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Development of Hybrid Crow Search Algorithm and Smell Agent Optimization for Optimal Deployment of Distributed Generators on Radial Distribution Networks to Improve Power Delivery

M.M Muhammad[1*]; Abdulsalam B. Muhammad[2]; Bukar U. Musa[3]; Lawan Dauda[4]
[1]Department of Electrical/Electronic Engineering, University of Maiduguri, Maiduguri, Nigeria

[*]Corresponding Author:- M.M Muhammad[1*]

Abstract:- The optimal location and sizing of Distributed Generation (DG) are crucial factors in integrating DGs into a network to minimize power losses and improve the voltage profile. This paper presents a hybridized solution that combines the Crow Search Algorithm (CSA) and Smell Agent Optimization (SAO) algorithm for determining the optimal location and sizing of DGs. The CSA, SAO, and the proposed CSA-SAO method were modeled and applied to validate their effectiveness using the standard IEEE-33 test bus. The results were compared with the base case scenario, which did not include DGs.

For the 33-bus system, the CSA method achieved a 37.54% reduction in system losses and a 40.99% improvement in the overall voltage profile. The SAO method resulted in a 45.43% reduction in losses and a 54.88% improvement in the average voltage profile. The proposed hybrid CSA-SAO method demonstrated even better performance, with a 47.56% reduction in losses and a 63.47% improvement in the average voltage profile. This comparison indicates that the proposed hybrid model is valid for solving optimal DG allocation problems. The results suggest that combining the CSA and SAO algorithms in a hybrid approach produces superior results compared to using the methods independently.

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

I. INTRODUCTION

Expeditious declining of our energy sources caused by pressure on the existing energy sources is endlessly increasing owing to man’s continually growing population and his daily activities. Hence, there is demand to uncover novel and enhanced ways of generating energy which would be environmentally friendly and self-sustaining.

Power utility providers are required to supply power within specified voltage limitations. The employment of Distributed Generator (DG) in distribution systems has copious benefits for power consumers as well as proprietors of DG equipment; as it stabilizes the voltage at the consumer end while serving as source of income to DG operators.

The exploration for an optimal location and size of DGs to be injected on a distribution network can be to a certain extent challenging. In most cases, the focal methods used for locating and sizing a DG in a distribution network are analytical and heuristic methods. For the hitch of optimal DG allocation, the analytical method may possibly appear straightforward to realize and execute, but it is computationally exhaustive and time consuming while most meta-heuristic methods on the other hand, are apparently robust but hardly produce optimal solution. Meta hueristic methods have emerged as accepted and powerful tools for solving complex engineering optimization problems. The principle of these methods is different from the traditional optimization methods as it requires only the function value, and not the derivative or gradient information of the problem. These function values are first generated using a random operator different solution spaces, this is called exploration (diversification). Then, the algorithm thoroughly searches these solution spaces for the optimal solution by exploitation (intensification). Balancing between exploration and exploitation is a major challenge which must be carefully considered to avoid trapping in local optimal problems. The most common approach to address this problem is through dynamic parameter selection or by hybridizing the positive features of two or more algorithms [1].

Many researchers have contributed extensively in the interest of searching for the optimal sizing and placement of DG units using various algorithms by different researchers. Clonal algorithm was utilized for the DG placement in a radial distribution system by [2]. [3] also presented a combination of analytical and complete AC optimal power flow approach in finding the optimal location and DG size was calculated using a complete AC which was described as an efficient method for determining the DG location and size in distribution power systems.. Furthermore, [4] proposed Cat Swarm Optimization (CSO) algorithm and Parallel Cat Swarm Optimization (PCSO) Algorithm to allocate the distributed generation (DG) units on distribution networks with the objective of minimizing total generation costs, total power losses, total emissions produced by the generation units and also improving the voltage stability.. [5] employs an artificial bee colony (ABC) algorithm to determine the optimal DG-unit's size and location. IEEE 33 bus system was used as the test system to check the reliability of the proposed algorithm in order to minimize the total system real power loss and improve the voltage profile. [6] Hybridized Genetic algorithm and Particle swarm optimization for optimal deployment of Distribution Generation units. [7] Proposed the allocation and sizing of DGs using PSO technique with the objective of minimizing voltage deviation and total power loss in a radial distributed system. . The simulation indicated significant reduction of total power loss as a result of allocating 3 DGs from 0.2233MW to 0.0227MW, which is corresponding to 89.83% reduction. The proposed technique was implemented on the standard IEEE-33 radial test system. Results were not compared with other meta heuristic techniques. [8] worked on realization of the optimal allocation and impact of DG on Electric power system in terms of power loss reduction. The Newton Raphson load flow analysis was carried out on 10 bus systems using ETAP software which revealed reduction in the active power losses from 3302.2 KW to 400.7 KW after the installation of DG with 5MW capacity at the optimum location. [9] proposed a Multi-leader Particle Swarm Optimization (MLPSO) for the determination of the optimal locations and sizes of DGs with the objective of active power loss minimization. [10] proposed Crow search algorithm (CSA) technique to solve the optimal allocation of multiple DGs of different types for minimization of active power loss in distribution network. The proposed method was tested on IEEE-33 and 69 bus test system and the obtained result was compared with improved analytical (IA) and particle swarm optimization (PSO) method. The proposed method gave better results compared to the existing PSO and IA methods.

The merit of CSA lies in the aptitude to evade the trapping in the local optimum efficiently when coping with multimodal optimization problems in a more complex searching space. Nevertheless, the exploitation phase of CSA is not much effective [11]. Hybridization of CSA with an algorithm good at exploitation will yield better results.

In this paper, deployment and sizing of distributed generation units will be optimized by using hybrid of Crow Search Algorithm and Smell Agent Optimization Algorithm. The algorithm will be tested on two standard distribution test systems, IEEE 33-bus radial distribution system.

II. MATERIALS AND METHODS

➢ *Stages of research*

The research work consisted of four distinct stages.

In the first stage, data collection was carried out, including line data, bus data, and a single-line diagram of the radial test buses. Power flow analysis was performed to determine the voltage profile and power losses of the system. These initial values served as the base case.

The second stage involved developing and implementing a program in the MATLAB environment. This program utilized a Hybrid Crow Search Algorithm and Smell Agent Optimization to identify the optimal sizes and locations of multiple distributed generators (DGs) within the network. The optimization process yielded the most suitable DG sizes and placement sites.

Moving on to the third stage, the DGs were placed at the designated buses and a subsequent load flow analysis was conducted. This analysis aimed to assess the impact of the DGs on distribution line losses and voltage profiles at various buses.

Lastly, in the fourth stage, simulations were performed, and the results obtained from the CSA, SAO, and hybrid CSA-SAO approaches were compared. The evaluations focused on varying the number of DGs to evaluate their performance.

➢ *Optimal placement of DG*

To optimally determine locations of multiple DGs, hybrid Crow Search Algorithm and Smell Agent Optimization was adopted. The hybridized algorithm was used in realizing the optimal locations and sizes of the DGs.

➢ *Hybrid Crow Search Algorithm and Smell Agent Optimization*

The step-by-step procedures for the development and evaluation of this hybrid Algorithm are highlighted as follows.

- *Development of the Hybrid Crow Search Algorithm and Smell Agent Optimization. This was achieved through the following steps.*

✓ Implementation of the standard Crow Search Algorithm
✓ Determining the best position and the worst positions of crows after evaluating the fitness of initial positions.
✓ Modeling the hybrid CSA-SAO by adopting the trailing mode behavior in SAO. This is done to ensure that all crows trail the position of the best crow found so far.

- *Determination of the Effectiveness of the Hybrid Approach Optimal Location and Sizing of Distributed Generators. This was achieved through the following steps;*

✓ Formulating the optimization function considering power loss and voltage improvement as the objective function.
✓ Formulation of the optimization constrains considering network control variables, voltage limits, generation limits, etc.
✓ Optimization of the formulated objective functions using the developed hybrid algorithm in (i) above.

- *Simulation and performance evaluation by comparing the hybrid CSA-SAO with the standard CSA and standard SAO.*

III. PROBLEM FORMULATION

The problem formulation contains the objective functions and constraints of the Smell Agent Optimization Algorithm in order to solve the optimization problem.

➢ *Objective Functions Formulation*

- The objective functions in this work are to minimize power losses and improve voltage profiles across the distribution line length.
- The test system used to verify the effectiveness of the technique is described below;
- To minimize a function consisting of some parameters, the general function is written as a summation of those parameters.

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

- *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;

$$f_1 = \sum_{i=1}^{N} P_{DG_i} \qquad (2)$$

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

- *Parameter of the Total Power Loss of the Network.*

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

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

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) (Witchit, *et. al.*, 2007) also called the exact loss formula.

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

Where,

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

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

- ✓ 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

$$f = f_1 + f_2 \qquad (7)$$

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

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

- *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 siting and sizing DGs.

- *Power Injection constraints*

This is given by

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

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.

- *Voltage constraints*

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

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

Here,

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

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

- *Summation of the DG Sizes.*

The sum of all the active power produced from all the DG units in the network should be less or equal to 20% of substation power

$$\sum_{i=1}^{N} P_{DG_i} \leq 20\% P_{substation} \qquad (13)$$

Here, N is the number of DG units.

P_{DG_i} is the DG active power

- *Total Power Balanced Constraint;*

$$\sum_{i=1}^{N} P_{DG} + P_{substation} = P_{load} + P_{losses} \qquad (14)$$

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

The proposed algorithm's flow chart is depicted in Figure 1. It illustrates the sequence of steps followed by the algorithm.

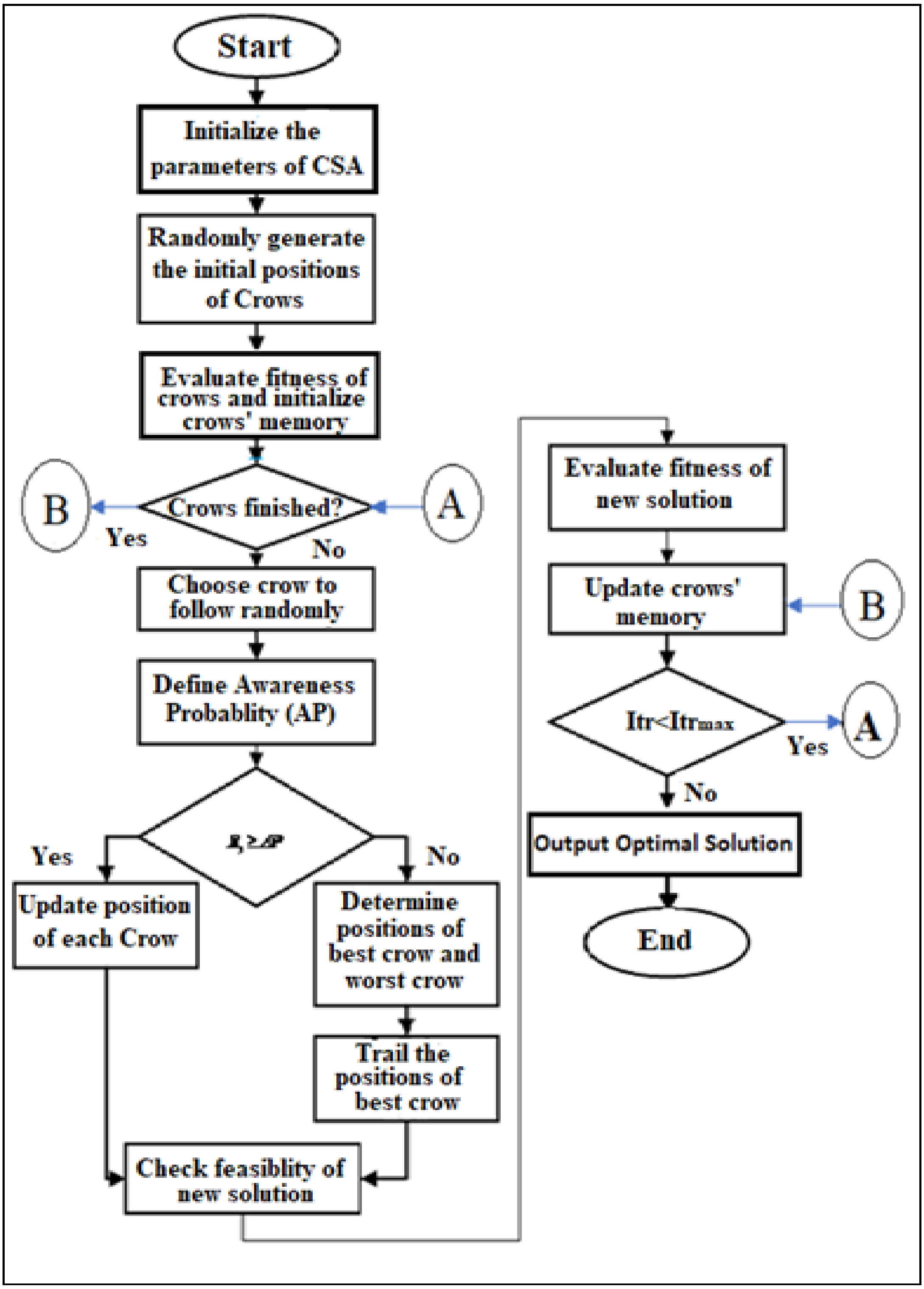

Fig 1 Flowchart of CSA-SAO

- *Effect of DG Placement using the Proposed Hybrid Algorithm (HCSA-SAO)*

The hybrid method described in section 3.3 was used for optimal allocation of DG for the standard IEEE 33-bus system. Optimal DG placement was done on the IEEE-33 bus system using the Smell Agent Optimization as described in chapter three. The total real power loss after optimum DG placement is presented in table 1 The average time of simulation was also noted and presented.

Table 1 Effect of DG Placement on Network Losses Reduction for IEEE-33 Bus using HCSA-SAO

Number of DGs	Location (Bus number)	DG size (kW)	Loss without DG(kW)	Loss With DG	% Loss Reduction	Time of Simulation(s)
2	11	0.74	202.7	114.5	43.51	10.44
	13	1.73				
3	10	1.14		106.6	47.56	13.42
	16	0.39				
	18	0.91				

The table presents the results of the simulation, showcasing the number of distributed generators (DGs), their corresponding locations (bus numbers), DG sizes (in kW), and the impact on loss reduction. Additionally, the simulation time (in seconds) for each scenario is also provided.

In the case of having two DGs, their specific locations and sizes were analyzed and loss reduction of 43.51% was recorded. However, for the scenario with three DGs, located at buses 10, 16, and 18, and with respective sizes of 1.14 kW, 0.39 kW, and 0.91 kW, the simulation yielded noteworthy results.

The overall loss reduction percentages were calculated based on the comparison between losses without DGs and losses with DGs. For the three-DG scenario, the system experienced a loss reduction of 47.56% when compared to the base case without any DGs. This indicates that the introduction of DGs effectively reduced power losses in the distribution system.

Furthermore, it's important to note that the simulation times for the different scenarios varied. For the three-DG scenario, the simulation took 13.42 seconds to complete.

The figures (2 and 3) below shows the real power loss plot after successful performance of the power flow analysis on the IEEE-33 network with varying numbers of DGs installed optimally.

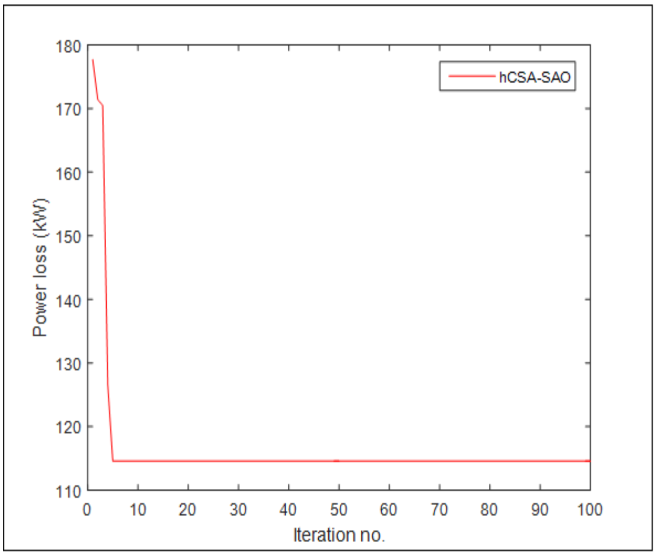

Fig 2 Real Power Loss of IEEE-33 Bus after Introducing 2 DGs Optimally using HCSA-SAO

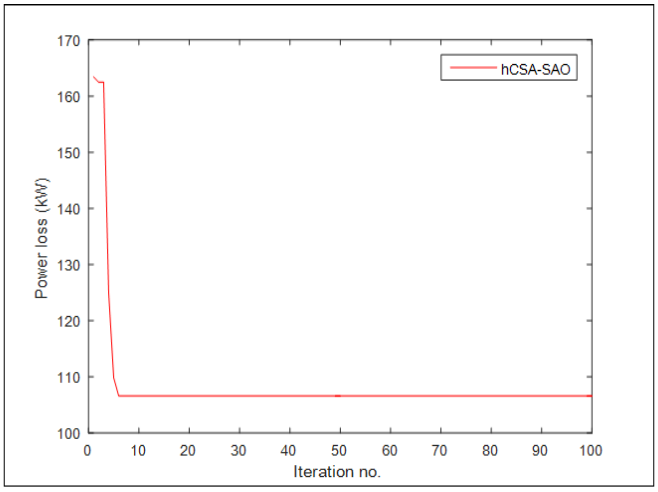

Fig 3 Real Power Loss of IEEE-33 Bus after Introducing 3 DGs Optimally using HCSA-SAO

- *Voltage Profile after DG Allocation using the Proposed Hybrid Algorithm (HCSA-SAO)*

The base case and improved voltage magnitudes were plotted against their respective bus numbers in order to see the improvement in voltage profile after DG location and sizing was done using the proposed hybrid algorithm.

The average base case voltage is **0.9488**. The average voltage profile after introduction of 2 and 3 numbers of DG is **0.9800** and **0.9813.**

- *The Voltage Profile Obtained after Integrating 2 and 3DGs is Shown in Figure 4.11 and 4.12 below:*

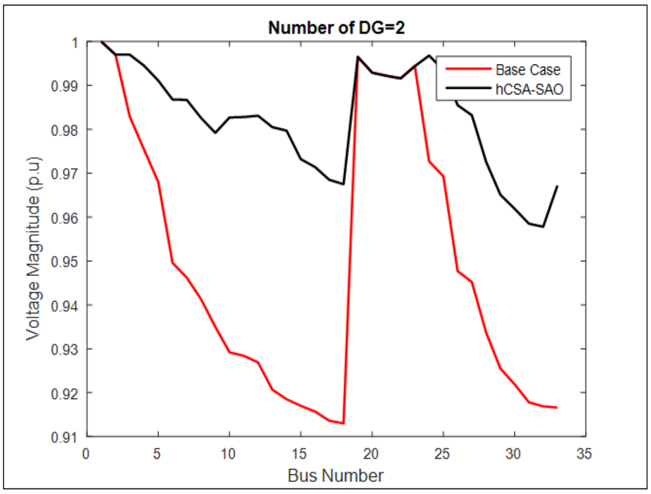

Fig 4 Voltage Profile for IEEE 33-Bus Network after 2 DG installation Using HCSA-SAO

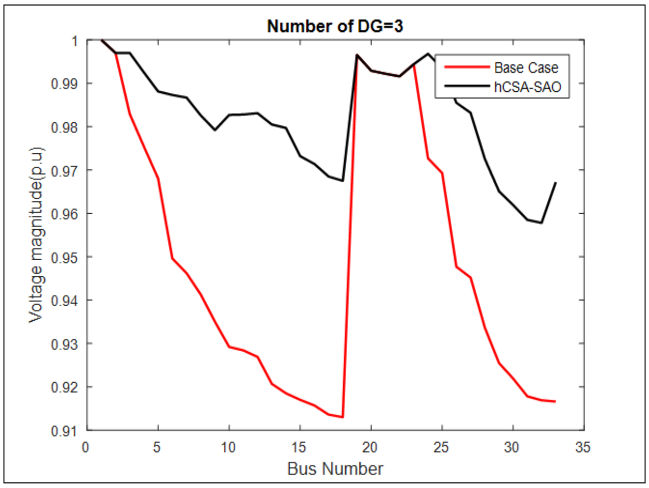

Fig 5 Voltage Profile for IEEE 33-Bus Network after 3 DG installation Using HCSA-SAO

The base case total real power loss which was obtained is **202.7 kW.** However, the average base case voltage obtained is **0.9488**

Table 2 shows a summary of results obtained when CSA, SAO and HCSA-SAO methods were used in the allocation DG for the standard IEEE 33-bus system. The hybrid algorithm performed better than the standalone methods in terms of voltage profile improvement and loss reduction.

Table 2 Summaries of Results Obtained using for the IEEE- 33 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**
Total Real Power loss (Base case)	202.7	202.7	202.7	202.7	202.7	202.7
Total Real Power loss (Improved) **Percentage Reduction in**	126.6	119.6	117.6	110.6	114.5	106.3
Total Loss	37.54%	40.99%	41.98%	45.43%	43.51%	47.56%
Voltage Profile Improvement	48.04%	53.13%	54.88%	55.47%	60.93%	63.47%
Convergence Iterations	7	7	41	40	8	7

The table shows that as the number of DGs increases, the total real power loss in the distribution network decreases for all three approaches. The Hybrid Algorithm consistently outperforms both CSA and SAO, achieving the highest reduction in total power loss. This indicates that the Hybrid Algorithm is more effective in minimizing power losses.

The percentage reduction in total loss further highlights the advantages of the Hybrid Algorithm. It consistently provides the highest reduction in total loss compared to CSA and SAO, indicating its superior ability to optimize the network's efficiency.

The voltage profile improvement is a critical factor in assessing the effectiveness of DG integration. The table shows that as the number of DGs increases, the voltage profile improvement also increases. The Hybrid Algorithm consistently offers the best voltage profile improvement, indicating its capability to enhance the network's voltage stability.

The number of convergence iterations required by each algorithm is also noteworthy. The Hybrid Algorithm typically converges with fewer iterations compared to the SAO approach. This suggests that the Hybrid Algorithm not only performs better but also converges more efficiently.

In summary, the results suggest that the Hybrid Algorithm is the most effective approach for reducing total real power losses, improving the voltage profile, and achieving convergence efficiency in the context of DG integration into the distribution network. It offers promising solutions for enhancing the overall performance and efficiency of the network, making it a favorable choice for practical applications.

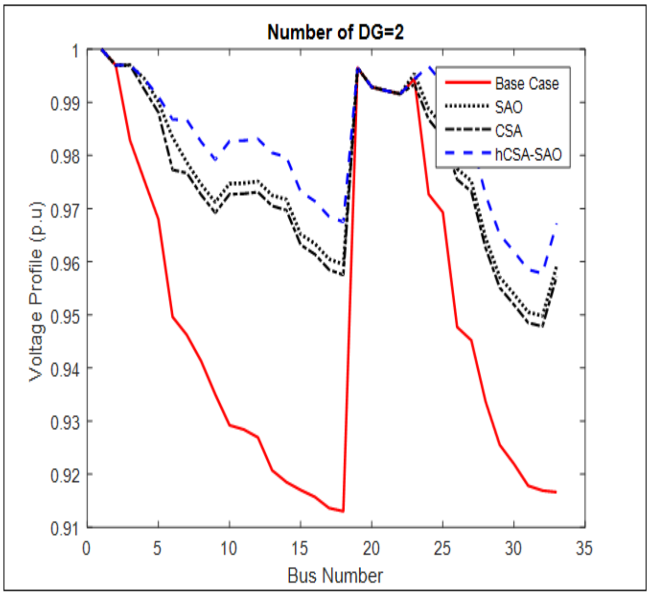

Fig 6 Comparison of Voltage Profile Obtained after Integrating 2DGs

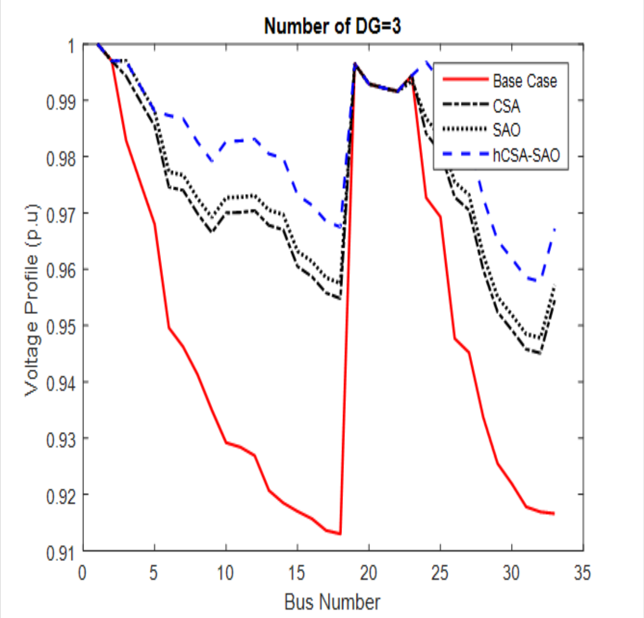

Fig 7 Comparison of Voltage Profile Obtained after Integrating 3DGs

Figure 6 and 7 shows the comparison of results of the voltage profile obtained when varying numbers of DGs are optimally installed..

In contrast, the dashed line, representing the Hybrid Algorithm, consistently demonstrates the most substantial improvements in the voltage profile as the number of DGs increases. This underscores the Hybrid Algorithm's exceptional effectiveness in boosting voltage profile within the distribution network.

Conversely, the dotted line associated with SAO and the dash-dot line for CSA also indicate enhancements in the voltage profile, albeit consistently achieving lower levels of improvement when compared to the Hybrid Algorithm.

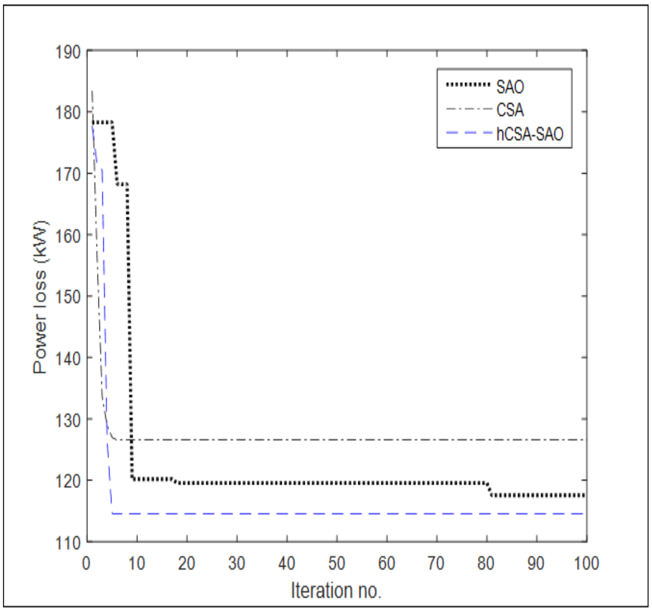

Fig 8 Comparison of Losses Obtained after 2 DG Installation

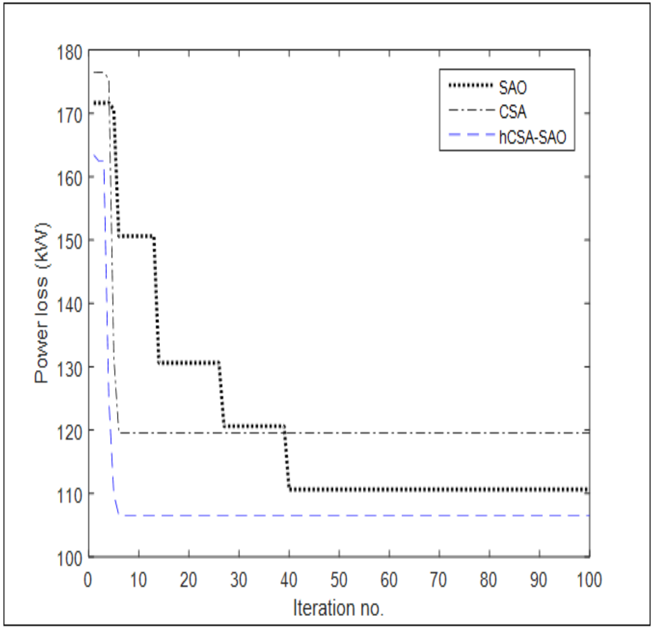

Fig 9 Comparison of Losses Obtained after 3DG Installation

Figure 8 and 9shows the plot of the losses obtained over a number of iterations for various numbers of DGs. The graph visually illustrates how three algorithms perform in terms of reducing total real power loss as more Distributed Generators (DGs) are added. The dashed line, which represents the Hybrid Algorithm, consistently achieves the most substantial reductions in total real power loss as the number of DGs increases. Conversely, the dotted line, corresponding to SAO, and the dash-dot line, representing CSA, also reduce power loss but consistently demonstrate less effectiveness compared to the Hybrid Algorithm. In essence, the graph clearly showcases the Hybrid Algorithm's consistent dominance over CSA and SAO in reducing total real power loss when DGs are incorporated into the distribution network.

IV. CONCLUSION

The aim of this research work was to develop a hybrid Crow Search Algorithm and Smell Agent Optimization for the optimal deployment of DGs in radial distribution networks.

Initially, the Crow Search Algorithm and Smell Agent Optimization were independently employed to determine the optimal locations and sizes of DGs for the standard IEEE 33 test system. Subsequently, a hybrid model was developed and utilized to allocate DGs for the same IEEE 33 test system. The obtained results were validated and compared favorably with those obtained using the Crow Search Algorithm and Smell Agent Optimization alone.

The objectives of the research work were significantly achieved, and it can be concluded that the proposed hybrid method exhibited faster convergence compared to the standalone methods in terms of simulation time. Furthermore, the hybrid approach demonstrated superior performance, superiority, and efficiency in improving power delivery.

Conclusively, this research successfully developed and applied a hybrid algorithm combining the positive features Crow Search Algorithm and Smell Agent Optimization for DG deployment in radial distribution networks. The hybrid approach outperformed the standalone methods in terms of convergence speed, while also showcasing improved power delivery performance, superiority, and efficiency.

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