_i} is the DG capacity of the ith bus, N is the set of possible locations.

3.1.2 Parameter of the total power loss of the network

The power loss of the network is calculated in equation (3)

$$f_2 = f(P_{loss}) = P_{loss} \tag{3}$$

Here, P_{loss} is the total power loss of the network. Real and reactive power loss analysis will be evaluated for the system with and without DG. The loss in the system can be calculated using equation (4) also called the exact loss formula.

$$f_2 = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\alpha_{ij} \left(P_i P_j + Q_i Q_j \right) + \beta_{ij} \left(Q_i P_j + P_i Q_j \right) \right] \tag{4}$$

Where,

$$\alpha_{ij} = \frac{R_{ij} \cos(\delta_i - \delta_j)}{V_i V_j} \tag{5}$$

$$\beta_{ij} = \frac{R_{ij} \sin(\delta_i - \delta_j)}{V_i V_j} \tag{6}$$

P_i and Q_i are net real and reactive power injection in bus i, respectively.

R_{ij} is the resistance between buses i and j

V_i and δ_i are the voltage and angle at bus i respectively.

According to the preceding equations, the final objective function to be minimized is acquired as follows:

$$f = f_1 + f_2 \tag{7}$$

Substituting the values of f_1 and f_2 into equation (7) yields:

$$f = \sum_{i=1}^{N} P_{DG_i} + \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\alpha_{ij} \left(P_i P_j + Q_i Q_j \right) + \beta_{ij} (Q_i P_j + P_i Q_j) \right] \tag{8}$$

3.2 Constraints

Constraints are issue of great importance in optimization procedures. An optimal answer is the answer that satisfies all of the constraints of the optimization problem. The following constraints will be considered while locating and sizing DGs.

3.2.1 Power Injection constraints

This is given by:

$$\sum_{i=1}^{N} P_{DG_i} \leq \sum_{i=1}^{N} P_{D_i} + P_L \tag{9}$$

Where, P_L is the real power loss in the system

P_{DG_i} is the real power generation of DG at bus i.

P_{D_i} is the power demand at bus i.

3.2.2 Voltage constraints

The variation range of all of the distribution buses should be within a specified limit. The voltage constraint is given below:

$$|V_i|^{min} \leq V_i \leq |V_i|^{max} \quad (10)$$

Here,

$$|V_i|^{min} = 0.95(\text{pu}) \quad (11)$$

$$|V_i|^{max} = 1.05(\text{pu}) \quad (12)$$

Voltages lower or higher than (±6%) exposes many power consumers' appliances to operation failure and damages.

3.2.3 Total Power Balanced Constraint

$$\sum_{i=1}^{N} P_{DG} + P_{substation} = P_{load} + P_{losses} \quad (13)$$

Where, P_{DG} is the Power supply by DG

$P_{substation}$ is the Power supply from substation

P_{load} is the Power delivered to the network connected loads

P_{losses} is the Power losses on the network

N is the Number of distributed generators connected

4.0 COMPARISON OF SIMULATION RESULTS AND PERFORMANCE EVALUATIONS OF CSA, SAO, AND HYBRID CSA-SAO

Initially, a load flow analysis was performed on the 69-bus system to determine the voltage levels at each bus and calculate the total real power loss. The resulting total real power loss for the base case was found to be 225.44. The average system voltage in the base case was recorded at 0.9590.

Table 1 summarizes the results obtained when CSA, SAO, and HCSA-SAO methods were used for allocating DG in the standard IEEE 69-bus system.

Table 1: Comparison of Results Obtained for IEEE-69 Bus Using CSA, SAO, and HCSA-SAO

PARTICULARS	**CSA APPROACH**		**SAO APPROACH**		**HYBRID ALGORITHM**	
	2 DGs	**3 DGs**	**2 DGs**	**3 DGs**	**2 DGs**	**3 DGs**
Real Power loss (Base case)(kW)	225.44	225.44	225.44	225.44	225.44	225.44
Real Power loss (Improved)(kW)	116.04	111.04	104.9	102.3	103.63	96.65
Percentage Reduction in Total Loss	48.74%	50.74%	53.46%	54.03%	54.03%	57.12%

Voltage Profile Improvement	8.85%	10.73%	33.65%	34.39%	52.44%	53.4%
Convergence Iterations	7	7	30	30	10	10

The table illustrates the performance of three optimization approaches: CSA, SAO, and the Hybrid Algorithm, applied to distribution networks with 2 and 3 Distributed Generators (DGs).
As the number of DGs increases, all three approaches demonstrate a decrease in total real power loss within the distribution network. Notably, the SAO approach and the Hybrid Algorithm consistently outperform the CSA approach, achieving higher reductions in total power loss. This underscores the superior ability of SAO and the Hybrid Algorithm in minimizing power losses.
The percentage reduction in total loss reaffirms the effectiveness of the SAO approach and the Hybrid Algorithm. They consistently deliver more substantial reductions in total loss compared to the CSA approach, with the Hybrid Algorithm yielding the highest reduction. This emphasizes the proficiency of these methods in optimizing the network's efficiency.
Enhancing the voltage profile is a fundamental aspect of DG integration. The table reveals that increasing the number of DGs leads to greater voltage profile improvements. Both the SAO approach and the Hybrid Algorithm consistently provide significant voltage profile enhancements, with the Hybrid Algorithm achieving the most substantial improvements. This highlights their capacity to enhance the network's voltage stability.
The number of convergence iterations required is another noteworthy aspect. Here, both the CSA approach and the Hybrid Algorithm stand out for requiring fewer iterations compared to the SAO approach, suggesting more efficient convergence.

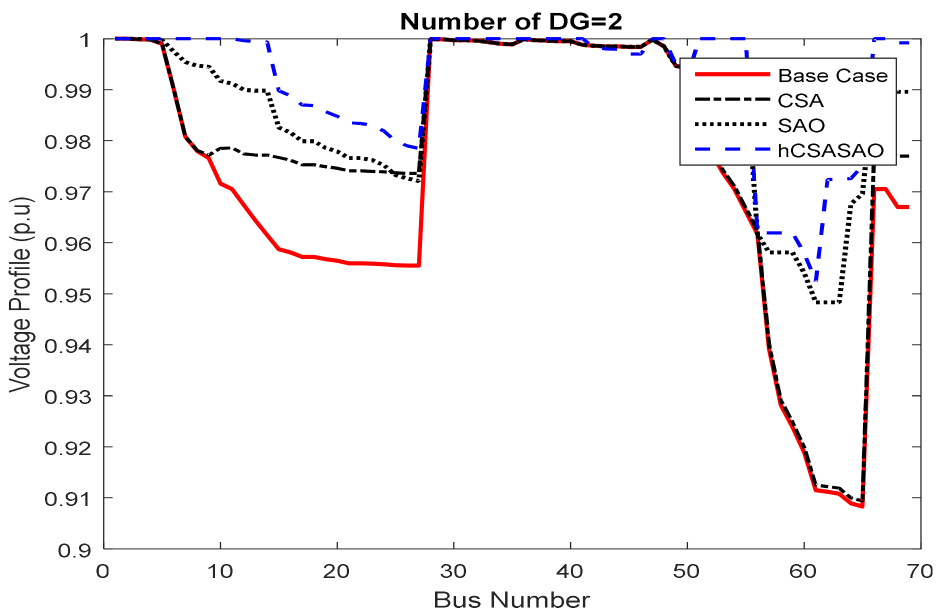

Figure 1: Comparison of voltage profile obtained after integrating 2 DGs

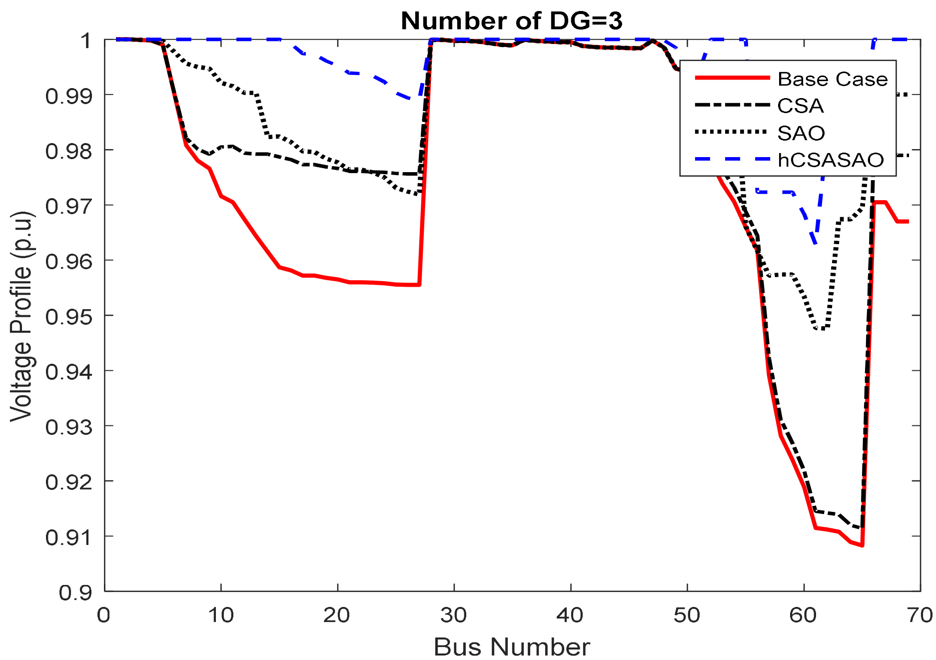

Figure 2: Comparison of voltage profile obtained after integrating 3 DGs

Figure 1 and 2 shows the comparison of results of the voltage profile obtained when varying numbers of DGs are optimally installed. The graph primarily focused on voltage profile improvement, visually represents how each algorithm performs as the number of Distributed Generators (DGs) increases. The solid line representing the base case serves as a reference point for the initial voltage profile without any DGs in the network. The dashed line representing the Hybrid Algorithm consistently shows the most significant improvement in voltage profile as the number of DGs increases. This indicates that the Hybrid Algorithm is exceptionally effective at enhancing voltage stability in the distribution network. The dotted line for SAO and the dash-dot line for CSA also depict improvements in voltage profile, but they consistently achieve lower levels of improvement compared to the Hybrid Algorithm.

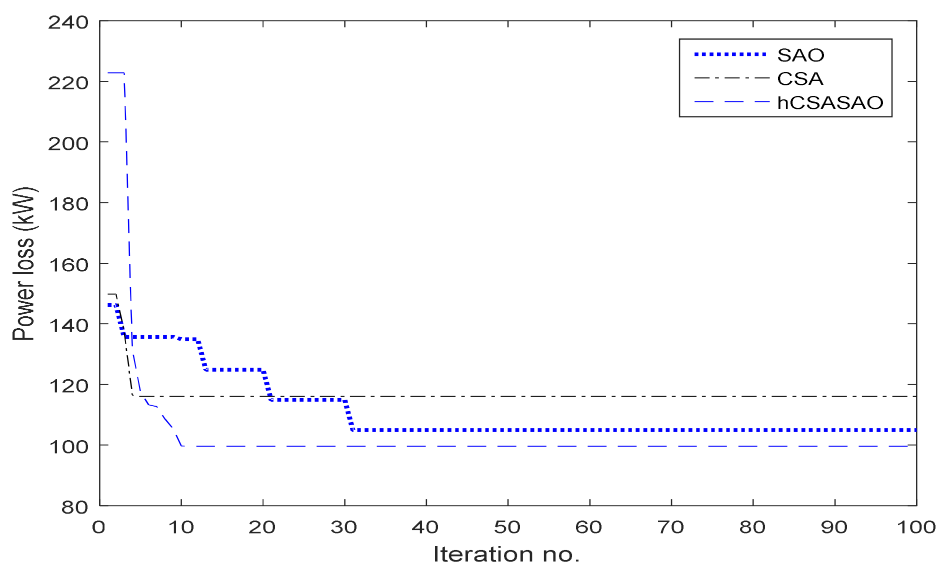

Figure 3: Comparison of losses obtained after installation of 2 DGs

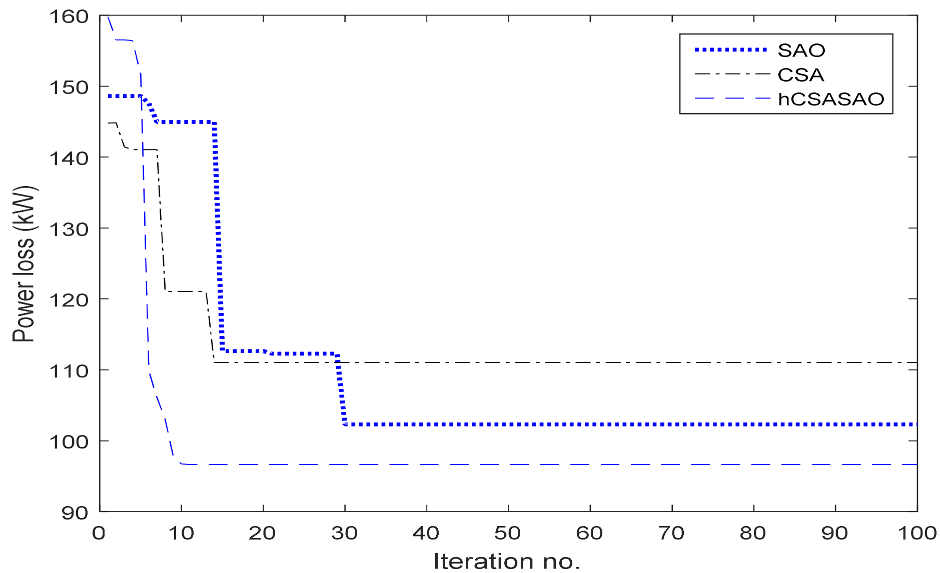

Figure 4: Comparison of losses obtained after installation of 3 DGs

Figure 3 and 4 shows the plot of the losses obtained over a number of iterations for various numbers of DGs. The graph visually depicts the performance of three algorithms in reducing total real power loss as the number of Distributed Generators (DGs) increases. The dashed line, representing the Hybrid Algorithm, consistently achieves the most significant reductions in total real power loss with the increasing number of DGs. In contrast, the dotted line for SAO and the dash-dot line for CSA also reduce power loss but to a lesser extent compared to the Hybrid Algorithm. To sum up, the graph clearly highlights the consistent superiority of the Hybrid Algorithm over CSA and SAO in reducing total real power loss as DGs are introduced into the distribution network.

5.0 CONCLUSION

The paper evaluates three optimization algorithms: Crow Search Algorithm (CSA), Smell Agent Optimization (SAO), and their hybrid CSA-SAO. These algorithms are used for placing and sizing up to three Distributed Generators (DGs) in the IEEE-69-bus test system. The results show significant reductions in system losses and improvements in voltage profiles compared to the base case. CSA exhibited the fastest convergence due to its fewer parameters to adjust, while SAO and the hybrid approach demonstrated superior performance in reducing losses and improving voltage profiles. These findings highlight how these optimization techniques can enhance the efficiency and stability of distribution networks with DGs.

REFERENCES

[1] P. Chiradeja and R. Ramakumar, "An approach to quantify the technical benefits of distributed generation," *IEEE Transactions on Energy Conversion*, vol. 19, no. 4, pp. 764-773, Dec. 2004.

[2] W. L. Theo, J. S. Lim, W. S. Ho, H. Hashim, and C. T. Lee, "Review of distributed generation (DG) system planning and optimization techniques:

Comparison of numerical and mathematical modeling methods," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 531-573, 2017.

[3] P. S. Georgilakis and N. D. Hatziargyriou, "Optimal distributed generation placement in power distribution networks: models, methods, and future research," *IEEE Transactions on Power Systems*, vol. 28, no. 3, pp. 3420-3428, 2013.

[4] B. Singh and J. Sharma, "A review on distributed generation planning," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 529-544, 2017.

[5] R. P. Payasi, A. K. Singh, and D. Singh, "Review of distributed generation planning: objectives, constraints, and algorithms," *International Journal of Engineering, Science and Technology*, vol. 3, no. 3, pp. 133-153, 2011.

[6] S. Ravindran and T. A. A. Victoire, "A bio-geography-based algorithm for optimal siting and sizing of distributed generators with an effective power factor model," *Comput. Electr. Eng.*, vol. 72, pp. 482-501, Nov. 2018

[7] A. El-Fergany and A. Y. Abdelaziz, "Multi-objective capacitor allocations in distribution networks using artificial bee colony algorithm," *Journal of Electrical Engineering and Technology*, vol. 9, no. 2, pp. 441-451, 2014.

[8] D. Rama Prabha and T. Jayabarathi, "Optimal placement and sizing of multiple distributed generating units in distribution networks by invasive weed optimization algorithm," *Ain Shams Engineering Journal*, vol. 7, no. 2, pp. 683-694, 2016.

[9] T. T. Nguyen, A. V. Truong, and T. A. Phung, "A novel method based on adaptive cuckoo search for optimal network reconfiguration and distributed generation allocation in distribution network," *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 801-815, 2016.

[10] A. Mohamed Imran, M. Kowsalya, and D. P. Kothari, "A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 63, pp. 461-472, 2014.

[11] T. T. Tran, K. H. Truong, and D. N. Vo, "Stochastic fractal search algorithm for reconfiguration of distribution networks with distributed generations," *Ain Shams Engineering Journal*, available at: www.sciencedirect.com/science/article/pii/S2090447919301248, 2019

[12] K. Nara, Y. Hayashi, K. Ikeda, and T. Ashizawa, "Application of tabu search to optimal placement of distributed generators," *Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conference*, vol. 2, pp. 918-923, 2001.

[13] M. S. El-Saeeda, M. A. El-Hameed, and A. F. AbdElGwaada, "Crow Search Algorithm for Allocation of Multi-Type Distributed Generation in Unbalanced Radial Distribution System," The Egyptian International Journal of Engineering Sciences and Technology*, vol. 25, pp. 7-23, Apr. 2018. Available: http://www.eijest.zu.edu.eg.

[14] A. T. Salawudeen, M. B. Mu'azu, Y. A. Sha'aban, and E. A. Adedokun, "On the Development of a Novel Smell Agent Optimization (SAO) for Optimization Problems," in *2nd International Conference on Information and Communication Technology and Its Applications (ICTA 2018)*, 2019.

[15] M. S. El-Saeeda, M. A. El-Hameed, and A. F. AbdElGwaada, "Crow Search Algorithm for Allocation of Multi-Type Distributed Generation in Unbalanced Radial Distribution System," *The Egyptian International Journal of Engineering Sciences and Technology*, vol. 25, pp. 7-23, 2018. Available: http://www.eijest.zu.edu.eg

[16] A. B. Muhammad, B. U. Musa, M. M. Muhammad, and L. Dauda, "Enhancing Power Delivery through Optimal Deployment of Distributed Generators on Nigerian Radial Distribution Networks: A Hybrid Crow Search Algorithm and Smell Agent Optimization Approach," *International Academic Journal of Information, Communication, Technology & Engineering*, vol. 8, no. 6, pp. 33-43, June 2024, doi: 222-3942-8342-542-865.