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Optimal Placement and sizing of DG Units Using LCA Algorithm

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Abstract

The motivation of this paper is to present an approach that relies on the league championship algorithm (LCA) to determine the most effective number, placement, and size of distributed generations (DG) within distribution systems. The primary objective of this approach is to minimize the losses of the power system, as well as to enhance the voltage profiles and stability index of the voltage. The optimal location of the DG units (solar PV) is determined through the use of the Loss Sensitivity Factor (LSF), while the optimal size of the DG units is found through the use of LCA. The IEEE 33-bus and 69-bus radial distribution systems were both tested to validate the proposed method, and the results obtained from LCA were compared to those of other methods found in the literature. The simulated results have shown that the LCA method proposed in this paper is highly effective and performs exceptionally well when addressing the problem of optimal location and sizing of DG units in radial networks.

Keywords: Distributed generation (DG); League championship algorithm (LCA); Radial distribution network (RDS).

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1. Introduction

Distributed generation (DG) systems are becoming increasingly important due to the rising demand for electricity. DG systems are small-scale power generators, typically ranging from 1 kW to 50 MW, that use renewable energy sources like solar and wind power[2] and [3].
Radial distribution networks, which are commonly used in low and medium-voltage networks, have a very high resistance-to-reactance ratio (R/X ratio). Traditional power flow techniques such as Gauss-Seidel (GS), Newton-Raphson (NR), and Fast Decoupled Load Flow (FDLF) are not operative in this scenario and most of time fails to converge. Therefore, alternative algorithms have been proposed to address this issue. The Backward Forward Sweep (BFS) approach is the most widely used algorithm [4] and [5].

Researchers worldwide are paying more attention to the use of DG units in radial distribution networks because they can minimise power losses, improve voltage stability, save money, and use renewable energy in a cost-effective way [6]. Different methods have been developed to find the best location and size for DG units, using both classical and meta-heuristic algorithms. One of the most popular methods, called the analytical method, was introduced in [7].Suggested using a Grid Search Algorithm (GSA) to minimize overall power losses. Other authors have proposed meta-heuristic approaches like Particle Swarm Optimization (PSO), Modified PSO (MPSO), and Artificial Bee Colony (ABC) [8] and [9].
DG placement and sizing were determined using the MOOP method known as WSM [10,11,12,13,14], which offers several advantages in real-world applications, including computational ease. However, a drawback of these methods is that the weighting variables have a cumulative impact on the answer. To address this, multi-objective evolutionary approaches [15] and [16] were

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employed to solve optimization problems in power systems, as they have the capability to look at the global optimum. Nevertheless, the difficulty of these approaches has prompted researchers to seek a more straightforward method to expedite convergence.

In this study, the League Championship Algorithm (LCA), a powerful optimization method, was utilized to define the optimal location and size of DG units in radial distribution systems. The effectiveness of the suggested method was demonstrated through testing on various real networks, including the 33-bus and 69-bus test systems. The results were then compared to recently published articles.

This study used the proposed LCA algorithm to calculate the optimal size of DG units in distribution systems. The voltage stability index was used as the objective function to find the best location and size for the DG units. Once the optimal-sized DG units were placed in the best location, various system performance metrics were calculated, such as minimizing real power loss, improving the voltage profile, and enhancing the voltage stability index. The LCA algorithm's results were compared to those of the HSA, TLBO, and SOS algorithms after performing calculations on two test systems: the IEEE 33-bus and the 69-bus radial distribution systems.

2. Loss sensitivity factor

Based on LSF, DG installation locations can be discovered [17 The benefit of utilizing this approach is that it narrows the problem search space during optimization.

Fig. 1 depicts an illustration of a two-bus distribution system. The following calculation can be used to calculate the LSF at the line segment between buses i and k:

$$P_{ik-loss} = \frac{(P_k^2 + Q_k^2)R_{ik}}{(V_k)^2} \quad (1)$$

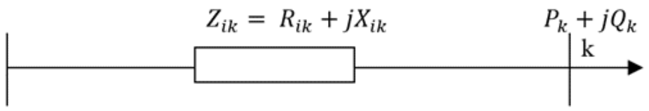

Figure 1. A two bus system one line diagrams [17]

3. Objective function

The suggested objective function minimizes power losses, enhances voltage profiles, and increases the Voltage Stability Index. It can be solved to obtain the optimal DG locations and sizes.

$$F_t = w_1 f_1 + w_2 f_2 + w_3 f_3 \quad (2)$$

Where f_1 can be expressed as shown in the following equation:

$$f_1 = \frac{\sum_{i=1}^{L}\left(P_{Lineloss}(i)\right)_{after\ DG}}{\sum_{i=1}^{L}\left(P_{Lineloss}(i)\right)_{before\ DG}} \quad (3)$$

f_2 can be defined as the following equation:

$$f_2 = \frac{\sum_{i=1}^{N}\left|V_i - V_{i,ref}\right|_{after\ DG}}{\sum_{i=1}^{N}\left|V_i - V_{i,ref}\right|_{before\ DG}} \quad (4)$$

f_3 can be defined as:

$$f_3 = \frac{1}{VSI(k)_{after\ DG}} \quad (5)$$

Where VSI is formulated as the following Eq:

$$VSI(k) = |V_i|^4 - 4(P_k X_{ik} - Q_k R_{ik})^2 - 4(P_k R_{ik} - Q_k X_{ik})|V_i|^2 \quad (6)$$

$|w_1| + |w_2| + |w_3| = 1$ in this paper, w_1 is taken as 0.5 while w_2 as 0.25 and w_3 as 0.25.

3.1. Constraints

3.1.1 Load balancing constraints

The constraints for each bus are expressed as follows:

$$Pgni - Pdni - Vni \sum_{j=1}^{N} V_{nj} Y_{nj} \cos\left(\delta_{ni} - \delta_{nj} - \theta_{nj}\right) = 0 \quad (7)$$

$$Qgni - Qdni - Vni \sum_{j=1}^{N} V_{nj} Y_{nj} \sin\left(\delta_{ni} - \delta_{nj} - \theta_{nj}\right) = 0 \quad (8)$$

Where $n_i = 1, 2, 3, \ldots, n_n$.

3.1.2. Voltage constraints

The considered range for the voltage of the buses is as follows:

$$V_{min} \leq V_{ni} \leq V_{max} \quad (9)$$

Where V_{min} is the minimum voltage at bus n_i, V_{max} is the maximum voltage at bus n_i.

3.1.3. DG Constraints

The DG source that is utilized must conform to the permissible size and power factor within the specified range:

$$S_{min}^{DG} \le S_{NI}^{DG} \le S_{max}^{DG} \quad (10)$$

Where S_{min}^{DG} is minimum apparent power at bus n_i,$S_{max}^{DG}$is maximum apparent power at bus n_i and S_{NI}^{DG} is the apparent power at bus n_i.

4. League championship algorithm (LCA)

4.1. Overview

Husseinzadeh Kashan [7] First proposed the LCA technique, a new metaheuristic approach for resolving continuous optimization issues [12]. Like other algorithms inspired by nature, LCA uses a population of solutions to develop to the best one. Each club in the league (each person in the population) stands for a workable solution to the issue at hand. These groups compete for several weeks (iterations) in a made-up league. Teams compete in pairs (i.e., team i plays versus team j) according to the league schedule each week, and the result is decided by each team's playing ability (equivalent to its fitness value) as a result of a certain team composition (solution). The tournament continues for a number of seasons (stopping criterion), and during the recovery period, each team designs the necessary alterations to its formation to set up a new configuration (a new solution is developed) for the next week's game.

4.2. LCA Algorithm

LCA is an evolutionary algorithm that operates on a population of individuals. It begins by creating a league of L teams, where L is the league size. Each team consists of n players, corresponding to the number of variables in the function being optimized. The playing strengths of the teams are evaluated during initialization. Teams with the highest scores are selected to form effective formations.

The next phase is a competition where teams compete against each other in pairs for S x (L - 1) weeks, where S is the number of seasons and t is the week. The outcome of each match is determined solely by the performance of each team, and the winning team is the team with the better performance.

Following the competition phase, the recovery phase begins. In this phase, each team devises a new formation based on successful strategies employed in the previous week and the current configuration of the team. The selection process in LCA is characterized by its voracity, ensuring that the current squad achieves the most optimal formation. This selection process takes into account the superior playing ability of the team members and aims to create a more efficient team structure. In other words, the new formation is considered the most suitable option for the team if it proves to be the best response discovered thus far for a specific member of the population.

The algorithm concludes once the halting criteria are met, indicating that the desired outcome has been achieved.

Algorithm: The League championship algorithm [26]

1. To begin, set the league size (L) and the number of seasons (S). Additionally, assign the value of t = 1;
2. create a league schedule;
3. Afterwards, generate a population of L solutions to initialize team formations. Determine the playing strengths of each team by evaluating their function or fitness value. It is important to note that the initialization of team formations should also serve as their current best formation;
4. While t is less than or equal to S multiplied by (L - 1), or there has been no change in the last 100 iterations.
5. Identify the victor and loser of each team pairing at week t, utilize a playing strength-based criterion based on the league schedule.
6. t = t + 1;
7. For i = 1 to L
8. Create a new formation for team I for the upcoming game, keeping in mind the team's best formation at the moment and the events of the previous week. Analyze the resulting arrangement's playing strength;
9. View the new formation as the team's current top arrangement if it is determined to be the most fitting one (i.e., the most excellent solution thus far for the ith member of the population);
10. End for
11. If mod (t,L - 1) = 0
12. Generate a league schedule;
13. End if
14. End while.

5. Results and Analysis of Numerical Data

The LCA algorithm under consideration is tested on both the IEEE 33 bus and 69 bus radial distribution systems. To assess its efficacy, it is pitted against the TLBO, HSA, and SOS algorithms. MATLAB software is employed to implement the LCA algorithm and identify the most optimal size and placement of DG within the distribution network.

5.1. The IEEE 33-bus radial distribution network

The testing configuration described in [30] comprises a network with 33 buses and 32 branches. The total active and reactive power loads for the system amount to 3.716 MW and 2.300 MVAr, respectively. The DG units have varying power outputs, with the largest at 3.4952 MVA and the smallest at 0.2 MVA. The system's DG penetration cap is fixed at 4.359 MVA, and the base voltage is established at 12.65 kV.

Power flow calculations show that the system has active and reactive power dissipation of 210.1 kW and 143.14 kVAr, respectively. Based on LSF factors, potential buses for DG placement have been identified. Table 1 shows the LSF values for each bus.

Table 1. LSF values for the 33-bus system

LSF	Bus No.	norm(i) = V (i)/0.95	Base Voltage
0.0173328	6	0.9994401	0.9494681
0.0139414	3	1.0346128	0.9828821
0.0138033	28	0.9826654	0.9335321
0.0103590	29	0.9740129	0.9253122
0.0103223	8	0.9813551	0.9322874
0.0080802	14	1.0188907	0.9679462
0.0080712	4	1.0267079	0.9753725
0.0060563	30	0.9702674	0.9217540
0.0047535	9	0.9746892	0.9259547
0.0047501	24	1.0238154	0.9726247
0.0045614	13	0.9595139	0.9115382
0.0045149	10	0.9685237	0.9200975
0.0037555	27	0.9947096	0.9449741
0.0030365	31	0.9658863	0.9175920
0.0028204	2	1.0494889	0.9970145
0.0027433	26	0.9974088	0.9475384
0.0026717	23	1.0308381	0.9792962
0.0023800	25	1.0203152	0.9692995
0.0022880	20	1.0451668	0.9929084
0.0013972	5	0.9571033	0.9092482
0.0013803	7	0.9957298	0.9459433
0.0013538	12	0.9660146	0.9177139
0.0011808	17	0.9519908	0.9043912
0.0009111	16	0.9541467	0.9064393
0.0008107	15	0.9556014	0.9078213
0.0007965	11	0.9676092	0.9192287
0.0006456	32	0.9649225	0.9166764
0.0004473	18	0.9513452	0.9037779
0.0004155	21	1.0444252	0.9922039
0.0003599	22	1.0437542	0.9915665
0.0003317	19	1.0489327	0.9964861
0.0002027	33	0.9646238	0.9163927

5.1.1. Predetermined number of DG units

The proposed solution has demonstrated its effectiveness in addressing the issue, particularly when dealing with a constrained number of DG units, specifically 1, 2, and 3, as illustrated in Table 2. A comparison of the obtained results from the suggested technique with those from established methods such as HSA [28] TLBO [29], and SOS [30] reveals that the proposed method performs better by identifying fewer total losses. The proposed LCA-based approach outperforms the SOS, HSA, and TLBO methods in reducing system power losses for the 33-bus test system. For a single fixed DG unit, the suggested approach achieves a system total loss of 109.07 kW, compared to 115.01 kW for the SOS method, 107.39 kW for the HSA method, and 124.695 kW for the TLBO method. For two fixed DG units, the suggested approach achieves a system total loss of 103.91 kW, compared to 107.39 kW for the HSA method. For three fixed DG units, the proposed approach achieves a system total loss of 101.13 kW, compared to 104.26 kW for the SOS method, 135.69 kW for the HSA method, and 124.695 kW for the TLBO method.

Table 2. Results comparison of the 33-bus system with predetermined number of DG units [28][29][30].

Method	Number of DG Units	Optimal result DG size in MW (location)			Loss (kW)
		DG1	DG2	DG3	
HSA	1	0.8491 (18)	-	-	144.23
	2	0.2012 (18)	0.6932 (17)	-	141.14
	3	0.1913 (18)	0.2133 (17)	0.5927 (16)	135.69
TLBO	1				
	2				
	3	1.1826 (12)	1.1913 (28)	1.1863 (30)	124.695
SOS	1	3.1322 (6)	-	-	115.01
	2	2.2861 (6)	0.8363 (28)	-	107.39
	3	2.2066 (6)	0.2 (28)	0.7167 (29)	104.26
LCA	1	2.0265 (14)	-	-	109.07
	2	1.1681 (14)	0.7232 (24)	-	103.91
	3	0..8523 (14)	0.1129 (24)	0.9012 (29)	101.13

5.1.2. Optimal Number of DG Units

To ascertain the optimal number of DG units for the system, various configurations were tested by installing diverse numbers of DG units, and their impact on active power loss was calculated. Through this analysis, it was determined that the ideal number of DG units could be identified by solving the problem iteratively, with each solution matching to a specific number of DG units. The evaluation spanned a range of DG unit counts, from 1 to 21. The amount of DG units leading to the minimal power loss was considered the most appropriate choice for the system.

After conducting the tests, it was determined that the minimum active power loss of 74.359 kW occurs when the number of DG units is set at 12. This result is consistent with the active power loss values observed across different DG unit counts. Therefore, it can be concluded that 12 DG units represent the optimal configuration for the 33-bus system, resulting in a total active power loss of 74.359 kW.

Table 3 presents the outcomes of employing the SOS and LCA methods to identify the optimal number of DG units. While the LCA method yields slightly lower power losses compared to the SOS method, both approaches converge on the same optimal number of DG units. The proposed LCA-based method proves highly effective in pinpointing the appropriate location, size, and quantity of DG units for the IEEE 33-bus radial distribution system.

Table 3. Results for the 33-bus system with 12 DG units obtained using both the SOS and LCA methods.

Power loss (KW)		Total DG Power Output (MW)	
SOS	LCA	SOS	LCA
76.967104	74.359012	2.509000089	2.50853254

Figure 2 illustrates the voltage profile curves after installing the optimal number of DG units using the SOS and LCA technics. The figure suggests that both approaches might have an identical impact on voltage profiles.

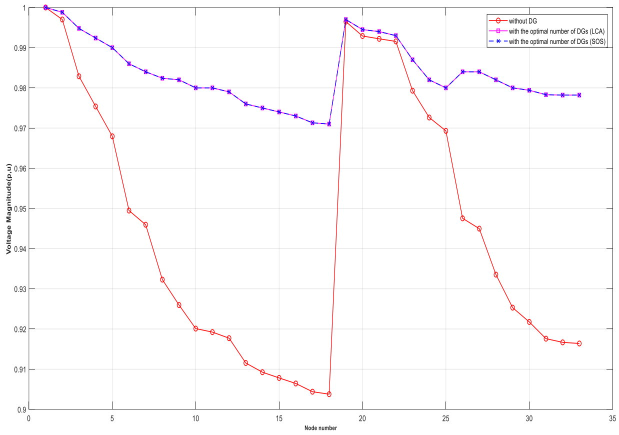

Figure 2. Voltage profile of the 33-bus system with optimal number of distributed generators (DGs).

5.2. The IEEE 69-bus radial distribution network

The next test system, described in [30] study, is a radial distribution network with 69 buses. It exhibits a total load demand of 3.81 MW and 2.70 MVAr. The system incurs active power losses of 225 kW and reactive power losses of 102.16 kVAr. Distributed generation (DG) units within this system generate power ranging from 0.2 MVA to 3.7248 MVA. The base voltage for the system is 12.66 kV, and the DG penetration limit is set at 4.656 MVA

5.2.1. Predetermined number of DG units

The issue regarding the number of DG units in the scenario where the amount of DG units is predetermined has been successfully resolved using the suggested approach. A comparison between the outcomes of the suggested technique and existing methods, such as HSA [30], TLBO [30], and SOS [30], has been presented in Table 4. The table clearly demonstrates that the proposed method is capable of achieving a reduced overall power loss when compared to the existing methods.

The proposed method outperforms the HSA, TLBO, and SOS methods in reducing system power losses for all cases with different numbers of DG units. For a single DG unit, the proposed method achieves a total power loss of 110.12 kW, compared to 112.1 kW for the HSA method and 118.62 kW for the SOS method. For two DG units, the suggested method achieves a total power loss of 94.87 kW, compared to 96.56 kW for the HSA method and 102.92 kW for the SOS method. For three DG units, the suggested method accomplishes a total power loss of 82.07 kW, compared to 86.66 kW for the HSA method, 82.172 kW for the TLBO method, and 82.07 kW for the SOS method.

In conclusion, the proposed LCA-based method offers a solution for determining the optimal position, size, and quantity of DG units for the IEEE 69-bus radial distribution system.

Table 4. Evaluating of results for the 69-bus system with Predetermined number of DG units [28][29][30].

Method	Number of DG Units	Optimal result			
		DG size in MW (location)			Loss (kW)
		DG1	DG2	DG3	
HSA	1	1.4363 (65)	-	-	112.10
	2	0.0544 (65)	1.5932 (64)	-	96.56
	3	0.0149 (65)	0.1416 (64)	1.6283 (63)	86.66
TLBO	1			-	
	2			-	
	3	0.9925 (17)	1.1998 (61)	0.7956 (63)	83.2
SOS	1	2.087 (57)	-	-	118.62
	2	0.3612 (57)	1.6948 (58)	-	102.92
	3	0.2588 (57)	0.2 (58)	1.5247 (61)	82.07
LCA	1	2.172 (11)	-	-	110.12
	2	0.3321 (11)	1.7284 (57)	-	94.87

3	0.2061 (11)	0.1962 (57)	1.2741 (61)	81.74

5.2.2. Optimal Number of DG Units

The suggested technique was tested to determine the impact of different DG unit counts on active power losses and total power losses. The results showed that the smallest active power loss of 71.444166 kW was achieved when there were 8 DG units among the tested values.
Table 5 illustrates the contrast between the proposed method and the SOS method in establishing the optimal number of DG units. The application of the LCA technique to the system with the ideal number of DG units yielded a reduced total power loss in comparison to the SOS method. Specifically, the active power losses calculated by the LCA and SOS techniques using the ideal number of DG units were 71.372133 kW and 71.444166 kW, respectively.

Table 5. Results comparison for the 69-bus system with 8 distributed generation (DG) units

Power loss (KW)		Total DG Power Output (MW)	
SOS	LCA	SOS	LCA
71.444166	71.444166	2.437403138	2.393254123

Figure 3 displays the voltage profiles of the system's buses following the installation of the optimal number of DG units determined by the SOS and LCA methods. Both techniques markedly enhance the voltage levels at the buses, with nearly identical improvements resulting from both SOS and LCA methods.

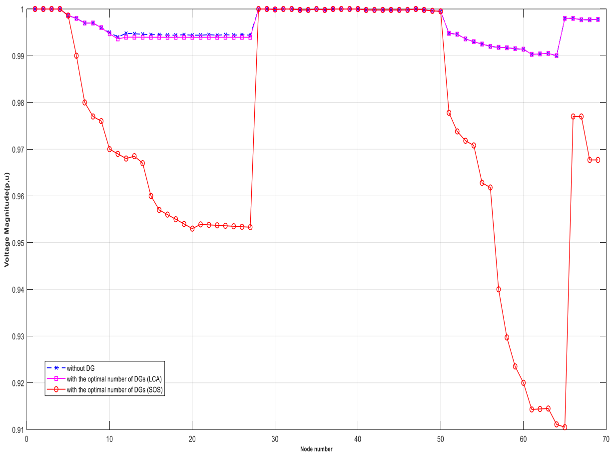

Figure 3. The voltage profile of the 69-bus system with the optimal number of distributed generation (DG) units installed.

6. Conclusion

In this study, a novel approach based on Life Cycle Assessment (LCA) has been successfully applied to tackle the challenge of determining the optimal of distributed generators location within distribution networks. This research specifically focuses on addressing the complexities associated with selecting the appropriate position, size, and quantity of DG units in radial distribution systems. The methodology involves the use of a loss sensitivity factor to prioritize potential DG unit locations and the application of the LCA method to determine the optimal size of DG units for a predefined number of units. The configuration resulting in the lowest overall power loss is then identified as the optimal solution. To assess the effectiveness of this proposed method, it was rigorously tested on both the IEEE 33-bus and 69-bus radial distribution systems. The obtained results were meticulously compared with outcomes from other methods documented in existing literature. These comparative analyses clearly demonstrate the efficiency of the suggested LCA-based strategy in effectively addressing the challenge of determining the placement of dispersed generators within distribution networks.

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