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Optimal distributed generator placement for loss reduction using fuzzy and adaptive grey wolf algorithm

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ABSTRACT

This research provides a new methodology for locating distributed generation (DG) units in distribution electrical networks utilizing the fuzzy and adaptive grey wolf optimization algorithm (AGWOA) to decrease power losses and enhance the voltage profile. Everyday living relies heavily on electrical energy. The promotion of generating electrical power from renewable energy sources such as wind, tidal wave, and solar energy has arisen due to the significant value placed on all prospective energy sources capable of producing it. There has been substantial research on integrating distributed generation into the electricity system due to the growing interest in renewable sources in recent years. The primary reason for adding distributed generation sources for the network is to supply a net quantity of power, lowering power losses. Determining the amount and location of local generation is crucial for reducing the line losses of power systems. Numerous studies have been conducted to determine the best location for distributed generation. In this study, DG unit placement is determined using a fuzzy technique. In contrast, photovoltaic (PV) and capacitor placement and size are determined simultaneously using an adaptive grey wolf technique based on the cunning behavior of wolves. The proposed method is developed using the MATLAB programming language; the results are then provided after testing on test systems with 33-bus and 15-bus.

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1. INTRODUCTION

Small-scale generation situated at or close to the load centers is referred to as "distributed generation" [1]. In the evolving landscape of power systems, distributed generation (DG) has emerged as a significant component in enhancing the reliability, efficiency, and sustainability of electricity networks. DG involves the placement of small-scale power generation units close to the load centers, providing numerous benefits including loss reduction, voltage improvement, and deferral of system upgrades. However, the optimal placement and sizing of these generators are crucial to maximize their potential benefits. Distributed energy, decentralized energy, embedded energy, on-site generation, scattered generation, and dispersed energy have all been other names.

There are numerous small-scale power generation methods used for distributed generation. Regardless of whether these technologies are linked to the electrical network, to increase the effectiveness of the electricity distribution network [2], [3], a diverse array of compact, modular power generation technologies are referred to as "distributed energy resources" (DER). These technologies can be employed in conjunction with energy storage and management systems. Because power is generated relatively close point to the load, occasionally even inside the same case, dispersed generation is a technique that lowers the value of power lost in electricity transmission. Additionally, fewer and smaller electrical cables need to be built. DG unit placement has been the subject of extensive investigation.

The goal of the DG location challenge is to choose the positions and dimensions of the DGs to reduce power loss. Even though optimal DG placement has been the subject of a sizable amount of study [4]-[14], more acceptable and efficient solutions still need to be developed. There are practical solutions to the optimal DG placement challenge. Their effectiveness is entirely dependent on how well the data is collected. The use of a fuzzy technique corrects any data that lacks uncertainty. The advantage of the fuzzy-approach is that it may reflect engineering decisions and incorporate heuristics into the problem of optimal DG placement. It is simple to assess the results of a fuzzy technique to find the best DG placements. The appropriate DG sizes can be obtained more effectively using the global optimization method. One of the newest metaheuristic techniques in all technical domains is the grey wolf algorithm (GWA) [15]-[17]. The fuzzy technique developed by Prasad *et al*. [10] and Raharjo *et al*. [11] is employed in the first stage to determine the best DG locations. The adaptive grey wolf algorithm (AGWA) is utilized in the second stage to choose the ideal DG sizes [18]. The results of testing the suggested strategy on test systems with 15 and 33 buses are reported.

2. PROBLEM FORMULATION

The entire active power-loss (P_L) in a distribution network having 'n' number of lines is given by (1).

$$P_L = \sum_{i=1}^{n} I_i^2 R_i \tag{1}$$

Here, 'I_i' denotes the size of the i^{th} line current, and 'R_i' denotes its resistance, respectively. The load flow solution can be used to determine the branch current. The actual component (I_a) and imaginary component are the two halves of the branch current (I_r). The loss connected to the reactive and active parts of branch currents is expressed as (2) and (3).

$$P_{La} = \sum_{i=1}^{n} I_{ai}^2 R_i \tag{2}$$

$$P_{Lr} = \sum_{i=1}^{n} I_{ri}^2 R_i \tag{3}$$

Because all active power must come from the sources of the root bus, the loss value 'P_La' considered with the real component of line currents cannot be decreased for one source radial line. The power loss 'P_{Lr}' related to the imaginary component of line currents can be reduced by locally supplying some of the reactive power demand. This study outlines a methodology that, by positioning the capacitors ideally, minimizes the loss caused by the reactive component of the branch current and, as a result, reduces the overall loss of the distribution system.

3. FUZZY APPROACH FOR IDENTIFICATION OF OPTIMAL DISTRIBUTED GENERATOR LOCATIONS

This work used the fuzzy technique suggested in [8], Gopi *et al.* [12] to choose appropriate places for DG installation. Two goals are considered when creating a fuzzy method for pinpointing the ideal siting for DGs. The two goals are to i) reduce actual power loss as much as possible and ii) keep the voltage within allowable ranges. Distribution system power loss indices and node voltages are modeled using fuzzy membership functions. Every node in the distribution network's suitability for DG placement is then evaluated using a fuzzy inference system (FIS) that has a set of criteria. The nodes with the highest suitability can accommodate DGs. The original system's load flow solution must be used in the first stage to determine the real and reactive power losses. Load flow solutions are once again necessary to reduce power loss by adjusting the entire reactive power load at each distribution system node. After that, the loss deductions are linearly normalized into a scale of (1–0), where the highest loss reduction has a value of 1, and the smallest loss deduction has a value of 0. To calculate the power-loss index value for the n^{th} node, utilize as (4).

$$\text{PLI(n)} = \frac{(Lossreduction\ (n) - Lossreduction\ (\text{min}))}{(Lossreduction\ (\text{max}) - Lossreduction\ (\text{min}))} \tag{4}$$

These nodal voltage indexes and the reduction in p.u. Power loss is the attribute of the fuzzy-inference system (FIS), which calculates which node is most suitable for adding capacitors. Two input variables and one output variable are used for this paper. Power-loss index (PLI) and per unit nodal voltage are the two input variables (V). DG suitability index is an output variable (DGSI). The range of the power loss index is 0 to 1, the per unit node voltage range is 1.1 to 0.9, and the scale of the DG suitability index is 0 to 1. For PLI, five membership roles have been chosen. LM, L, M, H, and HM are their names. According to Figure 1, each of the five membership functions is a triangle. For voltage, five membership functions have been chosen. LN, L, N, HN, and H are their names. According to Figure 2, these membership functions are triangular and trapezoidal. For DGSI, five membership roles have been chosen. H, HM, M, LM, and L are their names. The triangular shape of Figure 3 also represents these five membership functions.

A set of multiple-antecedent fuzzy rules has been developed to assess the suitability of DG deployment at a specific node. The voltage and power loss indices are the rules' inputs, and their result is whether the location of the DG is appropriate. Table 1 fuzzy decision matrix provides a summary of the laws. The dark area of the matrix contains the rule’s consequences. Based on the most excellent DG suitability index values, ideal DG locations are found.

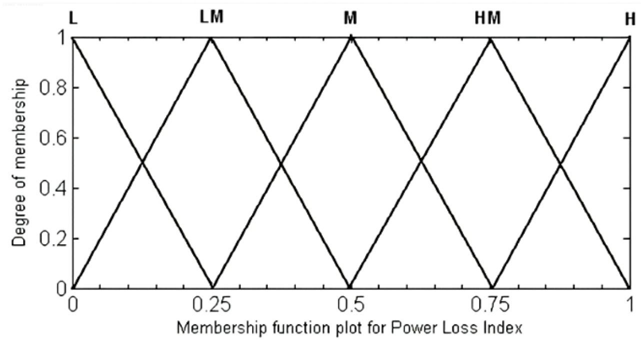

Figure 1. Plot of the PLI membership function

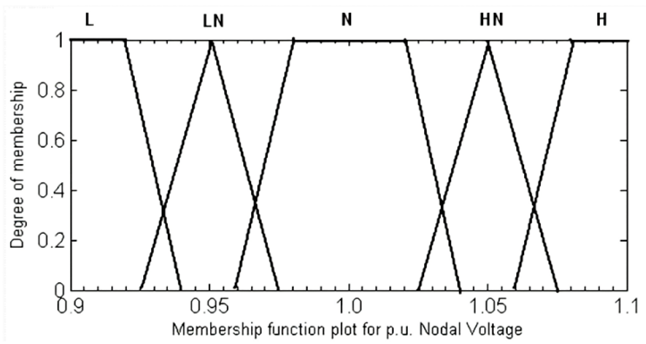

Figure 2. Plot of the p.u. nodal voltage membership function

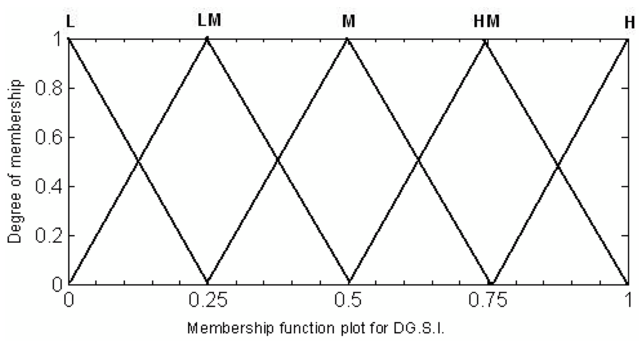

Figure 3. Plot of DGSI membership function

Table 1. Location-based decision-making matrix

DGSI		PLI				
		H	HM	M	LM	L
Voltage	H	LM	L	L	L	L
	HN	M	LM	LM	L	L
	N	M	M	LM	LM	L
	LN	HM	HM	M	LM	LM
	L	H	HM	HM	M	LM

4. ADAPTIVE GREY WOLF OPTIMIZATION ALGORITHM (AGWOA)

The grey wolf optimization (GWO) is a meta-heuristic algorithm developed by the researchers in [15]-[17] and is based on how grey wolves hunt in the wild. They are classified as alpha, beta, omega, and delta varieties of grey wolves in the social dominating hierarchy. The grey wolves form several groups for various tasks, such as staying together and searching for prey. Figure 4 depicts the grey wolf's life cycle and Figure 5 illustrates the hierarchy.

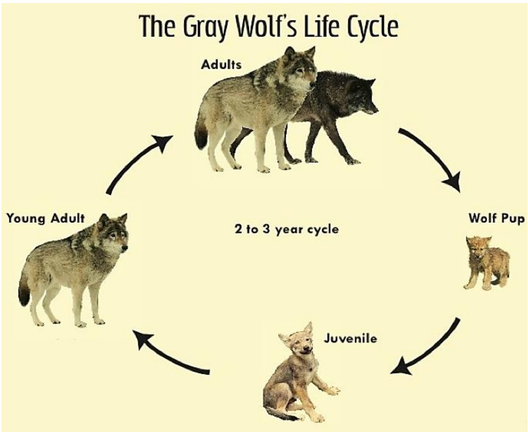

Figure 4. Life cycle of grey wolves

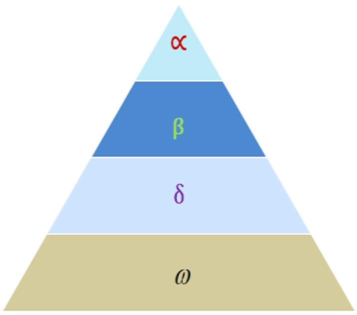

Figure 5. Hierarchical representation of grey wolves

Group hunting is another intriguing social characteristic of grey wolves, in addition to their social hierarchy. The following are the critical stages of grey wolf hunting, according to Mirjalili *et al.* [17]:

a. Seeking out prey: starting the search procedure off at random with potential solutions (also known as wolves) from the search space. grey wolves look for prey apart from one another before coming together when they do.
b. Surrounding prey: grey wolves circle their prey after searching for it, and this behavior can be mathematically described by (5) and (6).

$$\vec{E} = \left|\vec{O}.\vec{X}_p(k\,k) - \vec{X}(k\,k)\right| \quad (5)$$

$$\overrightarrow{X}\,(k\,k+1) = \overrightarrow{X\,p}\,(k\,k) - \vec{B}.\overrightarrow{E} \quad (6)$$

In this case, the coefficient vectors denote the current iteration. They are employed to keep searchers' grey wolves (GW) away from their prey. Depicts impediments in the prey's path during a hunt [18]. Here, the location vector of the grey wolf is shown by ‘X’ while the location array of its prey is shown by ‘Xp.’ The arrays are calculated in the manner specified in (7) and (9).

$$\overrightarrow{B} = 2 \times \vec{l} \times \vec{r}_1 - \vec{l} \tag{7}$$

$$\vec{O} = 2 \times \vec{r}_2 \tag{8}$$

c. Hunting the prey: grey wolves circle their prey and then focus on hunting. Types of wolves typically direct the hunts. Delivers the best potential answer out of those listed. The grey wolf's hunting habit formula is (7)-(15).

$$E_\alpha = \left|\left(\vec{O}_1 * \vec{X}_\alpha(kk)\right) - \vec{X}(kk)\right| \tag{9}$$

$$E_\beta = \left|\left(\vec{O}_2 * \vec{X}_\beta(kk)\right) - \vec{X}(kk)\right| \tag{10}$$

$$E_\omega = \left|\left(\vec{O}_3 * \vec{X}_\omega(kk)\right) - \vec{X}(kk)\right| \tag{11}$$

$$\vec{X}_1 = \vec{X}_\alpha(kk) - \left(\vec{B}_1 * \vec{E}_\alpha\right) \tag{12}$$

$$\vec{X}_2 = \vec{X}_\beta(kk) - \left(\vec{B}_2 * \vec{E}_\beta\right) \tag{13}$$

$$\vec{X}_3 = \vec{X}_\omega(kk) - \left(\vec{B}_3 * \vec{E}_\omega\right) \tag{14}$$

$$\overrightarrow{X}(kk+1) = \frac{(\vec{X}_1 + \vec{X}_2 + \vec{X}_3)}{3} \tag{15}$$

d. Attacking prey: grey wolves attack their prey once the hunt is over. The GWO procedure enables the wolves to modify their locations to hit the prey based on the place of the group of grey wolves. There are two factors to take into account when approaching the prey.

4.1. AGWOA implementation to address the issue of power loss minimization

The steps the AGWOA adopted to alleviate this study's power loss minimization problem are listed below [19]-[27]. In this adapted, the mutation process to conventional GWO algorithm for exploring new solutions, and avoiding local optima, thereby enhancing the overall effectiveness of the search process. AGWO algorithm implementation procedures for power loss minimization issues:

- Step 1: Initialization.
  a) Read the B coefficient, the cost coefficient, and the emission coefficients.
  b) Set each generator's output power limits.
  c) Maximum values of search variables are predetermined.
  d) The lower and upper search space restrictions in the GWO settings.
- Step 2: Place the initial fitness values' placements at random.

```
Alphaa_post=zeros(dim,1)’;
Alphaa_scores=inf;
Betaa_post=zeros(dim,1)’;
Betaa_scores=inf;
Omegaa_post=zeros(dim,1)’;
Omegaa_scores=inf;
Position=rand(Search Agents_no.,dim.).*(u.b-l.b)+l.b;
```

- Step 3: Assign the time step tt=0.
- Step 4: Determine the objective function's starting locations. Set each alphaa to his current position from his previous best location.
- Step 5: Let tt=tt+1.
- Step 6: Determine the neighbor of every alphaa and then determine its goal function.
- Step 7: Update every alphaa prior finest location and the historical best position among the search agents.
- Step 8: Continue from Step 6 until the objective function's beat value is attained by setting the convergence error (0.0000001), not before completing the maximum number of iterations.
- Step 9: Find the best-generating powers to achieve the objective function's ideal value.

5. RESULTS

The best DG locations are discovered using a fuzzy technique, and the best DG positions and sizes are found using AGWOA and it is continuous optimization problem. The suggested method is used with 15-bus and 33-bus model networks using MATLAB software, and the solutions are listed in Tables 2 and 3 accordingly.

5.1. The 15 and 33-bus system's results

The results show that the AGWOA optimized the DG values to obtain least losses, an improved voltage profile compared with the referred algorithm. In the 15-bus system the proposed algorithm reduced loss to 2.574 from intact case loss 61.74 and Naked mole rat algorithm 4.668. In 33-bus system the proposed algorithm reduced loss to 39.44 from intact case loss 210.99 and Naked mole rat algorithm 61.43, at the same time improved voltage profiles also.

Table 2. Sizes of the DG units at the proposed bus positions for the 15-bus network

Type of algorithm	Optimal DG		Least bus voltage (pu)		Complete power losses (kW)		
	Bus no.	DG size (MVA)	Before DGs	After DGs	Before DGs	After DGs	% reduction in power losses
Naked Mole Rat	4 6 11	0.670 0.561 0.414	0.945	0.994	61.734	2.574	95.83
Naked Mole Rat [12]	3 6 11	0.768 0.545 0.365	0.945	0.992	61.734	4.668	92.42

Table 3. Sizes of the DG units at the proposed bus stops for the 33-bus system

Type of algorithm	Optimal DG		Least bus voltage (pu)		Complete power losses (kW)		
	Bus no.	DG size (MVA)	Before DGs	After DGs	Before DGs	After DGs	% reduction in power losses
AGWOA	6 28 29 30	1.7785 0.0891 0.0674 1.7235	0.879	0.972	210.99	39.44	81.305
Naked Mole Rat [12]	6 28 29	1.844 0.093 0.107	0.879	0.966	210.99	61.43	70.88

6. CONCLUSION

This study introduces a dual-phase procedure for calculating the ideal DG sizes and locations for loss reduction in distribution systems. Adaptive grey wolf algorithm and fuzzy technique are proposed to choose the best PV and capacitor sizes and placements, respectively. These inferences are made in light of the simulation results: the complete active power loss of the network has been dramatically decreased by installing DG at all the ideal places, and bus voltages have improved significantly. They are considering the DGSI value the fuzzy technique, which can determine the best DG positions. The ideal sites and DG sizes are sought after iteratively by the suggested grey wolf algorithm.

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