

Simultaneous Network Reconfiguration and Optimal Allocation of Multiple DGs in Radial Distribution System to Reduce Real Power Loss

Shrunkhala S. Halve[†], Deepak M. Sonje, and M. Venkateswara Reddy, Non-members

ABSTRACT

This work addresses the challenging issue of minimizing actual power loss in radial distribution systems (RDS) by integrating network reconfiguration and multiple distributed generations (DG). A critical survey demonstrates that NR can reduce power losses on its own; however, the implementation process is challenging. While the incorporation of DGs can reduce losses, voltage instability and increased losses can result from poor placement or sizing. Consequently, it is crucial to allocate DGs optimally. The authors propose two modern optimization methods—the Rao-1 algorithm, which lacks metaphors, and the Sine Cosine Algorithm (SCA)—to optimize DG and NR allocation in order to resolve these challenges. This investigation employs Modified Load Flow (MLF) to ascertain the optimal network reconfiguration and loss sensitivity analysis to identify DG. Rao-1 and SCA are employed to size DGs in order to enhance voltage profiles and minimize actual power losses in IEEE 33-bus and 69-bus test systems. In comparison to SCA, Rao-1 enhances efficiency, convergence, voltage profile, and efficiency, particularly when multiple DGs are incorporated with NR. Rao-1's exceptional performance in both systems is supported by statistical analyses. The proposed approach reduces loss by 74.9% for the IEEE 33-bus system and 83.8% for the IEEE 69-bus system when contrasted with the Enhanced Sine Cosine Algorithm (ESCA).

Keywords: Radial Distribution System (RDS), Network reconfiguration (NR), Modified Load flow (MLF), Distributed generation (DG), Metaphor-less algorithm (Rao-1), Sine cosine algorithm (SCA)

1. INTRODUCTION

Distribution system is a major component of the power system, connecting the bulk power transmission network to the customers at the load points. These networks are expanding in size and covering enormous areas. Their low X/R ratio and long length cause severe

power losses in the lines and low node voltages at the client end. Power losses have a negative influence on efficiency and economic performance.

Salkuti and Battu [1] developed a method for reconfiguring the distribution system to solve issues such as high-power losses and reduced voltage profile, hence improving the overall performance of the distribution network. In an RDS, component failures can cause service interruptions and the subsequent disconnection of several load points. Such failures often lead to abnormal variations in voltage levels and increased power losses, resulting in reliability concerns. To address these issues, Srividhya et.al [2] worked on feeder reconfiguration to enhance system reliability, minimize voltage deviations, and reduce losses. A Binary Particle Swarm Optimization (BPSO)-based search function is employed to efficiently handle the reconfiguration process.

The integration of Distributed Generators (DGs) at optimal locations and with appropriately determined sizes within the distribution system can greatly enhance its overall performance. This strategy also offers a cost-effective solution for addressing the planning challenges of distribution networks, as presented in [3]. The integration of NR and DG enhances network performance. Muhammad et al. [4] used a dataset-based approach to tackle the complex problem of optimal DG sizing and siting with NR.

To address the optimal sizing and siting of DG or NR in a RDS, the first step is to develop a load flow method. In [5], the Backward/Forward Sweep Method is used to obtain the load flow solution for RDS. In [6], the authors proposed a MLF method for NR to minimize real power loss in RDS. Various reliability indices were estimated to measure system performance after and before NR. In [7], the Rao-3 and SCA are employed in RDS to identify the best sizing of various types of DGs, with the goal of minimizing power losses.

In [8], several reliability indices in RDS are efficiently assessed, analysed, and compared without and with the integration of DGs at suitable sites for the typical test system. In [9], various well-being measures are examined using Monte Carlo simulation in RDS with DGs. Raut and Mishra [10] proposed an enhanced sine-cosine algorithm (ESCA) in RDS for simultaneously incorporating NR and DG allocation. Ganney and Pallikonda [11] addressed DG installation and NR with a hybrid approach that combines binary particle swarm optimization with Ant Lion Optimizer (BPSO-ALO).

Manuscript received on June 25, 2025; revised on September 25, 2025; accepted on October 16, 2025. This paper was recommended by Associate Editor Chawasak Rakpenthai.

The authors are with Department of Electrical Engineering of Gokhale Education Society, R H Sapat COEMS&R, Nashik.

[†]Corresponding author: shrunkhala123@gmail.com

©2026 Author(s). This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivs 4.0 License. To view a copy of this license visit: <https://creativecommons.org/licenses/by-nc-nd/4.0/>.

Digital Object Identifier: 10.37936/ecti-ec.2026241.259980

Rao et.al [12] used a metaheuristic Harmony Search Algorithm (HSA) to solve the problem of concurrently NR and optimal allocation of DG units in a DN. The Modified Plant Growth Simulation (PGS) algorithm was successfully used in [13] to reduce real power loss in RDS. Unlike other methods, it does not require barrier elements because the objectives and restrictions are addressed individually. The main advantage of this technique is that it may be used in real-time applications with the necessary changes. Bardan et.al [14] reviewed recent methods for distribution NR and DG allocation, all aimed at minimizing power losses and improving the voltage profile. Kanwar et.al [15] used Teaching-Learning-Based Optimization (TLBO) to optimize the reduction in annual energy loss while optimizing DG's in RDS using a penalty function technique. Raut and Mishra [16] implemented an improved sine-cosine algorithm to solve the NR problem, aiming to minimize power loss in distribution system. They also demonstrated the effectiveness of this algorithm related to other methods. Uniyal and Sarangi [17] worked on an optimal DG allocation and NR to improve voltage stability and reduce power losses in the RDS, taking into account stochastic loads and DGs with changing power factors.

Nowadays, there is an increasing trend of incorporating battery energy storage systems (BESS) into distribution networks. The choice of BESS technology for DS installation is determined by a number of variables, including energy capacity, efficiency, cost, advantages and disadvantages, and storage system reliability. In [18], the appropriate location and sizing of BESS in DS combined with PV generating and electric vehicles (EVs) is examined with the goal of lowering total system cost. To tackle the optimization problem, three metaheuristic algorithms were used: particle swarm optimization (PSO), African vulture optimization algorithm (AVOA), and salp swarm algorithm (SSA). Boonluk et al. [19] investigated the best sizing and location of BESS in RDS with renewable energy sources. The primary goal was to minimize the total cost of DS, which includes the costs of voltage deviation, power loss, and peak demands. The optimal sizing and placement of multiple BESS units in distribution systems (DS) integrated with distributed generators (DGs) is addressed in [20]. The main objective was to minimize the overall cost of the distribution system. The IEEE 33-bus and 69-bus test systems were used to evaluate the effectiveness of the proposed approach. To solve this complex optimization problem, a newly developed algorithm, namely the Crayfish Optimization Algorithm (COA), was applied, and its performance is compared with that of Particle Swarm Optimization (PSO).

For the simultaneous optimal sizing of multiple DGs with NR in RDS, the literature survey highlighted the use of various heuristic and population-based optimization techniques. However, the performance of these algorithms often depends on a large number of parameters. Selecting and tuning these parameters to effectively

minimize the objective function can be time-consuming and tedious, and improper parameter tuning may lead to premature convergence or local optima. Furthermore, the literature review reveals that the combined evaluation of reliability indices alongside simultaneous optimal allocation of DGs with NR has received limited attention and remains largely unexplored.

The main objectives of this work are as follows:

1. To apply the Modified Load Flow (MLF) method described in the literature [6] for determining the optimal network reconfiguration (NR) in IEEE 33-bus and 69-bus RDS.
2. To develop an algorithm for minimizing the total real power loss in RDS through the simultaneous optimal allocation of multiple DGs and NR, using the metaphor-less Rao-1 and Sine Cosine Algorithm (SCA).
3. To compare the results obtained by the proposed Rao-1 and SCA algorithms for simultaneous allocation of multiple DGs with NR with existing algorithm from the literature.
4. To evaluate the performance of the proposed algorithms through statistical inference.
5. To assess the impact of the proposed approach on various reliability indices of the test systems.

The paper is planned as follows: **Section 1**, presents an introduction. **Section 2** describes the problem formulation. **Section 3** presents Metaphor-less Rao-1 algorithm to minimize real power loss in RDS by simultaneous NR and DG allocation. **Section 4** gives a proposed SCA algorithm to minimize real power loss in RDS by simultaneous NR and DG allocation. **Section 5** gives results for 33 and 69 bus RDS and **Section 6** presents conclusions with future scope.

2. PROBLEM FORMULATION

The primary goal of RDS is to reduce the overall real power loss (TPL), which is determined by Eq. (1)

$$\min(TPL) = \min \left\{ \left(\sum_{i=1}^{nb} R_{nb} \times |I_{nb}|^2 \right) \right\} \quad (1)$$

where TPL is total real power loss in RDS, nb is total number of branches, R_{nb} is the resistance of branch nb , and I_{nb} is current in branch nb .

The following are the most prevalent constraints.

- 1) Constraints of DG operation

$$P_{i,\min} \leq P_{DG,i} \leq P_{i,\max} \quad (2)$$

where $P_{i,\min}$ and $P_{i,\max}$ are lower and upper bounds of DG capacity respectively.

- 2) Constraints of Power balance

$$\sum_{i=1}^k P_{DG} + P_S = P_L + TPL \quad (3)$$

where k is the number of DG's, P_S is total active power supplied by substation, P_L is total active load on RDS, and TPL is total real power loss in RDS.

3) Voltage balance constraints

$$V_{i,\min} \leq V_i \leq V_{i,\max} \quad (4)$$

where $V_{i,\min}$ and $V_{i,\max}$ are lower (0.9 per unit) and upper (1 per unit) limits of voltage at i^{th} bus respectively.

4) Maintain radial arrangement and constraints of isolation

Following NR, the system must continue to operate radially and all buses must be revived.

3. COMPUTATIONAL TECHNIQUE TO MINIMIZE TPL IN RDS BY SIMULTANEOUSLY ALLOCATING NR AND DG UTILIZING METAPHOR LESS I.E., RAO-1 ALGORITHM

In this work, the problem of total real power loss (TPL) minimization in RDS is addressed through the simultaneous integration of multiple distributed generations (DGs) and network reconfiguration (NR) using the metaphor-less Rao-1 algorithm [22]. Unlike many traditional population-based metaheuristic algorithms, Rao-1 relies on a simple mathematical relationship between the best and worst solutions in the population. The only control parameters required are the population size and the number of iterations, thereby eliminating the parameter-tuning difficulties commonly associated with other heuristic algorithms. In this approach, the Modified Load Flow (MLF) method [6] is employed to determine the optimal NR in RDS, while the metaphor-less Rao-1 method is applied to determine the optimal DG capacity. The algorithm is as follows.

Step 1: Read the system load, line, and tie switch data [24,25].

Step 2: Execute the load flow program for the base case i.e. without NR. Calculate TPL for RDS and identify critical buses for the test system. Critical buses are those that violate their limit as stated by Eq. (4).

Step 3: Use the MLF approach implemented in [6] to find the optimal NR in RDS. Calculate TPL after NR and record voltages at crucial buses after NR.

Step 4: Set the maximum number of iterations (t_{max}), number of design variables (k), and population size (np). Create the initial population as indicated in [22].

Step 5: Use Eq. (1) and MLF [6] to calculate TPL in RDS for all populations and set $t = 1$.

Step 6: Determine the worst and best solutions from the present population using objective function values.

Step 7: Find a new solution for the entire population during the t^{th} iteration.

Where $P_{DG,j,np,t}$ is old value of j^{th} variable at t^{th} iteration for np the individual, $P_{DG,j,w,t}$ and $P_{DG,j,b,t}$ are the old values of j^{th} variable for worst and best individual in the t^{th} iteration respectively.

Step 8: Modify each candidate solution with Eq. (5) [22].

$$P'_{DG,j,np,t} = P_{DG,j,np,t} + r_{1,j,t}(P_{DG,j,b,t} - P_{DG,j,w,t}) \quad (5)$$

where $P'_{DG,j,np,t}$ is updated value of $P_{DG,j,np,t}$ and $r_{1,j,t}$ is random number generated between [0,1].

Step 9: If any control variables obtained using equation (5) are violated, use bounce back technique [23] to bring them inside the bounds of the violation.

Step 10: Accept the solution matching to $P'_{DG,j,np,t}$ is better than $P_{DG,j,np,t}$ it and replace the previous one. If not, stick with prior one.

Step 11: TPL is calculated, t is raised to $t+1$, and the procedure is repeated from steps 7 to 10 until the termination criteria are not met.

Fig.1 shows detailed flow chart for simultaneous allocating multiple DG's and NR using Metaphor less i.e., Rao-1 algorithm

4. COMPUTATIONAL TECHNIQUE TO MINIMIZE TPL IN RDS BY SIMULTANEOUSLY ALLOCATING NR AND DG UTILIZING SINE COSINE ALGORITHM (SCA)

In this work, the highly complex problem of total real power loss (TPL) minimization in RDS is addressed through the simultaneous integration of multiple DG's and NR using SCA. The SCA, introduced by Mirjalili [21], differs from many traditional population-based metaheuristic algorithms as it achieves a balanced trade-off between exploration and exploitation through simple trigonometric mathematical functions. Its structure is straightforward, requiring fewer control parameters compared to other heuristic algorithms. In this approach, the Modified Load Flow (MLF) method [6] is employed to determine the optimal NR in RDS, while the SCA is applied to identify the optimal DG capacity. The algorithm is as follows:

Step 1: Read system load, line, and tie-switches data [24,25].

Step 2: Execute the load flow program for case 1 i.e. before NR and Calculate the TPL for the RDS, and Identify critical buses.

Step 3: Implement the MLF approach as described in [6] to determine the optimal NR in the RDS and calculate the

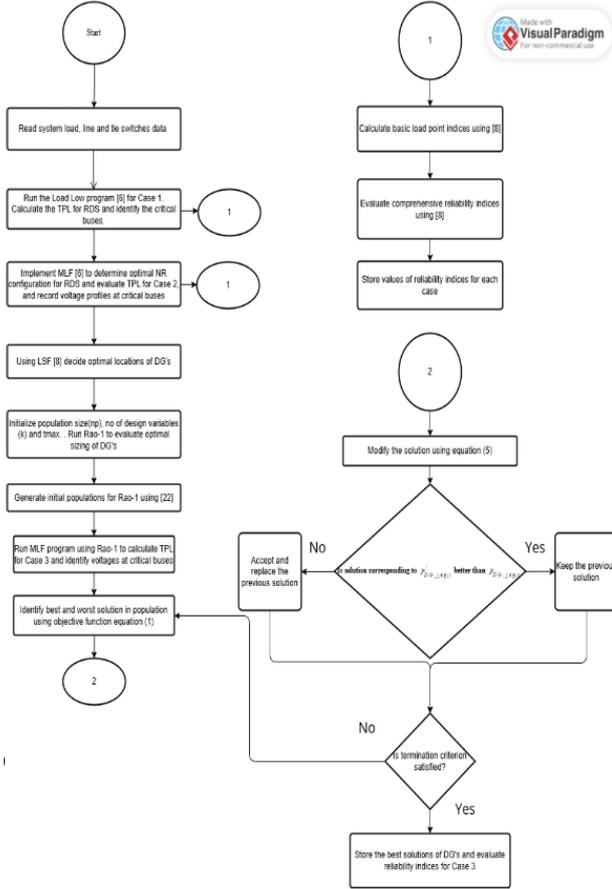


Fig. 1: Flow chart for simultaneous allocating multiple DGs and NR using Metaphor less i.e., Rao-1 algorithm.

TPL after performing NR and record the voltage levels at critical buses.

Step 4: Use Eq. (1) and the MLF [6] method to calculate the TPL in the RDS for all individuals in the population and set $t=1$.

Step 5: Identify the best candidate solution that yields the minimum TPL.

Step 6: Evaluate $r_{1,t}$ using Eq. (6)

$$r_{1,t} = 2 - \left(\frac{2 \times t}{t_{\max}} \right) \quad (6)$$

where t_{\max} and t is the maximum and current number of iteration.

Step 7: Use the updated equation (sine or cosine variant) to compute $P'_{DG,j,np,t}$ for each candidate

$$P'_{DG,j,np,t} = \begin{cases} \{P_{DG,j,np,t} + r_{1,t} \sin(r_{2,j}) | r_{3,j} P_{DG,j,b,t} - P_{DG,j,np,t} \} & (r_{4,j} < 0.5) \\ \{P_{DG,j,np,t} + r_{1,t} \cos(r_{2,j}) | r_{3,j} P_{DG,j,b,t} - P_{DG,j,np,t} \} & (\text{otherwise}) \end{cases} \quad (7)$$

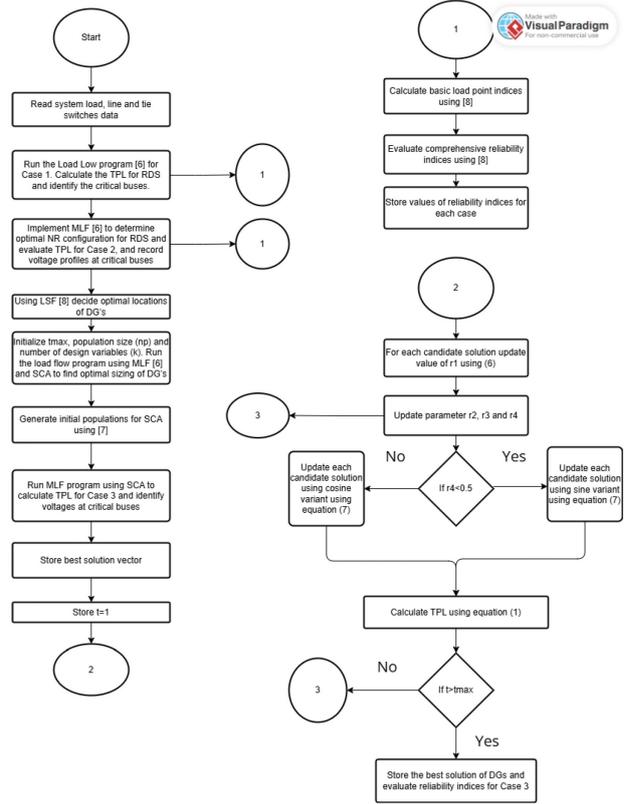


Fig. 2: Flow chart for simultaneous allocating multiple DGs and NR using SCA algorithm.

where $P'_{DG,j,np,t}$ and $P_{DG,j,np,t}$ represents np^{th} solution vector at $(t+1)^{th}$ and $(t)^{th}$ iteration. $P_{DG,j,b,t}$ is best solution got during t^{th} iteration and $r_{2,j}$, $r_{3,j}$, and $r_{4,j}$ are random number generated between $[0,1]$.

Step 8: Check all control variables after updating and ensure they comply with bounds if not apply bounce back technique [23] and update $r_{1,t}$ using Eq. (6)

Step 9: Calculate the TPL for the current configuration after both NR and DG (integration using the SCA. Repeat Steps 5 to 8 until t_{\max} is reached.

Step 10: Record optimal DG sizes and TPL and voltage profile values on critical busses for optimal NR and DG integration using SCA.

Fig. 2 describes a detailed flow chart for simultaneous allocating multiple DG's and NR using Sine cosine algorithm

5. RESULTS AND DISCUSSION

The findings were obtained by placing three DGs with NR for two standard RDS using Rao-1 and SCA algorithms. The analysis was carried out with MATLAB programming. Both approaches are used to measure system performance, including real power loss, critical

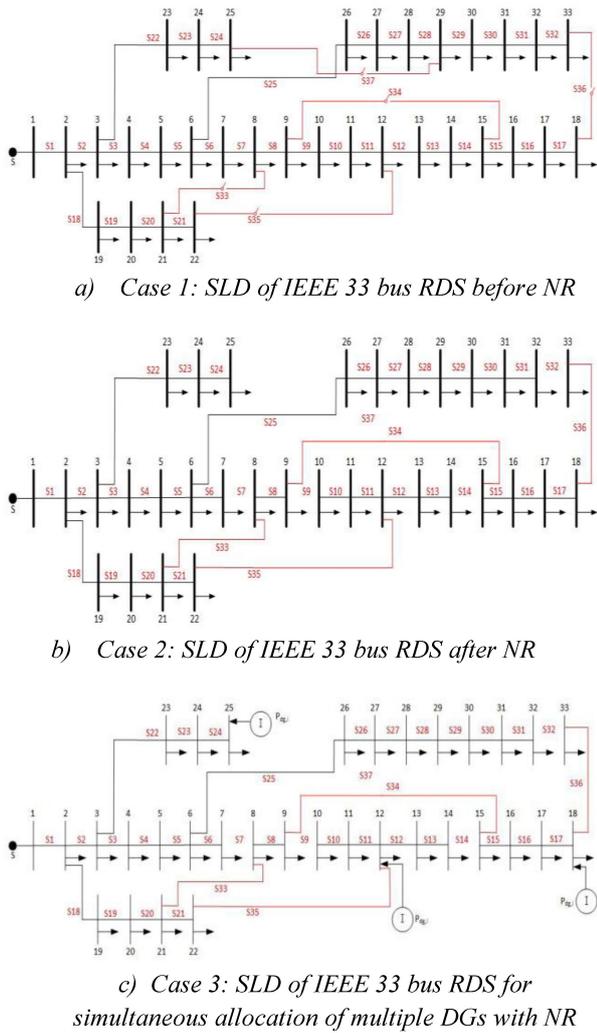


Fig. 3: SLD of 33 bus RDS for all cases.

bus voltages, and other factors. The following three cases were utilized to analyze the outcomes.

Case 1: Before NR (Base case)

Case 2: After NR

Case 3: Simultaneous multiple DGs placement with NR

5.1 33 BUS RDS

The control parameters selected for the Rao-1 and SCA algorithms are consistent with those provided in the literature [7]. The base voltage and MVA for the 33-bus RDS are 12.66 kV and 100, respectively. According to [24], the system’s aggregate active load is 3715 kW, with a reactive load of 2300 kVAR.

Fig. 3 provides a detailed schematic of the test system under different scenarios. Case 1 represents SLD of the 33-bus RDS, which contains 32 sectionalizing and 5 tie switches, with the latter represented by red lines. Case 2 illustrates the optimal network configuration obtained using the MLF [6] method. For this configuration, sectionalizing switches 7, 9, 14, and 32 are opened, while tie switches 33, 34, 35, and 36 are closed. Case

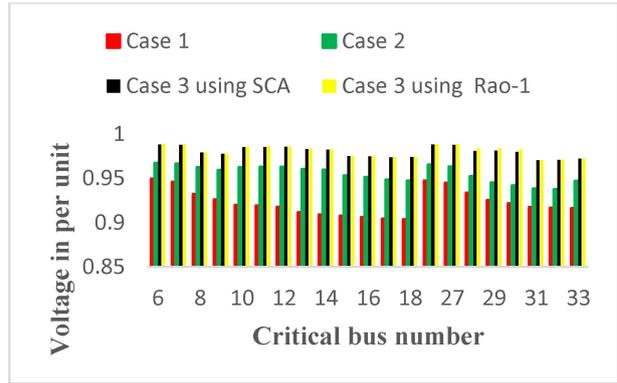


Fig. 4: Voltage profiles at critical buses for 33 bus RDS for all cases.

3 highlights the SLD 33-bus RDS with simultaneous NR and the integration of three DGs at optimal locations. The optimal locations for Type-I DGs, as identified in [10], are buses 12, 18, and 25

Table 1 provides a detailed performance analysis of the 33-bus RDS for all three cases. In case 1, the TPL is observed to be 210.998 kW, with critical buses identified as buses 6 to 18 and 26 to 33. V_{min} is recorded at bus 18 is 0.9037 per unit. For case 2, i.e., after NR using the MLF [6] method, the TPL is reduced to 138.548 kW, representing a 34.33% decrease in real power loss compared to case 1. Number of critical buses is significantly reduced to just buses 29, 30, 31, 32, and 33. V_{min} is observed at bus 31 is 0.9432 per unit. In case 3, TPL is minimized further by integrating three Type-I DGs at best locations i.e., bus 12, 18, and 25. The TPL obtained using the Rao-1 method is 52.8723 kW, while the SCA method achieves a TPL of 52.9497 kW. The optimal DG capacity calculated is 2656.13 kW for the Rao-1 method and 2582.83 kW for the SCA method. No critical buses are observed in Case 3. From Table 1, it is evident that the Rao-1 algorithm achieves the highest reduction in real power loss of 74.94% with respect to case 1 which is better as compared to SCA and other existing algorithms, such as ESCA [10].

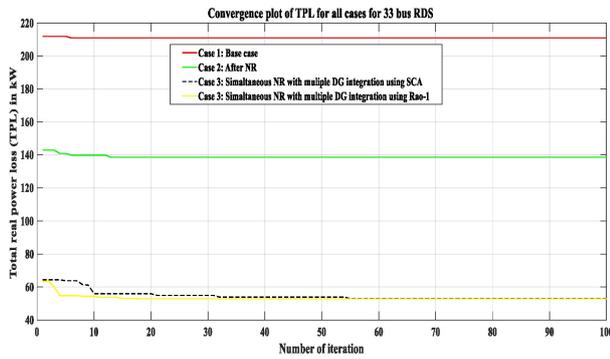
Fig. 4 illustrates the comparison of voltage patterns at critical buses from case 1 to 3. In Case 3, the voltage profiles at critical buses indicate a considerable improvement when using the Rao-1as approach instead of the SCA.

Fig. 5 depicts the convergence curves obtained for the 33-bus RDS across all cases. In Case 3, it is observed that the Rao-1 method achieves a slightly lower TPL as compared to SCA. Furthermore, the Rao-1 algorithm demonstrates faster convergence, requiring fewer iterations than the SCA method.

Table 2 shows the performance evaluation of the suggested algorithms, Rao-1 and SCA, using statistical metrics such as mean, best, worst, and standard deviation of the objective function (minimizing TPL). Each measure is determined from twenty separate runs. The Rao-1

Table 1: Performance analysis of 33 bus RDS.

Parameters	Case 1 (Before NR)	Case 2 (After NR)	Case 3 (Simultaneous multiple DGs placement with NR)		Case 3 (Simultaneous multiple DGs placement with NR)
			Rao-1	SCA	
Method/Algorithm	LF [6]	MLF [6]	Rao-1	SCA	ESCA [10]
Open switches	33,34,35,36,37	7,9,14,32,37	7,9,14,32,37	7,9,14,32,37	7,9,14,27,30
Total real power loss (TPL) in kw	210.998	138.548	52.8723	52.9497	53.53
% Reduction in real power loss (RPL)	----	34.33	74.94	74.90	73.58
Critical buses	6 to 18, 26 to 33	29,30,31,32,33	----	----	-----
Minimum bus voltage (V_{\min}) in per unit (bus number)	0.9037(18)	0.9432(31)	0.9706(31)	0.9704(31)	0.9651(31)
Optimal size in kW (location of DG)	----	----	570.2475 (12) 795.4826 (18) 1290.4 (25)	552.2845 (12) 801.0498 (18) 1229.5 (25)	567.23(12) 712.5(18) 1190 (25)
Total DG capacity (kW)			2656.13	2582.83	2469.73

**Fig. 5:** Convergence plot of total real power loss for all cases for 33 bus RDS.**Table 2:** Evaluation of Rao-1 and SCA for Case 3 based on statistical inference and convergence time (seconds) for 33 bus RDS.

Statistical inference for 20 runs (kW) for Case 3	Optimization methods		Convergence time (second)	
	Rao-1	SCA	Rao-1	SCA
Mean (M)	52.8723	53.072	12.4707	19.987
Best (B)	52.8723	52.9497		
Worst (W)	52.8723	53.3956		
Standard deviation (SD)	0	0.0293		

approach reliably produces the same optimal solution throughout all runs, with 0% variance, providing a considerable advantage over the SCA method.

Table 3 displays several customer reliability indices such as SAIFI, SAIDI, and CAIDI, as well as energy-based indices such as ENS, AENS, and ASUI, which were tested and examined for 33 bus RDS, as detailed in [6]. It is seen

that in case 3, energy not supplied (ENS) is lowered to 4480.88 kwh/year, while in case 1 it is 7097.95 kWh/year. This test uses system reliability statistics from [26].

5.2 69 BUS RDS

The 69-bus RDS operates with a base voltage of 12.66 kV and a base MVA of 100. The system's total load consists of an aggregate active power of 3801 kW and a reactive power of 2694 kVAR, as reported in [25]

Fig. 6 provides a detailed schematic of the 69-bus RDS under different scenarios, case 1 indicates the SLD of 69-bus RDS which involves 68 sectionalizing and 5 tie switches, represented by red lines. Case 2 depicts the optimal NR obtained using the MLF [6] method. In this configuration, sectionalizing switches 14, 57 and 61 are opened, while tie switches 71, 72, and 73 are closed. Case 3 presents the SLD for the same system with simultaneous NR and the integration of three DGs at optimal locations. The optimal locations for Type-I DGs, as identified in [10], are buses 11, 61, and 65.

Table 4 provides a detailed performance analysis of 69-bus RDS for all three cases. In case 1 the TPL is obtained to be 224.903 kW, with critical buses identified as buses 57 to 65. V_{\min} is recorded at bus 64 is 0.909 per unit. In case 2 i.e. after NR using the MLF [6] method, the TPL is reduced to 98.068 kW, reflecting an RPL of 56.395% compared to case 1. Number of critical buses is significantly reduced, with only bus 61 remaining critical. V_{\min} is observed at bus 61 is 0.9462 per unit. In case 3, TPL is further reduced by installing three Type-I DGs at appropriate positions (buses 11, 61, and 65). The TPL obtained using the Rao-1 method is 36.448 kW, while the SCA method achieves a TPL of 36.477 kW. The total optimal DG capacity is calculated to be 2477.961 kW for the Rao-1 method and 2435.7636 kW for the SCA method. No critical buses are observed in case 3.

Table 4 shows that the Rao-1 approach obtains the

Table 3: Reliability indices evaluation for 33 bus RDS.

Reliability Indices	Case 1 (Before NR)	Case 2 (After NR)	Case 3 (Simultaneous multiple DGs placement with NR)
SAIFI (interruptions/customer)	2.412	2.326	1.888
SAIDI (hours/customer)	2.043	1.544	1.283
CAIDI (hours/customer interruption)	0.847	0.664	0.679
ENS (kWh/year)	7097.95	5493.5	4480.88
AENS (kWh/year/customer)	0.39	0.302	0.246
ASAI	0.9997	0.9998	0.9998
ASUI	0.00024	0.000176	0.0001464

Table 4: Performance analysis of 69 bus RDS.

Parameters	Case 1 (Before NR)	Case 2 (After NR)	Case 3 (Simultaneous multiple DGs placement with NR)		Case 3 (Simultaneous multiple DGs placement with NR)
			Rao-1	SCA	
Method/Algorithm	LF [6]	MLF [6]	Rao-1	SCA	ESCA [10]
Open switches	69,70,71,72,73	14,57,61,69,70	14,57,61,69,70	14,57,61,69,70	12,19,57,63,69
Total real power loss (TPL) in kw	224.903	98.068	36.448	36.477	36.95
% Reduction in real power loss (RPL)	----	56.395	83.8	83.78	83.57
Critical buses	57 to 65	61	----	----	-----
Minimum bus voltage (V_{min}) in per unit (bus number)	0.909 (64)	0.9462(61)	0.9779(61)	0.9777(61)	0.9774(61)
Optimal size in kW (location of DG)	----	----	521.338 (11) 1464.91 (61) 488.712 (65)	475.2646 (11) 1475.6 (61) 484.899 (65)	436(11) 1300(61) 461.6 (65)
Total DG capacity (kW)			2477.961	2435.7636	2197.6

Table 5: Comparison of RAO-1 and SCA for Case 3 based on statistical inference and convergence time (second) for 69 bus RDS

Statistical inference for 20 runs (kW) for Case 3	Optimization methods		Convergence time (second)	
	Rao-1	SCA	Rao-1	SCA
Mean (M)	36.448	36.5282	19.925	28.251
Best (B)	36.448	36.477		
Worst (W)	36.448	36.6959		
Standard deviation (SD)	0	0.01201		

highest RPL of 83.8% when compared to case 1, beating the SCA method and other current algorithms, such as ESCA [10].

Fig. 7 compares voltage patterns at crucial buses for 69-bus RDS for cases 1 to 3. In case 3, the voltage profiles at crucial buses indicate a significant improvement, with the Rao-1 technique slightly outperforming the SCA method.

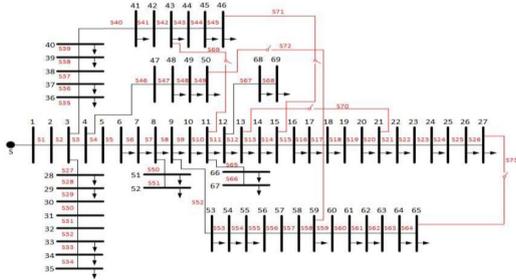
Fig. 8 displays the convergence curves derived for 69-bus RDS across all cases. It is discovered that the Rao-1 technique produces a little larger decrease in TPL than the SCA for case 3. Furthermore, the Rao-1 algorithm exhibits faster convergence and requires less iterations than the SCA approach.

Table 5 shows the performance evaluation of the suggested methods, Rao-1 and SCA, using statistical inference for 69 bus RDS, including the M, B, W, and SD of TPL value. The Rao-1 approach reliably produces the same optimal solution in all runs, with zero deviation, giving it a considerable advantage over the SCA method.

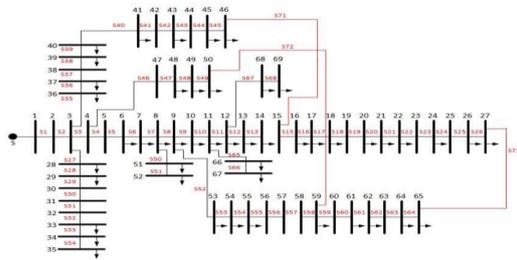
Table 6 compares the various reliability indices for 69

Table 6: Reliability indices evaluation for 69 bus RDS.

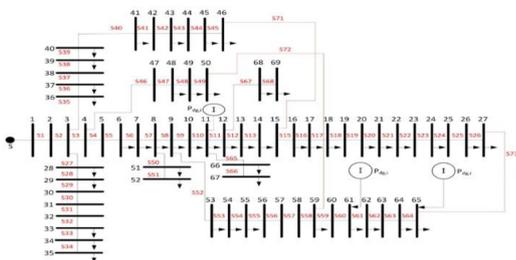
Reliability Indices	Case 1 (Before NR)	Case 2 (After NR)	Case 3 (Simultaneous multiple DGs placement with NR)
SAIFI (interruptions/customer)	2.22	1.63	0.753
SAIDI (hours/customer)	1.667	1.419	0.544
CAIDI (hours/customer interruption)	0.751	0.871	0.722
ENS (kWh/year)	6250.07	5330.708	2071.422
AENS (kWh/year/customer)	0.366	0.312	0.121
ASAI	0.9998	0.9997	0.9999
ASUI	0.00019	0.00016	0.000062



a) Case 1: SLD of IEEE 69 bus RDS before NR.



b) Case 2: SLD of IEEE 69 bus RDS after NR.



c) Case 3: SLD of IEEE 69 bus RDS for simultaneous allocation of multiple DGs with NR.

Fig. 6: SLD of 69 bus RDS for all cases.

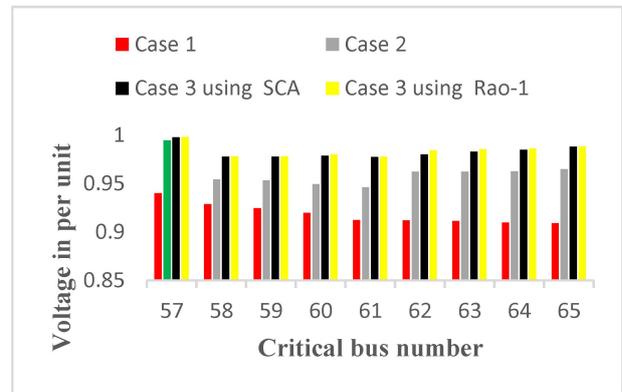


Fig. 7: Voltage profiles at critical buses for 69 bus RDS for all cases.

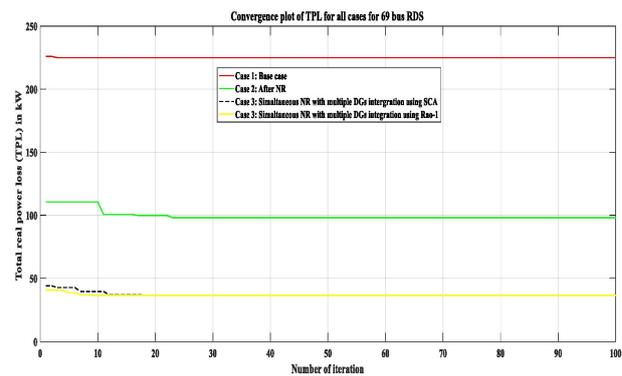


Fig. 8: Convergence plot of total real power loss for all cases for 69 bus RDS.

bus RDS in all circumstances. It is noticed that customer-based reliability indices (SAIFI, SAIDI) are much lower in

case 3 compared to case 1. Energy-based indices like ENS are significantly lowered, from 6250.07 kWh/year (case 1) to 2071.422 kWh/year (case 3). For this, system reliability data is assembled from [26].

6. CONCLUSION

This research proposes a coordinated strategy for optimal Distributed Generation (DG) allocation and network reconfiguration (NR) in RDS using the metaphor less Rao-1 and the Sine Cosine Algorithm (SCA). The primary objective is to minimize total real power loss. Optimal sizing of DGs and NR is inherently challenging due to the large search space and high computational complexity. Compared to SCA, the Rao-1 method offers a simpler structure, requires fewer control parameters, and delivers lower computational time. Moreover, the simultaneous application of DG placement and NR (Case 3) using both algorithms demonstrates substantial improvements in system performance relative to Case 1 (before NR) and Case 2 (After NR). In particular, the Rao-1 algorithm achieves a reduction in real power loss of approximately **74.94% for the IEEE 33-bus system** and **83.8% for the IEEE 69-bus system** under Case 3. Significant improvements in the voltage profile at critical buses are also observed. Additionally, several reliability indices were evaluated across all cases for both test systems, confirming that simultaneous DG allocation with NR considerably enhances overall system reliability compared to other cases. For future work, this study will extend to the optimal placement and sizing of Battery Energy Storage Systems (BESSs) in conjunction with multiple DGs, targeting not only real power loss minimization but also overall system cost reduction in RDS.

REFERENCES

- [1] S. R. Salkuti, N. R. Battu, "An effective network reconfiguration approach of radial distribution system for loss minimization and voltage profile improvement," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 4, pp. 1819-1827, 2021.
- [2] P. Srividhya, K. Mounika, S. Kirithikaa, K. Narayanan, G.Sharma, R. G. Ganesan, T. Senjyu, "Reliability Improvement of Radial Distribution System by Reconfiguration," *Advances in Science, Technology and Engineering Systems Journal*, vol. 5, no. 6, pp. 472-480, 2020.
- [3] M. M. Ansari, C. Guo, M. S. Shaikh, N. Chopra, I. Haq, and L. Shen, "Planning for Distribution System with Grey Wolf Optimization Method," *Journal of Electrical Engineering & Technology*, vol. 15, pp.1485-1499, 2020.
- [4] M. A. Muhammad, H. Mokhlis, K. Naidu, A. Amin, J. F. Franco, and M. Othman, "Distribution network planning enhancement via network reconfiguration and DG integration using dataset approach and water cycle algorithm", *Journal of Modern Power Systems and Clean Energy*, vol. 8, no. 1, 2020.
- [5] J. A. M. Rupa, and S. Ganesh, "Power Flow Analysis for Radial Distribution System Using Backward/Forward Sweep Method", *World Academy of Science, Engineering, and Technology International Journal of Electrical and Computer Engineering*, vol. 8, no. 10, 2014.
- [6] S. S. Halve, S. S. Raghuwanshi and D. M. Sonje, "Radial Distribution System Network Reconfiguration for Reduction in Real Power Loss and Improvement in Voltage Profile, and Reliability", *Journal of Operation and Automation in Power Engineering*, vol.14, no.2, pp.78-85, Apr. 2026.
- [7] S. S. Halve, R. Arya, and A. Koshti, "Metaphor-Less RAO-3 and Sine Cosine Algorithm for Optimal Sizing of Distributed Generations of Multiple Types in Radial Distribution System", *Electrica Journal*, vol. 23, no. 2, pp. 177-191, 2023.
- [8] S. S. Halve, R. Arya and A. Koshti, "Locating, optimal sizing and reliability analysis of solar based DGs in radial distribution system", *Journal of Institution of Engineering, Series-B*, vol. 104, pp. 201-213, 2023.
- [9] S. S. Halve, A. Koshti, and R. Arya, "A sampling method based on system state transition for distribution system adequacy assessment using distributed generation", *Journal of Operation and Automation in Power Engineering*, vol. 11, no. 4, pp. 249-257, 2023
- [10] U. Raut and S. Mishra, "Enhanced Sine-cosine algorithm for optimal planning of distribution network by incorporating network reconfiguration and distributed generation", *Arabian Journal in Science and Engineering*, vol. 46, pp. 1029-1051, 2021.
- [11] P. C. R. Ganney and R. B. Pallikonda, "Network reconfiguration and optimal allocation of multiple DG units in radial distribution system", *International Journal of Advanced and Technology and Engineering Exploration*, vol. 8, no. 81, pp. 1019-1032, 2021.
- [12] R. S. Rao, K. Ravindra, K. Satish, and S. V. L. Narasimham, "Power Loss Minimization in Distribution System Using Network Reconfiguration in the Presence of Distributed Generation", *IEEE Transactions on power systems*, vol. 28, no. 1, pp. 317-325, 2013.
- [13] R. Rajaram, K. S. Kumar, and N. Rataranjan, "Power system reconfiguration in a radial distribution network for reducing losses and to improve voltage profile using modified plant growth simulation algorithm with Distributed Generation (DG)", *Energy reports*, vol. 1, pp. 116-122, 2015.
- [14] O. Badran, S. Mekhilef, H. Mokhlis, and W. Dahalan, "Optimal reconfiguration of distribution system connected with distributed generations: A review of different methodologies", *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 854-867, 2017.
- [15] N. Kanwar, N. Gupta, K. R. Niazi, and A. Swarnkar, "Optimal Allocation of DGs and Reconfiguration of Radial Distribution Systems Using an Intelligent Search-based TLBO", *Electric Power Components*

and *System*, vol. 45, no. 5, 2017.

- [16] U. Raut, and S. Mishra, "Power distribution network reconfiguration using an improved sine cosine algorithm based on meta-heuristic search", *Advanced in intelligent system and computing*, vol. 816, pp.1-13, 2018.
- [17] A. Uniyal, and S. Sarangi, "Optimal network reconfiguration and DG allocation using adaptive modified whale optimization algorithm considering probabilistic load flow", *Electric Power System*, vol. 192, 2021.
- [18] N. Pompern, S. Premrudeepreechacharn, A. Siritariwat, S. Khunkitti, "Optimal Placement and Capacity of Battery Energy Storage System in Distribution Networks Integrated with PV and EVs Using Metaheuristic Algorithms", *IEEE Access*, vol.11, pp. 68379-68394, 2023.
- [19] P. Boonluk, A. Siritariwat, P. Fuangfoo, S. Khunkitti, "Optimal siting and sizing of battery energy storage systems for distribution network of distribution system operators", *MPDI batteries*, vol.6, no.4, 2020.
- [20] K. Wichitkraitat, S. Premrudeepreechacharn, A. Siritariwat, S. Khunkitti, "Optimal Sizing and Locations of Multiple BESSs in Distribution Systems Using Crayfish Optimization Algorithm", *IEEE Access*, vol.12, pp. 94733-94752, 2024.
- [21] S. Mirjalili, "SCA: A sine cosine algorithm for solving optimization problems," *Knowledge-Based Systems*, vol. 96, pp. 120-133, 2016.
- [22] R. V. Rao, "Three metaphor-less simple algorithms for solving optimization problems," *International Journals of Industrial Engineering Computations*, vol. 11, no. 1, pp. 107-130, 2020
- [23] L. D. Arya, A. Koshti, and S. C. Choube, "Distributed generation planning using differential evolution accounting voltage stability consideration," *Int. J. Electr. Power Energy Syst.*, vol. 42, no. 1, pp. 196-207, 2012.
- [24] M. E. Baran and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing", *IEEE Transactions on Power Delivery*, vol. 4, no. 2, pp. 1401-1407, 1989.
- [25] N. C. Sahoo and K. Prasad, "A fuzzy genetic approach for network reconfiguration to enhance voltage stability in radial distribution system", *Energy Conservation and Management*, vol. 47, pp. 3288-3306, 2006.
- [26] N. Gupta, A. Swarnkar, and K. Niazi, "Distribution network reconfiguration for power quality and reliability improvement using genetic algorithms," *Int. J. Electr. Power Energy Syst.*, vol. 54, pp. 664-671, 2014.



Shrunkhala S. Halve received her B.E (Electrical) degree from Pune University in 2004, M.E (Electrical) degree from Shivaji University, India, in 2009 and Ph.D. degree in Electrical Engineering Department from Medicaps University, Indore in 2023. Since 2010, she has been working as Assistant Professor in Department of Electrical Engineering of Gokhale Education Society, R H Sapat COEMS&R, Nashik. Her area of research includes Power system optimization, distributed generations and power system operation and control.



Deepak M. Sonje received the B.E. degree in electrical engineering from Government College of Engineering, Karad, Shivaji University, Kolhapur, in 1999, M.E. degree in control systems from Savitribai Phule University, Pune, India, in 2009, and awarded Ph.D. degree from Sardar Vallabhbhai National Institute of Technology, Surat in 2019. Since, 2010 he has been with Department of Electrical Engineering, Gokhale Education Society's R. H. Sapat College of Engineering, Management Studies and Research, Savitribai Phule University, Pune. His areas of interest include condition monitoring of electrical machines, machine learning tools and modelling of electrical machines and drives. He has published fourteen papers in refereed journals and thirteen papers in the proceedings of international conferences. He is a member of the Institution of Engineering and Technology (IET).



M. Venkateswara Reddy received his B.E. (Electrical and Electronics Eng.) degree from University of Madras in 2003, M.E(Power Electronics and Drives) degree from Anna University, India, in 2006 and Pursuing Ph.D. degree in Electrical Engineering Department from Osmania University, Hyderabad. He has been working as Assistant Professor in Department of Electrical Engineering of Gokhale Education Society, R H Sapat COEMS&R, Nashik. Her area of research includes Power Electronics, Electrical Drives, Electric Vehicles, FACTS distributed generations and power system operation and control.