OPTIMAL ALLOCATION OF DISTRIBUTION GENERATOR FOR RADIAL DISTRIBUTION NETWORK USING GREY WOLF OPTIMIZER

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Electric power utilities are paying a lot of attention right now to the optimal location and size of distributed generation (DG) at the radial distribution grids with the goal of minimizing real power loss. Power loss minimization has several built-in advantages, such as reducing the power flow on reducing the power flow on the feeder lines, relieving stress on feeder loading to extend their life, increasing the possibility of using the current facility to meet any increase in load demand, avoiding the need to buy power from the grid, saving money on loss-compensating equipment, lowering customer bills, etc. In this paper, the optimal location and size of distributed generation (DG) units will be addressed using one of the most popular metaheuristic optimization techniques, namely the Grey Wolf Optimizer (GWO). The main aim of this paper is to minimize the real power losses on the distribution network, improve the voltage profiles, and enhance the voltage stability index by adding DG units to the optimal location and determining the optimal size while satisfying the equality and inequality constraints. The approach proposed determining the optimal location by reconfiguring the DG on all buses, calculating the real power losses, and improving the voltage deviation. The optimal location is achieved on a bus with the lowest real power losses. The optimal sizing of the DG unit can be achieved by using Grey Wolf Optimizer (GWO). GWO is a meta-heuristics optimization technique inspired by the social behavior of gray wolves. The IEEE 69 bus power system and Babylon Radial Distribution Network (BRDN) will be tested to prove the superiority and efficiency of the proposed algorithm. According to the simulation results that were obtained and the evaluation of the various cases that were taken into consideration, the placement of DG units results in a large loss reduction with a favorable voltage profile as well as a release in the line loading in the power distribution networks.

Keywords: Distributed generation, Grey Wolf Optimizer, Optimal location, Optimal sizing, real power Loss minimization, IEEE 69-bus system, Babylon Radial Distribution Network (BRDN)

1. Introduction

The high-voltage transmission systems are connected to the low-voltage electric power distribution networks, which ultimately provide power to clients at

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low voltage. Due to low voltage and high current in comparison to high-voltage networks, distribution network lines have substantial total power losses. This leads to a rise in energy costs and a poor voltage profile along the distribution feeder. Real power loss and reactive power loss make up the total power loss in the distribution network. The first loss is caused by the flow of active current required by the load, whereas the second loss is caused by the flow of reactive current needed to make up for the reactive power needs of network components and, as a result, control the voltage of the system. The impact of active power loss is crucial since it degrades the voltage profile and lowers power transfer efficiency, which represents one of these losses. In comparison to the transmission system, minimizing real power loss in the distribution networks is particularly crucial. Electric power distribution is primarily responsible for reducing power loss and improving the power efficiency of the electric power delivery system. According to reports, power losses at the distribution level account for up to 13% of all wasted energy [1]. Since the capacity of radial lines is frequently constrained, it is important to consider various alternate techniques to meet future load demands while ensuring supply quality and dependability.

Due to the inductive nature of the majority of distribution network components, such as motors and transformers, the power factor in the network will be lagging, which reduces system capacity, raises system losses, and lowers voltage. Some of these issues are resolved using shunt capacitors [2–4]. Shunt capacitors improve the voltage profile, power factor, and voltage stability of the system, in addition to reducing power losses. Since distributed generation (DG) integration into the distribution system defers major system upgrades, lowers total energy loss, and enhances supply quality and reliability, it can now play a significant role in distribution system planning [5]. Although DG technologies have favorable effects on the distribution system, adding active DG units to a traditional passive system may present certain technical difficulties. It is important to note that DG units should be used effectively without impairing supply quality, system performance, or dependability. On the other hand, while planning the expansion of a distribution system, shunt capacitors, which are frequently used for reactive power compensation, can also be considered. On the other hand, while planning the expansion of a distribution system, shunt capacitors with DG units, which are frequently used for reactive power compensation, can also be considered. Any loss reduction is advantageous to distribution utilities, who typically bear the burden of keeping losses at a minimum. Therefore, loss minimization is the most crucial issue to take into account when planning and operating DG [6].

According to the literature, shunt capacitors' reactive power injection can efficiently lower system energy loss, ease feeder stress, and enhance supply reliability [7]. To prevent voltage, rise problems and thereby lower the operating cost of DG units, special consideration must be given to the placement and sizing of shunt capacitors. The placement of capacitors, network reconfiguration, DG deployment, network reconfiguration in the presence of DG, and DG capacitor placement are some of the techniques that can be utilized to reduce power losses in distribution networks [8].

In power systems, various optimization techniques have been used to solve multiple problems. For example, several techniques are used to solve optimal power flow, such as Differential Evolution (DE) [9], Grey Wolf Optimizer (GWO) [15, 16], Hunger Games Search (HGS) [12], Harris Hawks Optimization (HHO) [14, 15], Improved Differential Evolution (IDE) [16, 18], Modified Artificial Bee Colony (MABC) [18], Slime Mould Algorithm (SMA) [19],Modified Fibonacci Search Algorithm (MFSA) [20], oppositional-based manta ray foraging optimization algorithm (OMRFO) [21], and honey badger algorithm (HBA) [22]. In optimal allocation (placement and sizing) of DG in the distribution networks, many optimization methods were proposed to reduce power loss, such as analytical methods [20–23], genetic algorithms (GA) [27], artificial bee colony (ABC) algorithms [28], evolutionary programming (EP) [29], GA-TS [30], Manta Ray Foraging Optimization algorithm (MRFO) [31], and black widow optimization (BWO) [32], and improved whale optimizer algorithm (IWOA) [33] were used.

All the above techniques used the optimal siting and sizing of DG units in the most effective way. The optimal distribution of DG is considered in the current work, considering that DG can also deliver reactive power in addition to real power. The optimal placement and sizing are the main goals of this paper: to minimize real power losses in the distribution network, improve the voltage profiles, and enhance the voltage stability index while satisfying the equality and inequality constraints. The placement of DG units is determined using the reconfiguration approach. The best bus to place a DG unit on is the one with the lowest real power losses after selecting the best size. The optimal sizing of DG units will be determined by the proposed algorithm, Grey Wolf Optimizer (GWO). The convergence speed of the proposed algorithms is fast and requires less iteration to reach optimal solutions compared to the other optimization techniques reported in the literature. The proposed algorithms have been tested on two radial power systems: the IEEE 69-bus system and the Babylon Radial Distribution Network (BRDN).

This paper will be arranged as follows: Section 2 includes the problem formulation, which includes objective functions and constraints. Section 3 presents the overview and mathematical model of the proposed algorithm, Grey Wolf Optimizer (GWO). Section 4 involved the simulation results and discussion to determine the optimal location and sizing for the IEEE 69-bus system and

Babylon Radial Distribution Network (BRDN) to reduce the real power losses. Finally, the conclusions are represented in Section 5.

2. Problem formulation

2.1 Objective function

The main goal of the proposed approach is to set the best location and size for DG to achieve the optimal objective function (real power losses) under various operational constraints. It can be formulated for the real power losses as follows [34]:

$$Min(f_{loss}) = \sum_{i=1}^{N} P_{loss} \tag{1}$$

Where:

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} \left(\alpha_{ij} \left(P_i P_j + Q_i Q_j \right) + \beta_{ij} \left(Q_i P_j - P_i Q_j \right) \right) \tag{2}$$

$$P_i = P_{G_i} - P_{D_i} \tag{3}$$

$$Q_i = Q_{G_i} - Q_{D_i} \tag{4}$$

$$\alpha_{ij} = \frac{r_{ij}}{v_i v_j} \cos(\delta_i - \delta_j) \tag{5}$$

$$\beta_{ij} = \frac{x_{ij}}{v_i v_j} \sin(\delta_i - \delta_j) \tag{6}$$

And

$$r_{ij} + jx_{ij} = z_{ij} \tag{7}$$

ijth element of [Z_bus] matrix is

$$\left[Z_{bus} \right] = \left[Y_{bus} \right]^{-1} \tag{8}$$

P_{loss} : Total real power losses of whole system. P_i and P_j are the real power flowing out of bus *i* and bus *j*. Q_i and Q_j are the reactive power flowing out of bus *i* and bus *j*. P_{Gi} and P_{Di} are the real power supplied by DG and demand at bus *i*. Q_{Gi} and Q_{Di} are the reactive power output for DG unit and demand at bus *i*. v_i is voltage at bus *i*, r_{ij} and x_{ij} are resistance and reactance of the line section between buses *i* and *j* respectively.

2.3 Constrain

The following constraints apply to these objective functions as follows:

a) Power balance constraint

$$\sum_{i=2}^{n} P_{DG_i} \leq \sum_{i=2}^{n} P_i + \sum_{i=1}^{b} P_{loss_{i \to i+1}} \tag{9}$$

$$\sum_{i=2}^{n} Q_{DG_i} \leq \sum_{i=2}^{n} Q_i + \sum_{i=1}^{b} Q_{loss_{i \to i+1}} \tag{10}$$

where and P_{DGi} and Q_{DGi} are the real and reactive power supplied by DG at bus *i*. $P_{loss(i,i+1)}$ and $Q_{loss(i,i+1)}$ are the real and reactive power loss from buses *i* to *i+1*.

b) Voltage constraint

$$|V_1 - V_i| \leq \Delta V_{\max} \qquad \forall i = 1, 2, \ldots n \tag{11}$$

c) Thermal limit

$$|J_i| \leq J_{i\max} \tag{12}$$

$J_{i\max}$ maximum thermal current through line *i*. Utilizing the amount of current flowing via each branch, the thermal limit is computed. The objective function penalizes the violation of the inequality constraints.

3. Proposed methodology

In this section, the authors have proposed two approaches to finding the optimal location and sizing. The first approach is used to find the optimal location. The reconfiguration method is the approach used to select the optimal placement (bus number) of the DG unit. The second method is used to find the optimal size (MW) of the DG unit. Grey Wolf Optimizer (GWO) is the proposed optimization method to determine the optimal sizing of the DG unit. These approaches can be summarized as follows:

3.1 Reconfiguration Method (RM)

In a single DG connection, the proposed method to determine the optimal location is the reconfiguration method. The reconfiguration method is the approach used to select the best bus by placing the DG unit at each bus and calculating the real power losses at this bus. The total losses of all buses will be arranged, and the bus that has the lowest value represents the optimal bus. The reconfiguration method is the proposed method used to find the optimal location of the DG unit. The optimal size of the DG unit will be determined by GWO. The main steps are:

1. Calculate the real power loss at each bus after connecting the DG unit, thus selecting the optimal size based on GWO.
2. The bus showing the lowest real power loss is the candidate bus to connect the DG unit.

3.2 Grey Wolf Optimizer (GWO)

The Grey Wolf Optimizer (GWO) is a novel heuristic optimization algorithm that draws inspiration from the social behavior exhibited by grey wolves, who are members of the Canidae family [35]. The grey wolves are categorized into four hierarchical levels based on their leadership roles, namely alpha (α), beta (β), delta (δ), and omega (ω), as illustrated in Figure 1. In the Grey Wolf Optimization (GWO) algorithm, the alpha wolf denotes the most optimal solution, while the beta and delta wolves represent the second and third best options, respectively. The omega wolf symbolizes the subsequent solutions that succeed the solutions of the preceding three wolves in order to attain the best solution. The primary stages involved in grey wolf hunting are as follows:

A. Encircling Prey

This procedure exemplifies the optimal strategy for encompassing prey within a circular area during the act of hunting. The phenomenon of Grey Wolves surrounding their prey might be conceptualized as:

$$D = \left| C \cdot Y_p(t) - Y(t) \right| \tag{13}$$

$$Y(t+1) = Y_p(t) - B \cdot D \tag{14}$$

$$B = 2b \cdot r_1 - b \tag{15}$$

$$C = 2 \cdot r_2 \tag{16}$$

Here B and C are the coefficients. t denotes the current iteration. Y and Y_p are the position vector of the grey wolf and prey, respectively. b is changed from 2 to 0 decreasingly. r_1 and r_2 are random vectors in [0, 1]

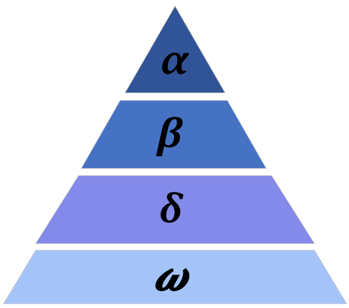

Fig. 1. Hierarchy of grey wolf in GWO

B. Hunting

During this process, the vector adjusts its position inside the search space based on the optimal positions of alpha, beta, and delta. The placements of the remaining agents will be adjusted within the search space in order to converge towards the location of the most optimal search agents. The agents' positions will be updated based on the selection of the three most optimal solutions, which have been saved and utilized in prior instances, as depicted in Figure 2. Hunting behavior can be characterized by the following formulas:

$$D_\alpha = \left|C_1 \cdot Y_\alpha - Y\right|, D_\beta = \left|C_2 \cdot Y_\beta - Y\right|, D_\delta = \left|C_3 \cdot Y_\delta - Y\right| \tag{15}$$

$$Y_1 = Y_\alpha - B_1 \cdot D_\alpha, Y_2 = Y_\beta - B_2 \cdot D_\beta, Y_3 = Y_\delta - B_3 \cdot D_\delta \tag{16}$$

$$Y(t+1) = \frac{Y_1 + Y_2 + Y_3}{3} \tag{17}$$

The estimation of position can be represented by Y_1, Y_2 and Y_3 based on alpha, beta and delta, respectively. The final position was updated by $Y(t+1)$.

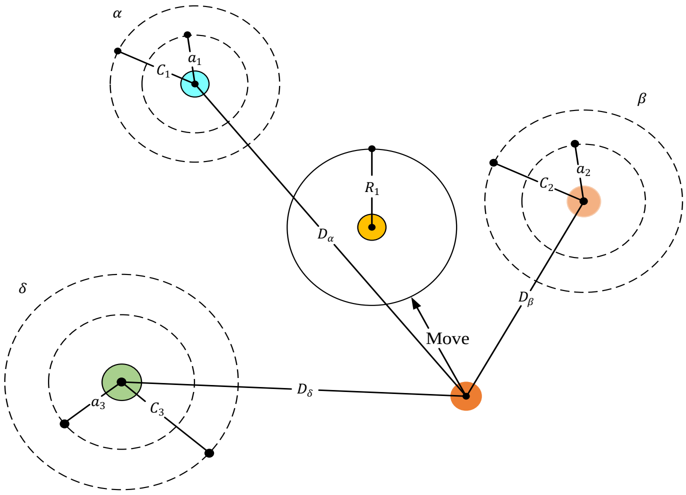

Fig. 2. Position updating in GWO.

C. Attacking

The act of attacking the prey signifies the final stage in the hunting behavior of Grey wolves, occurring when the prey ceases its movement. The mathematical description of this procedure involves iteratively decreasing the value from 2 to 0. The local search mechanism of the Grey Wolf Optimizer (GWO) can be analogously conceptualized as the hunting behavior of wolves targeting their prey.

D. Searching

The initiation of prey seeking in Grey wolves is contingent upon the spatial arrangement of α, β, and δ individuals. The divergence of Grey wolves occurs during the process, whereas the convergence takes place during the attack on the prey. When the value decreases, it implies that the wolves are compelled to seek out more suitable prey. The procedure outlined here is the global search or exploration for the Global Welfare Organization (GWO). Figure 3 depicts the flowchart of the Grey Wolf Optimization (GWO) method.

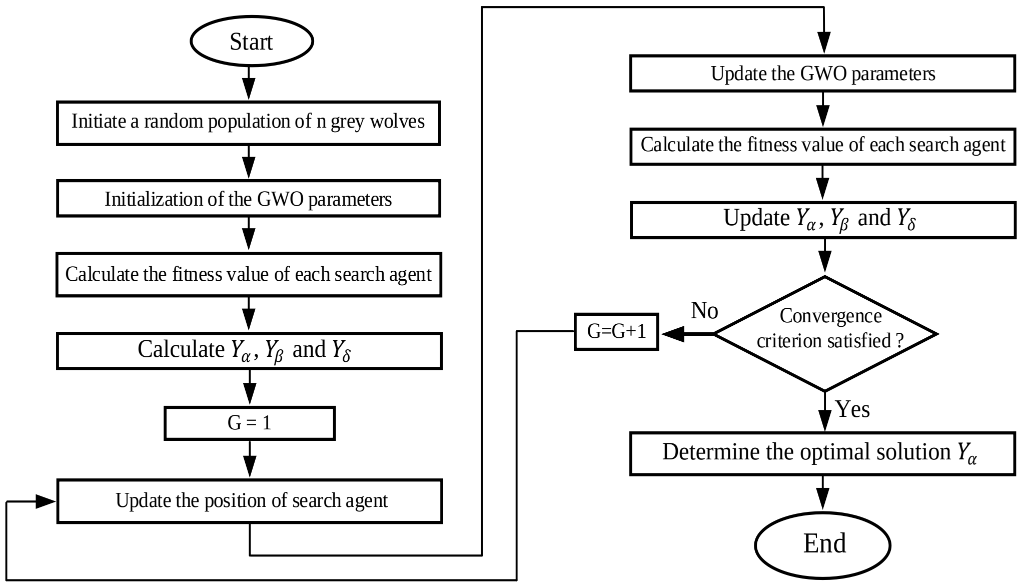

Fig. 3. Flowchart of the Grey Wolf Optimizer GWO

4. Simulation results

The proposed method is tested on the IEEE-69 bus system and the Babylon Radial Distribution Network (BRDN) to demonstrate its efficacy. Both test systems share the same initialized GWO algorithm parameters. MATLAB software is utilized to run the power flow, execute the GWO algorithm, and determine the best position and size for DG units.

4.1. IEEE-69 Bus system.

The IEEE 69 bus system is the first case-tested system using the proposed algorithm, GWO. Fig. A.1 represents the single-line diagram for the IEEE 69 bus power system. The bus and line data of the IEEE 69 bus system are tabulated in Table A.1. The main characteristics of this system are 69 buses and 68 lines; the voltage bus is 12.6 [kV], and the active and reactive loads are 3800 [kW] and 2690 [kVAr], respectively. The reconfiguration approach is the method used to select the optimal location of the DG unit. The GWO algorithm is the method used to determine the optimal size. Table 1 presents the optimal location and size for the IEEE 69 bus system. It can be observed that the optimal size of the DG unit is 2.375 MW. The optimal location of the DG unit is bus 61. The real power losses will be reduced from 224.94 [kW] in the initial case (without DG) to 91.48

[kW] in the optimal case (with DG unit), with a reduction rate of 58.94%. Also, the reactive power losses have been reduced from 101.22 [kVAr] in the initial case (without DG) to 43.19 [kVAr] in the optimal case (with DG units). Fig. 4 illustrates the effect of the placement and size of the DG unit on reducing the real power losses in the IEEE 69 bus system. Fig. 5 shows the voltage profiles of all buses without and with the DG unit. The minimum voltage improved from 0.909 [p.u.] (Bus 65) in the initial case (without DG unit) to 0.9713 [p.u.] (Bus 27) in the optimal case (with DG unit). Fig. 6 illustrates the effect of the installation of the DG unit on the voltage stability index. It can be observed that the minimum voltage stability index ranges from 0.6852 (Bus 65) in the initial case (without DG) to 0.890 (Bus 27) in the optimal case (with DG units). Table 2 shows the comparison results obtained by the proposed algorithm GWO with other modern optimization techniques. This table demonstrates the effectiveness and efficiency of the proposed algorithm to solve optimal power flow in a distribution network.

Table 1

The optimal location and sizing on IEEE 69 bus system

Items	Without DG	With DG units using GWO
Location (Bus No.)	-----	61
Size [kW]	-----	2,375
Total real loss [kW]	224.94	91.48
Total reactive loss [kVAr]	101.22	43.19
Reduction of real loss (%)	-----	58.94%
Min voltage [p.u.]	0.9093	0.9713
Minimum VSI	0.6852	0.890
Total VSI	61.27	65.55

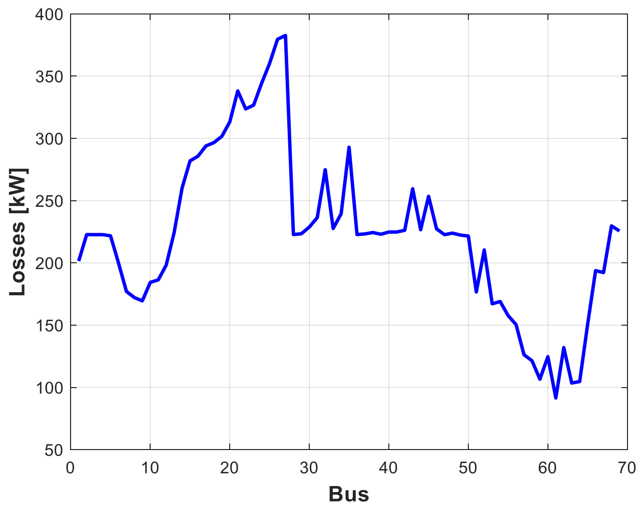

Fig. 4. Real power losses after installation DG unit at each bus on IEEE-69 bus system

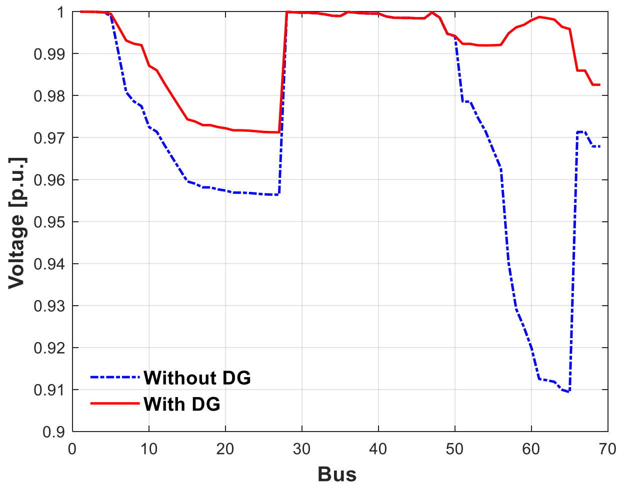

Fig. 5. Voltage profile with and without DG for IEEE-69 bus system.

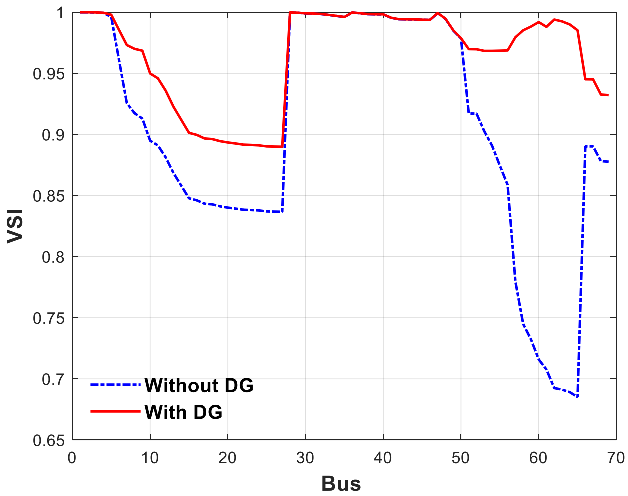

Fig. 6. Voltage stability index without and with DG for IEEE-69 bus system.

Table 2

Comparison the optimal results of proposed algorithm with other optimization techniques

Technique	Real power loss	
	Value (kW)	Percentage %
Initial (without DG units)	224.94	----
GWO [36]	98.5687	56.17
PSO [36]	98.5687	56.17
GWO-PSO [36]	98.5687	56.17
GA [37]	89.0	60.44
SGA [38]	89.4	60.3
Analytical [39]	92	59.1
GWO	**91.48**	**58.94**

4.2. Babylon Radial Distribution Network (BRDN)

The Babylon Radial Distribution Network (BRDN) is the particle system that has been applied in this study to demonstrate the efficiency and superiority of the proposed algorithm. The bus and line data of BRDN are tabulated in Table A.2. This system contains 100 buses and 99 branches. The real power load is 10467 [kW], and the reactive power load is 5069.4 [kVAr]. According to the reconfiguration of the DG unit, the candidate bus number is 33. The optimal sizing of DG units is determined by using the proposed algorithm, GWO. Table 3 illustrates the optimal location and sizing for BRDN. The optimal sizing [kW] is 8440. The real power losses will be decreased from 409.85 [kW] in the initial case (without DG) to 93.363 [kW] in the optimal case (with DG unit), with a reduction rate of 77.22%. Also, the reactive power losses have been reduced from 453.33 [kVAr] in the initial case (without DG) to 104.956 [kVAr] in the optimal case (with DG unit). Fig. 7 illustrates the effect of the placement and size of the DG unit on reducing the real power losses in the IEEE 69 bus system.

Table 3

The optimal location and sizing on IEEE 69 bus system

Items	Without DG	With DG units using GWO
Location (Bus No.)	-----	33
Size [kW]	-----	8440
Total real loss [kW]	409.85	93.363
Total reactive loss [kVAr]	453.33	104.956
Reduction of real loss (%)	-----	77.22 %
Min voltage [p.u.]	0.9374	0.9766
Minimum VSI	0.7721	0.9097
Total VSI	93.243	83.348

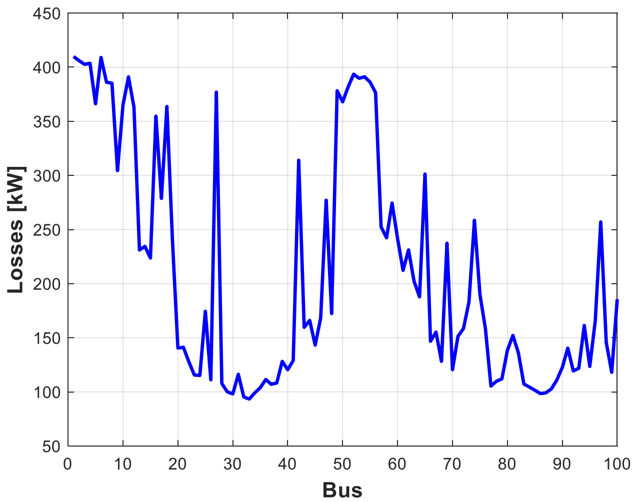

Fig. 7. Real power losses after installation DG unit at each bus on BRDN network.

Fig. 8 presents the voltage profiles of all buses without and with the DG unit. The minimum voltage improved from 0.9374 [p.u.] (Bus 48) in the initial case (without DG unit) to 0.9766 [p.u.] (Bus 48) in the optimal case (with DG unit). Fig. 9 illustrates the effect of the installation of DG units on the voltage stability index. It can be observed that the minimum voltage stability index ranges from 0.7721 (Bus 48) in the initial case (without DG) to 0.9097 (Bus 48) in the optimal case (with DG unit).

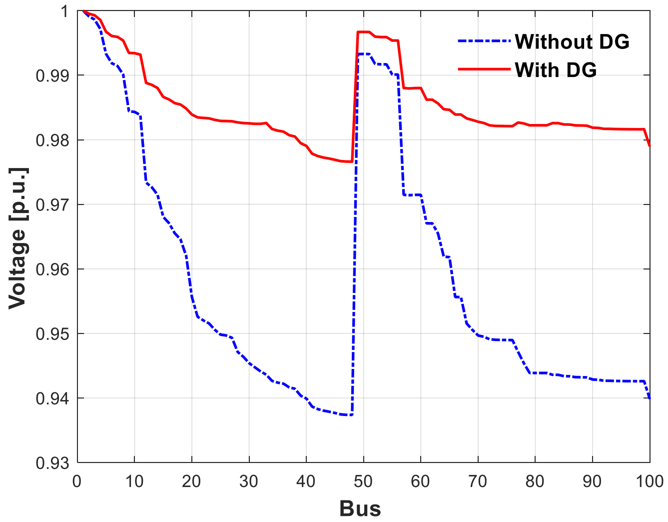

Fig. 8. Voltage profile with and without DG on BRDN network.

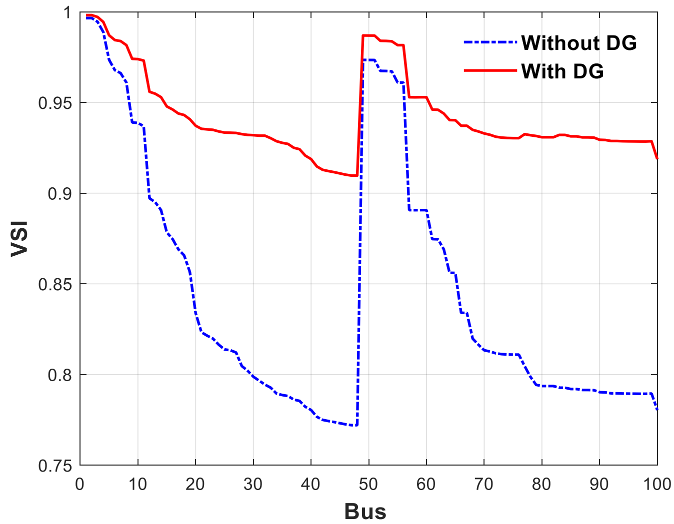

Fig. 9. Voltage stability index without and with DG on BRDN network.

5. Conclusion

This paper offers a study aimed at determining the ideal position and sizing (allocation) of a distributed generation (DG) unit using the Grey Wolf Optimizer (GWO), which is a widely used metaheuristic optimization technique. The primary objective of this study is to mitigate the actual power losses within the entire system while enhancing the voltage profiles and voltage stability. The reconfiguration technique is employed to ascertain the most favorable placement of distributed generation (DG) units. The GWO algorithm is offered as the method for determining the size of the DG unit. In order to validate the efficacy and practicality of the algorithm under consideration, experimental evaluations were conducted on two distinct power systems, namely the IEEE 69 bus power system and the Babylon Radial Distribution Network (BRDN). The Global Weight Optimization (GWO) algorithm is known for its ease of implementation, shorter execution time, and improved accuracy. The suggested algorithm demonstrated higher performance and efficiency compared to alternative algorithms, providing favorable solutions for radial distribution networks. The acquired findings from the two systems, namely the IEEE 69 bus and BRDN, demonstrate the rapid convergence characteristics and resilience of the proposed approach. Based on the observed results, it can be inferred that the suggested method is well-suited for determining the optimal position and size of distributed generation (DG) units in distribution networks. The suggested approach offers several key advantages, including ease of implementation, reduced computational effort, the ability to achieve optimal or near-ideal solutions, and the capability to identify plausible outcomes.

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APPENDIX

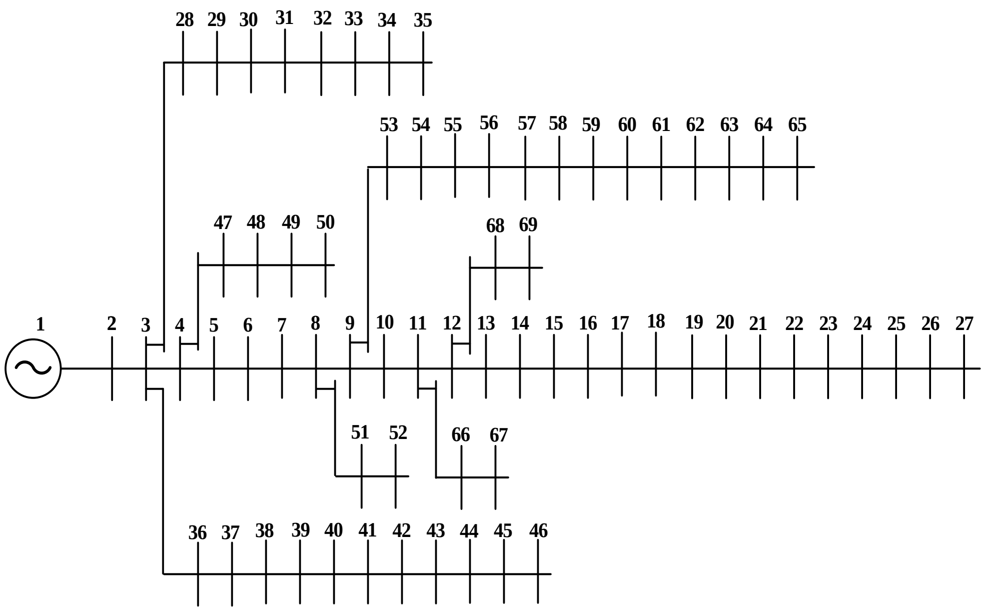

Fig. A. 1 Single line diagram of IEEE 69 bus power system.

Table A. 1

The Bus and Line data of IEEE 69 bus system

Bus Data			**Line Data**			
Bus	P load [kW]	Q Load [kVAr]	From (Bus)	To (Bus)	R [Ω]	X [Ω]
1	0	0	1	2	0.0005	0.0012
2	0	0	2	3	0.0005	0.0012
3	0	0	3	4	0.0015	0.0036
4	0	0	4	5	0.0251	0.0294
5	0	0	5	6	0.366	0.1864
6	2.6	2.2	6	7	0.3811	0.1941
7	40.4	30	7	8	0.0922	0.047
8	75	54	8	9	0.0493	0.0251
9	30	22	9	10	0.819	0.2707
10	28	19	10	11	0.1872	0.0619
11	145	104	11	12	0.7114	0.2351
12	145	104	12	13	1.03	0.34
13	8	5	13	14	1.044	0.345
14	8	5.5	14	15	1.058	0.3496
15	0	0	15	16	0.1966	0.065
16	45.5	30	16	17	0.3744	0.1238

17	60	35	17	18	0.0047	0.0016
18	60	35	18	19	0.3276	0.1083
19	0	0	19	20	0.2106	0.069
20	1	0.6	20	21	0.3416	0.1129
21	114	81	21	22	0.014	0.0046
22	5.3	3.5	22	23	0.1591	0.0526
23	0	0	23	24	0.3463	0.1145
24	28	20	24	25	0.7488	0.2475
25	0	0	25	26	0.3089	0.1021
26	14	10	26	27	0.1732	0.0572
27	14	10	3	28	0.0044	0.0108
28	26	18.6	28	29	0.064	0.1565
29	26	18.6	29	30	0.3978	0.1315
30	0	0	30	31	0.0702	0.0232
31	0	0	31	32	0.351	0.116
32	0	0	32	33	0.839	0.2816
33	14	10	33	34	1.708	0.5646
34	19.5	14	34	35	1.474	0.4873
35	6	4	3	36	0.0044	0.0108
36	26	18.55	36	37	0.064	0.1565
37	26	18.55	37	38	0.1053	0.123
38	0	0	38	39	0.0304	0.0355
39	24	17	39	40	0.0018	0.0021
40	24	17	40	41	0.7283	0.8509
41	1.2	1	41	42	0.31	0.3623
42	0	0	42	43	0.041	0.0478
43	6	4.3	43	44	0.0092	0.0116
44	0	0	44	45	0.1089	0.1373
45	39.22	26.3	45	46	0.0009	0.0012
46	39.22	26.3	4	47	0.0034	0.0084
47	0	0	47	48	0.0851	0.2083
48	79	56.4	48	49	0.2898	0.7091
49	384.7	274.5	49	50	0.0822	0.2011
50	384.7	274.5	8	51	0.0928	0.0473
51	40.5	28.3	51	52	0.3319	0.1114
52	3.6	2.7	9	53	0.174	0.0886
53	4.35	3.5	53	54	0.203	0.1034
54	26.4	19	54	55	0.2842	0.1447
55	24	17.2	55	56	0.2813	0.1433
56	0	0	56	57	1.59	0.5337
57	0	0	57	58	0.7837	0.263
58	0	0	58	59	0.3042	0.1006
59	100	72	59	60	0.3861	0.1172
60	0	0	60	61	0.5075	0.2585
61	1244	888	61	62	0.0974	0.0496

62	32	23	62	63	0.145	0.0738
63	0	0	63	64	0.7105	0.3619
64	227	162	64	65	1.041	0.5302
65	59	42	11	66	0.2012	0.0611
66	18	13	66	67	0.0047	0.0014
67	18	13	12	68	0.7394	0.2444
68	28	20	68	69	0.0047	0.0016
69	28	20				

Table A. 2

The Bus and Line data of BRDN network.

Bus Data			**Line Data**			
Bus	P load [kW]	Q Load [kVAr]	From (Bus)	To (Bus)	R [Ω]	X [Ω]
1	0	0	1	2	0.00693	0.01155
2	0	0	2	3	0.00459	0.00595
3	0	0	3	4	0.01296	0.0168
4	225	108.9725	4	5	0.0351	0.0455
5	90	43.58899	5	6	0.01404	0.0182
6	0	0	6	7	0.00495	0.00385
7	0	0	7	8	0.01344	0.0168
8	0	0	8	9	0.06705	0.05215
9	0	0	9	10	0.00108	0.0014
10	0	0	10	11	0.00486	0.0063
11	225	108.9725	11	12	0.10665	0.13825
12	0	0	12	13	0.00729	0.00945
13	0	0	13	14	0.01188	0.0154
14	0	0	14	15	0.03591	0.04655
15	225	108.9725	15	16	0.01026	0.0133
16	0	0	16	17	0.01755	0.02275
17	0	0	17	18	0.0126	0.0098
18	0	0	18	19	0.0351	0.0273
19	0	0	19	20	0.09765	0.07595
20	0	0	20	21	0.0468	0.0364
21	0	0	21	22	0.00855	0.00665
22	0	0	22	23	0.0072	0.0056
23	0	0	23	24	0.01316	0.01645
24	0	0	24	25	0.01064	0.0133
25	0	0	25	26	0.00189	0.00315
26	225	108.9725	26	27	0.00588	0.00735
27	0	0	27	28	0.03612	0.04515
28	0	0	28	29	0.01155	0.01925
29	0	0	29	30	0.0168	0.021
30	0	0	30	31	0.01029	0.01715
31	0	0	31	32	0.01148	0.01435

32	0	0	32	33	0.01131	0.01015
33	0	0	33	34	0.03136	0.0392
34	0	0	34	35	0.00952	0.0119
35	225	108.9725	35	36	0.00546	0.0091
36	225	108.9725	36	37	0.02436	0.03045
37	0	0	37	38	0.0108	0.0084
38	0	0	38	39	0.04508	0.05635
39	225	108.9725	39	40	0.02128	0.0266
40	0	0	40	41	0.07095	0.07525
41	225	108.9725	41	42	0.02541	0.02695
42	0	0	42	43	0.01551	0.01645
43	360	174.356	43	44	0.01386	0.0147
44	360	174.356	44	45	0.02409	0.02555
45	225	108.9725	45	46	0.03762	0.0399
46	225	108.9725	46	47	0.01782	0.0189
47	0	0	47	48	0.0045	0.0035
48	360	174.356	5	49	0.00741	0.00665
49	360	174.356	5	50	0.00621	0.00805
50	0	0	50	51	0.00594	0.0077
51	225	108.9725	6	52	0.06808	0.01295
52	0	0	52	53	0.046	0.00875
53	225	108.9725	53	54	0.01485	0.01155
54	0	0	8	55	0.01482	0.0133
55	0	0	55	56	0.06669	0.05985
56	0	0	14	57	0.00486	0.0063
57	0	0	57	58	0.02772	0.0294
58	225	108.9725	57	59	0.0099	0.0077
59	0	0	59	60	0.00864	0.0112
60	0	0	16	61	0.0126	0.0098
61	360	174.356	61	62	0.0171	0.0133
62	0	0	17	63	0.02268	0.0294
63	225	108.9725	19	64	0.01485	0.01155
64	0	0	64	65	0.01258	0.00595
65	900	435.8899	20	66	0.01215	0.00945
66	0	0	66	67	0.00594	0.0077
67	0	0	23	68	0.00294	0.0049
68	225	108.9725	24	69	0.01008	0.0126
69	225	108.9725	25	70	0.01755	0.01575
70	0	0	70	71	0.02324	0.02905
71	0	0	71	72	0.04347	0.05635
72	225	108.9725	72	73	0.01485	0.01925
73	360	174.356	73	74	0.00594	0.0077
74	0	0	74	75	0.00891	0.01155
75	0	0	75	76	0.00308	0.00385
76	225	108.9725	28	77	0.00609	0.01015

77	225	108.9725	30	78	0.00693	0.01155
78	225	108.9725	32	79	0.03976	0.0497
79	567	274.6106	79	80	0.00616	0.0077
80	0	0	80	81	0.00273	0.00455
81	0	0	81	82	0.01848	0.0231
82	0	0	33	83	0.01482	0.0133
83	0	0	83	84	0.00962	0.00455
84	90	43.58899	33	85	0.01242	0.0161
85	0	0	85	86	0.00504	0.0084
86	225	108.9725	85	87	0.00972	0.0126
87	0	0	87	88	0.00567	0.00945
88	225	108.9725	87	89	0.00297	0.00385
89	360	174.356	89	90	0.03348	0.0434
90	0	0	90	91	0.00399	0.00665
91	225	108.9725	91	92	0.01998	0.0259
92	0	0	92	93	0.00231	0.00385
93	225	108.9725	92	94	0.00729	0.00945
94	0	0	94	95	0.00294	0.0049
95	0	0	95	96	0.00252	0.0042
96	225	108.9725	96	97	0.00225	0.00175
97	0	0	97	98	0.00336	0.0056
98	225	108.9725	34	99	0.01782	0.0189
99	225	108.9725	40	100	0.04095	0.03185
100	225	108.9725				