Optimal placement and sizing of distributed generations in distribution systems for minimizing losses and THD v using evolutionary programming

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Optimal placement and sizing of distributed generations in distribution systems for minimizing losses and THD_v using evolutionary programming

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Abstract: Growing concerns over environmental impacts, improvement of the overall network conditions, and rebate programs offered by governments have led to an increase in the number of distributed generation (DG) units in commercial and domestic electric power production. However, a large number of DG units in a distribution system may sometimes contribute to high levels of harmonic distortion, even though the emission levels of the individual DG units comply with the harmonic standards. It is known that the nonoptimal size and nonoptimal placement of DG units may lead to high power losses, bad voltage profiles, and harmonic propagations. Therefore, this paper introduces a sensitivity analysis to determine the optimal location of DG units, as well as evolutionary programming and harmonic distribution load flow for determining the optimal size of DG units in radial distribution systems. A multiobjective function is created to minimize the total losses and average total harmonic distortion voltage (THD_v) of the distribution system. The proposed methodology is tested with a 69-bus radial distribution system. The proposed optimal placement and sizing of the DG units is found to be robust and provides higher efficiency for the improvement of the voltage profile and the minimization of the losses and THD_v.

Key words: Distributed generation, optimization, evolutionary programming, harmonic distortion, sensitivity analysis

1. Introduction

Many utility companies currently promote the interconnection of independent alternative energy sources in the utility grid. However, the insertion of distributed generation (DG) into the distribution system could either have a positive or negative impact, depending on the operating characteristics of the DG and the distribution network. DG can be beneficial if it meets the basic requirements of the system's operating philosophy and feeder design [1]. Some recent studies have examined the impact of DG on a system's power quality. It was found that the effect of DG on the power quality depends on the type of DG, its interfaces with the utility system, the size of the DG unit, the total capacity of the DG unit relative to the system, the size of the generation relative to a load at the interconnection point, and the feeder voltage regulation practice [2].

Having a DG unit connected to a distribution system may contribute to harmonic distortion in the system, depending on the type of DG unit and the power converter technology. In terms of the DG interfacing, DG units can be classified into 2 types, namely inverter-based DG and non-inverter-based DG [3]. Examples of inverter-based DG units are photovoltaic systems, wind turbine generators, fuel cells, and microturbines, which

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use power converters as interfacing devices to the grid. On the other hand, small hydro synchronous generators and induction generators are considered to be non-inverter-based DG units.

It is well known that DG units need to be installed at the distribution system level of the electric grid and located close to the load center. The impacts of the DG unit on power losses, voltage profile, short-circuit current, harmonic distortions, and power system reliability are usually tested separately before connecting it to the distribution system. The achievement of the benefits from DG units depends greatly on how optimally they are installed. Studies have indicated that approximately 13% of the generated power is consumed as a loss at the distribution level [4]. Another problem in the distribution system is the voltage profile, which tends to drop below acceptable operating limits along distribution feeders with increased loads. This arises due to the increasing electricity demand, which will require the upgrading of the distribution system infrastructure [5]. Therefore, to reduce the power losses and to improve both the voltage profile and the total harmonic distortion voltage (THD_v) reduction, appropriate planning must be carried out for incorporating DG into power systems. In this process, several factors need to be considered, such as the technology to be used, the number and the capacity of the units, the optimal location, and the type of network connection [5,6].

Currently, the problem of DG placement and sizing is rising in importance. The installation of DG units at nonoptimal places with nonoptimal sizing can cause higher power losses, power quality problems, instability of the system, and escalating operational costs [7,8]. Optimization approaches are capable of indicating the best solution for a given distribution network. There are several methods to allocate and size the DG unit in the distribution power system. The power flow algorithm [7,9] can be used to find the optimum DG unit size at each load bus by assuming that each load bus is able to have a DG unit. This method is inefficient due to the requirement of a large number of load flow computations. Another method for determining the location and size of DG units is the genetic algorithm (GA) method [10,11]. The GA is suitable for multiobjective problems such as DG unit allocation and gives very satisfactory solutions. However, the computational time for the GA is very long, with an extremely lengthy convergence time. Analytical methods can also be used to allocate the DG unit in radial or meshed systems [12]. In this method, separate expressions for radial and meshed network systems are required. Furthermore, complex procedures based on phasor current are used to solve the location problem; however, this method only optimizes the location by considering a fixed-size DG unit. For the same purpose, a combination of sensitivity analysis (SA) methods [4] and other heuristic algorithm methods are commonly used [4,13–16]. In these methods, the location of the DG unit is determined through SA and the sizing of the DG unit is determined through a heuristic algorithm method. The advantage of this method is the reduction of the search space, which eventually increases the overall speed of optimization processes.

Harmonic analysis methods are required to study the impact of DG units on harmonic propagations in the distribution system. A fast harmonic load flow method was introduced in [17,18] for a 3-phase radial distribution system in order to implement a harmonic analysis; this was more efficient and accurate compared to other conventional harmonic load flow algorithms.

The optimal placement and sizing of DG units using particle swarm optimization (PSO) and SA was also studied in [4]. There, the aim was to minimize the total cost of the system by reducing losses and THD and by improving the voltage profile. Another similar study was reported in [15]. In that study, the harmony search algorithm was used for solving the optimal placement and sizing of the DG unit. The objective function of this study was to improve the voltage profile and to minimize the loss and THD_v.

Similar to the work in [4,15,16], this paper proposes SA for determining the optimal location of the DG unit in a radial distribution system. In order to determine the optimal size of the DG unit, however, an evolutionary program integrated with harmonic distribution load flow (EP-HDLF) is proposed for the optimization. The proposed methodology is then tested in a 69-bus radial distribution system. The results show the efficiency of the proposed algorithm at minimizing the losses and THD$_v$, as well as improving the voltage profile.

2. Problem formulation

A multiobjective optimization technique, formulated as a constrained nonlinear integer optimization problem, is proposed for DG unit placement and sizing in a distribution system. The objective is to minimize the total power loss and THD$_v$, as well as improve the voltage profile of the distribution system. The fitness function is given by Eq. (1):

$$F_{\min} = \alpha(P_{loss}) + \beta(THD_v), \tag{1}$$

where F is the fitness function, P_{loss} is the total power loss, α is the weighted factor for the total power loss, THD_v is the average THD$_v$ at all of the system busbars, and β is the weighted factor for the THD$_v$.

The total real power loss is defined by:

$$P_{loss} = \sum\nolimits_{i=1}^{n} P_{loss_i} i = 1, 2, 3, ..., n, \tag{2}$$

where n is the number of lines. The average THD$_v$ is defined by:

$$THD_V = \frac{\sum_{i=1}^{m} THD_{Vi}}{m}, \tag{3}$$

where m is the number of buses.

The total power loss and THD$_v$ must be minimized according to the network power flow equations at fundamental and harmonic frequencies. Typical technical constraints, such as the maximum feeder capacity, short-circuit level, maximum allowable over voltage and voltage drops, and voltage harmonics, are to be complied with, as well. Generally, multiobjective methods provide a set of optimal solutions. For this paper, the sum of the weighted methods is used to decide the relative importance of the objectives in order to obtain the best optimization solution. The weighted factor for the total power loss is 0.7, while the average THD$_v$ is 0.3. The factor for the power loss is greater than that for the THD$_v$, because the reduction of the power loss in distribution networks has a significant impact on economic and technical prospects.

The inequality constraints involve those associated with the bus voltages and the DG unit to be installed. The bus voltage magnitudes are to be kept within acceptable operating limits throughout the optimization process, as follows:

$$V_{\min} \le |V_i| \le V_{\max}, \tag{4}$$

where V_{min} is the lower bound of bus voltage limit, V_{max} is the upper bound of the voltage limit, and $|V_i|$ is the root mean square value of the ith bus voltage.

The total harmonic level at each bus is to be less than or equal to the maximum allowable harmonic level, expressed as follows:

$$THD_{vi}(\%) \le THD_{v\max}, \tag{5}$$

where $THD_{v\max}$ is the maximum allowable level at each bus (5%).

3. Proposed algorithm

With the growing use of DG units in distribution systems, several methods have been used to achieve various objectives in power system optimization problems. In this paper, SA and EP are used to determine the optimal placement and sizing of DG units in a distribution system. Harmonic load flow analysis is integrated with this optimization technique in order to obtain the fitness functions for the total power loss, average THD_v, and voltage profile.

3.1. Sensitivity analysis

The SA method is used to find the most sensitive candidate for allocating the DG based on loss reduction. The advantage of this method is that it reduces the research space and increases the speed of the EP algorithm convergence. The theory behind this method is illustrated in Figure 1 [4].

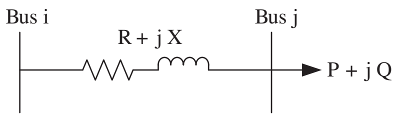

Figure 1. Connected line between bus i and bus j.

Figure 1 shows the line impedance of $R + jX$ between buses i and j, connected to the load $P + jQ$. The active power loss in the kth line is indicated by Eq. (6):

$$Ploss = \left[I_k^2\right] \times \; R\left[k\right], \tag{6}$$

where I_k is the branch current and R is the resistance of the line. In addition:

$$I_k = \left(\frac{P[j] + jQ[j]}{V[j]}\right)^* = \frac{P[j] + jQ[j]}{V[j]^*}, \tag{7}$$

where P is the real power load at the receiving bus, Q is the reactive power load at the receiving bus, and V is the voltage at the receiving bus. By substituting Eq. (7) into Eq. (6), we obtain:

$$P_{loss} = \frac{\left(P^2[j] + Q^2[j]\right) R[k]}{\left(V[j]\right)^2}. \tag{8}$$

Thus, the SA factor is a derivative of the power loss with real power, P, as indicated in Eq. (9):

$$\frac{\partial P_{loss}}{\partial P} = \frac{(2 \times P\ [j] \times R[k])}{(V\ [j])^2}. \tag{9}$$

Thus, the buses will be ranked based on Eq. (9) accordingly. Some buses will be nominated as the most sensitive to the DG unit placement in order to have the best effect on the loss reduction.

3.2. Evolutionary programming

EP is a heuristic population-based search technique that is used for both random variation and selection. The search for an optimal solution is based on the natural process of biological evolution and is accomplished using a parallel method in parameter space. EP-based techniques have been applied in various studies involving static and dynamic system stability. The advantages of EP over other conventional optimization techniques can be summarized as follows [19]:

1. EP explores the problem space using a population of trials, as opposed to a single point, to demonstrate potential solutions to a problem. This makes EP less likely to get trapped in local minima. Hence, EP can achieve a global optimal solution.

2. EP uses objective function information to guide the exploration of a solution. Thus, EP is able to simply deal with noncontinuous objective functions.

3. EP employs probabilistic transition rules instead of nondeterministic rules to make decisions. Furthermore, EP is a type of stochastic optimization algorithm that can search a complicated and uncertain area to find the global minimum. This makes EP more flexible and robust than conventional methods.

EP is used as the main optimization technique to solve the optimal placement and sizing of the DG problem. The EP method consists of the initialization, fitness computation, mutation, combination, selection, and transcription of the next generation [20,21]. The method starts by randomly choosing a nominee solution population over a number of generations. The potency of each nominee solution is determined by its fitness function, which is evaluated based on the constraint in the objective function of the optimization method. The individuals that survive according to the fitness function are referred to as the objective function. If the individuals pursue the fitness setting range during the initialization, the fittest individuals will survive to the next generation, while the others will be combined through a process of mutation to breed new populations. During mutation, the Gaussian mutation operator is performed in order to generate a new population (offspring) with a randomly selected individual $x_{i,j}$ using the standard deviation, σ. The standard deviation decides the character of the offspring produced as related to its parent. Each element of the offspring is calculated according to the following equation:

$$\begin{aligned} x_{i+m,j} &= x_{i,j} + N\left(0,\ \sigma_{i,j}^2\right) \\ \sigma_{i,j} &= \gamma\left(x_{j\,\max} - x_{j\,\min}\right)\left(\frac{f_i}{f_{\max}}\right) \end{aligned}, \tag{10}$$

where $x_{i+m,j}$ are the offspring, $x_{i,j}$ are the parents, γ is the search step, $x_{j\,\max}$ are the maximum parents, $x_{j\,\min}$ are the minimum parents, f_i is the ith fitness, and f_{max} is the maximum fitness.

The γ value can be manually adjusted to achieve better convergence. Reducing the value of γ allows for a faster convergence of EP and vice versa. A combination process takes place after the mutation process is complete. This process combines parents and offspring in a cascade mode. EP employs the tournament scheme in order to choose the survivors for the next generation. This selection is used to identify the candidates that can pass into the next generation from the combined population of the parents and offspring. The population of individuals with better fitness functions is then sorted in ascending order. The first half of the population is then retained as the new individuals or parents to the next generation, and the others are removed from the pool. This process continues until the solution converges [20,21].

The convergence criterion is defined as the difference between the maximum and the minimum fitness of the objective functions. The optimal solution is achieved when there is no significant change between the new generation and the last generation. The convergence criterion process will be achieved if:

$$fitness_{\max} - fitness_{\min} \leq 0.0001. \tag{11}$$

3.3. Harmonic distribution load flow

The growing number of DG units may contribute to harmonic pollution in power system networks. Therefore, the harmonic analysis tool is very important to distribution system analysis and design. It can be used to assess the harmonic distortion in the voltage and current at various buses and can also determine the existence of unsafe resonance phenomena in the power system. Generally, harmonic analysis algorithms can be divided into 2 categories. The first category is based on transient-state analysis techniques, such as time-domain analysis and wavelet analysis. The second category is steady-state analysis, which is based on load flow programs and the use of frequency-based component models. Steady-state–based algorithms are more efficient compared to transient-state–based algorithms due to their large-scale power system application and lower computational time [17].

Conventional harmonic analysis methods utilize the Newton–Raphson and Gauss–Seidel methods, which need an admittance matrix to obtain the harmonic penetration in distribution systems. These methods do not consider the particular topology characteristics of the distribution systems, such as radial and weakly meshed configurations. Therefore, they take more computational time to calculate the solution for each harmonic order. In order to save computational time and to be applied to large-scale distribution systems, a harmonic distribution load flow (HDLF) method is used in this paper, as proposed in [18].

This study aims to determine optimal sizing for DG units when they are installed in a distribution system. This technique is founded on population-based search techniques that apply both random variation and selection. The technique estimates the value of multiple DG units and then these values are used as inputs for the HDLF program. Again, the goal is to minimize the power loss and THD_v. The proposed EP technique is used to find the best solution of the formulated problem. The flow chart of the SA and EP-HDLF is shown in Figure 2.

Table 1. Load data of the 69-bus radial distribution system.

Bus number	P_L (kW)	Q_L (kW)	Bus number	P_L (kW)	Q_L (kW)
6	2.60	2.20	37	26.00	18.55
7	40.40	30.00	39	24.00	17.00
8	75.00	54.00	40	24.00	17.00
9	30.00	22.00	41	1.20	1.00
10	28.00	19.00	43	6.00	4.30
11	145.00	104.00	45	39.22	26.30
12	145.00	104.00	46	39.22	26.30
13	8.00	5.00	48	79.00	56.40
14	8.00	5.50	49	384.70	274.50
16	45.50	30.00	50	384.70	274.50
17	60.00	35.00	51	40.50	28.30
18	60.00	35.00	52	3.60	2.70
20	1.00	0.60	53	4.35	3.50
21	114.00	81.00	54	26.40	19.00
22	5.00	3.50	55	24.00	17.20
24	28.00	20.00	59	100.00	72.00
26	14.00	10.00	61	1244.00	888.00
27	14.00	10.00	62	32.00	23.00
28	26.00	18.60	64	227.00	162.00
29	26.00	18.60	65	59.00	42.00
33	14.00	10.00	66	18.00	13.00
34	19.50	14.00	67	18.00	13.00
35	6.00	4.00	68	28.00	20.00
36	26.00	18.55	69	28.00	20.00

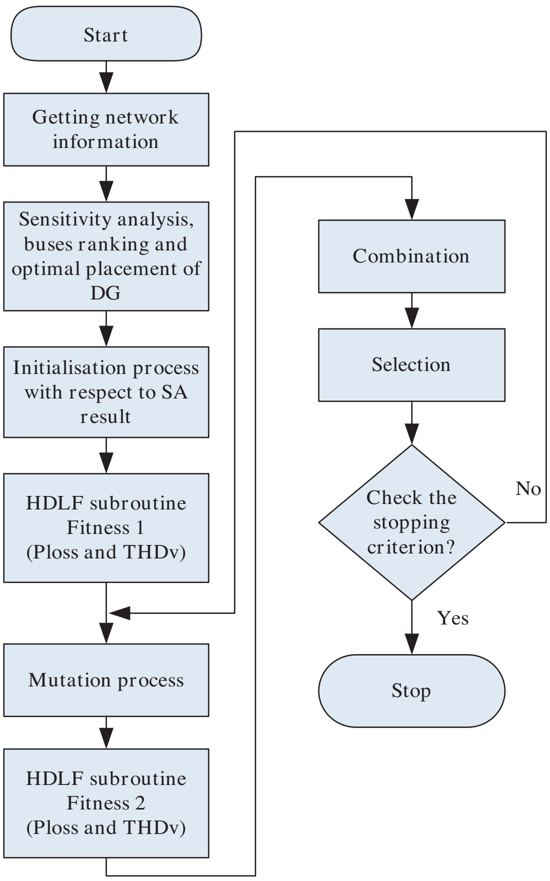

Figure 2. Flow chart of SA and EP-HDLF.

4. Results and discussion

The proposed method for DG unit placement and sizing is tested on a 69-bus radial distribution system, as shown in Figure 3. The load and bus data of the 69-bus radial distribution system are shown in Tables 1 and 2, respectively. The system loads are considered as spot loads, with the total being 3.8 MW and 2.69 MVAr. The minimum and maximum voltage limits are set at 0.9 p.u. and 1.05 p.u. The maximum iteration for the EP algorithm is chosen as 100. The only supply source in the system is the substation at bus 1, which is a slack bus with a constant voltage.

The occurrence of the harmonics in the system can be incorporated with the harmonic producing loads, such as adjustable speed drives. These nonlinear loads are located at buses 19, 30, 38, and 57. Another harmonic producing device is added to the distribution system when inverter-based DG units are installed in the system. The typical harmonic spectrum of these nonlinear loads and inverter-based DG are provided in Table 3 [17,22].

The EP-HDLF–based technique is applied to determine the optimal sizing of the DG units in the 69-bus radial distribution system, considering the harmonic propagation in the analysis. The total harmonic distortion level of each DG unit is to be maintained within 5% according to IEEE Std.51-1992 [23]. Two cases are considered with regard to the impact of the DG unit installation on the harmonic distortion, power loss, and voltage regulation in the 69-bus radial distribution system, as follows:

1. No DG unit installed in the system;
2. Multiple DG units are installed in the system.

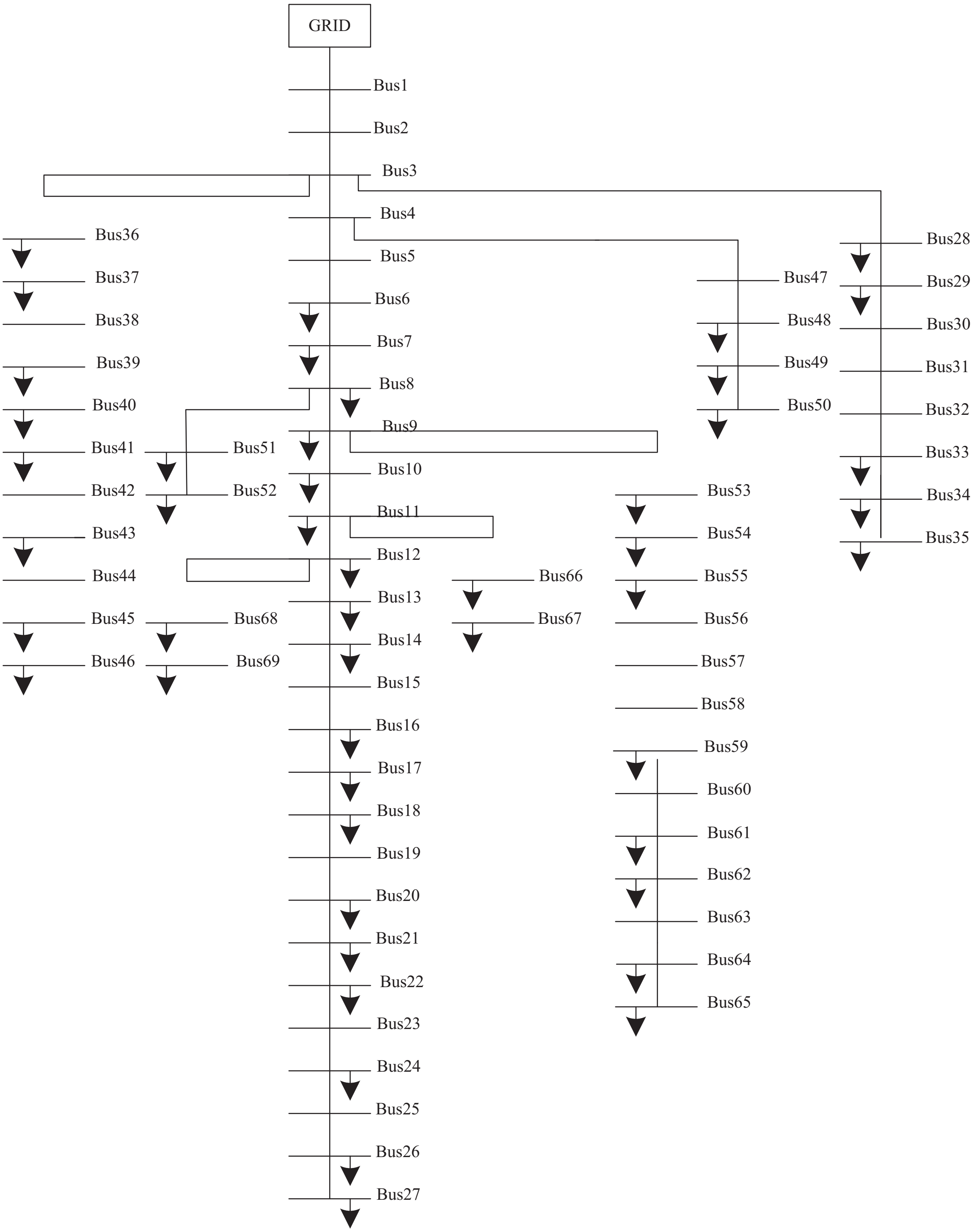

Figure 3. The 69-bus radial distribution system.

Table 2. Bus data of the 69-bus radial distribution system.

Branch number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0251	0.0294
5	5	6	0.3660	0.1864
6	6	7	0.3811	0.1941
7	7	8	0.0922	0.0470
8	8	9	0.0493	0.0251
9	9	10	0.8190	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.0300	0.3400
13	13	14	1.0440	0.3450
14	14	15	1.0580	0.3496
15	15	16	0.1966	0.0650
16	16	17	0.3744	0.1238
17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.0690
20	20	21	0.3416	0.1129
21	21	22	0.0140	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021
26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.0640	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.3510	0.1160
32	32	33	0.8390	0.2816
33	33	34	1.7080	0.5646
34	34	35	1.4740	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.0640	0.11565
37	37	38	0.1053	0.1230
38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509
41	41	42	0.3100	0.3623
42	42	43	0.0410	0.0478
43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0.0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091

Table 2. Continued.

Branch number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.1114
52	9	53	0.1740	0.0886
53	53	54	0.2030	0.1034
54	54	55	0.2842	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.5900	0.5337
57	57	58	0.7837	0.2630
58	58	59	0.3042	0.1006
59	59	60	0.3861	0.1172
60	60	61	0.5075	0.2585
61	61	62	0.0974	0.0496
62	62	63	0.1450	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.0410	0.5302
65	11	66	0.2012	0.0611
66	66	67	0.0047	0.0014
67	12	68	0.7394	0.2444
68	68	69	0.0047	0.0016

Table 3. Harmonic spectrum of the nonlinear loads and inverter-based DG.

Harmonic order	Nonlinear loads at buses 19, 30, 38, and 57 (%)	Inverter-based DG (%)
1	100	100
5	68.3	38.4
7	47.8	11.41
11	0.2	10.8
13	6.1	7.3
17	4.2	5.4

In this paper, the number of DG units is assumed to be 2 and the DG unit size ranges between 400 kW and 2000 kW. The application of the SA can reduce the exploration space of the EP and thus increase the speed of the simulation. Table 4 shows the results from the SA.

Table 4. SA results.

Bus number	Sensitivity to loss reduction
61	16.790
64	4.282
21	2.246
65	1.351
59	1.324
18	1.046
17	1.045
12	1.019
16	0.746
11	0.739

The SA results show the top 10 most sensitive buses for DG unit placement in order to have the best effect on loss reduction. However, in this study, only 2 DG units are considered for placement, namely at buses 61 and 21. The EP parameters are tuned to enhance the performance of the proposed algorithm. A population size of 20 and a strategic parameter of 7 are selected for the EP algorithm. Figure 4 shows the best result among 30 simulation runs. The convergence speed of the proposed EP-HDLF–based solution technique is important in determining the global optimal solution of the DG unit sizing problem. The results of the optimal placement and sizing of the DG unit with SA and EP-HDLF are summarized in Table 5.

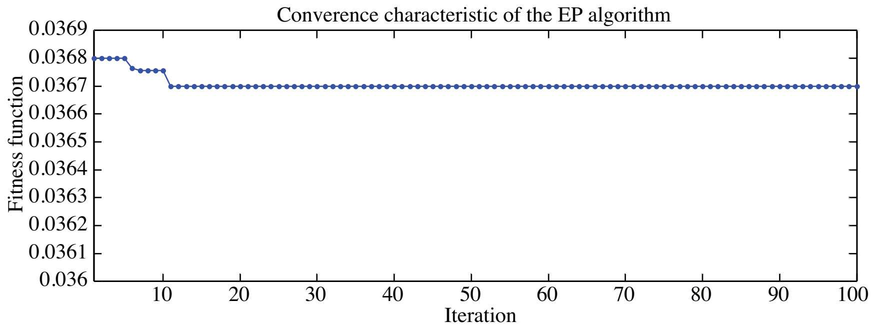

Figure 4. Convergence characteristics of the EP-HDLF algorithm.

Table 5. Results of the optimal placement and sizing of DG.

Optimal DG placement	Optimal DG sizing
Bus 61	1.794 MW
Bus 21	0.594 MW

The results of the power loss and average THD$_v$ for the 2 cases are shown in Table 6, while the voltage profile for both cases is illustrated in Figure 5.

Table 6. Results of the power losses and THD$_v$ for both cases.

Objectives	No DG installed in the system	Multiple DG units installed in the system
Total real power losses	243.9 kW	61.18 kW
Average THD$_v$	18.097%	1.097%

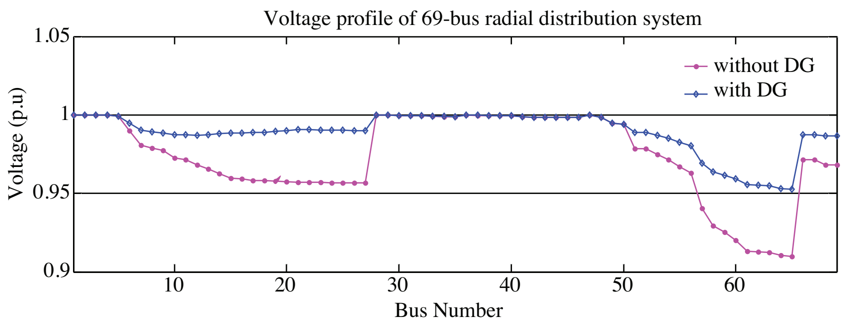

Figure 5. Voltage profile of the 69-bus radial system for both cases.

From the results shown in Table 6, we can conclude that installing the DG unit with optimal placement and sizing has significant impacts on the reduction of the total loss and average harmonic distortion in the distribution system. The losses are decreased dramatically when 2 DG units with optimal sizing and placement are installed in the system. The voltage profile of the 69-bus radial distribution system also greatly improves with the addition of DG units. To validate the proposed method, a comparison has been made with the existing results in the literature. With the aim of comparing the result of the proposed method, the optimal sizing of the DG units in [16] was used as an input to obtain the total losses and the THD_v results. The comparison between the proposed method and the existing results by installing 2 DG units with optimal sizing with the total losses and THD_v is indicated in Table 7. It is clearly shown in this result that the proposed method gives the best solution for minimizing the losses and THD_v as compared to the other methods.

Table 7. Comparison of the proposed method with the existing results.

Method	Proposed method	Results in [16]
Size DG_1	1.794 MW	1.776 MW
Size DG_2	0.594 MW	0.507 MW
Losses	61.18 kW	62.78 kW
THD_v	1.097%	2.154%

5. Conclusion

This paper proposed an algorithm for computing the optimal placement and sizing of DG units. First, the optimal placement of the DG unit was obtained through SA. Next, the optimal sizing of the DG unit was calculated with the EP-HDLF algorithm technique. The multiobjective function of this study was to minimize the total power loss and THD_v, as well as improve the voltage profile. The results indicated that the proposed algorithm was effective at finding optimum locations and sizes of DG units in distribution power systems. Moreover, the improvement of the voltage profile, as well as the reduction of the losses and THD_v, was clearly seen after optimal DG unit placement and sizing. The proposed method performed better compared to the other methods for minimizing the losses and THD_v for DG unit placement and sizing.

Acknowledgment

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Nomenclature

DG	Distributed generation
SA	Sensitivity analysis
EP	Evolutionary programming
HDLF	Harmonic distribution load flow
THD_v	Total harmonic distortion voltage
GA	Genetic algorithm
PSO	Particle swarm optimization
EP-HDLF	EP integrated with HDLF
F	Fitness function
P_{loss}	Total power loss
α	The weighted factor for total power loss
β	The weighted factor for THD_v
m	The number of buses
$V_{\min}$	The lower bound of bus voltage limits
$V_{\max}$	The upper bound of bus voltage limits
$\lvert V_i \rvert$	The root mean square value of the ith bus voltage
$THD_{\max}$	The maximum allowable level of the THD
I_k	The branch current
R	The resistance of the line
P	the real power load
Q	The reactive power load
V	The voltage at the receiving bus
$x_{i+m,j}$	The offspring
$x_{i.j}$	The parents
γ	The search step
$x_{j\max}$	The maximum parents
$x_{j\min}$	The minimum parents
f_i	The ith fitness
$f_{\max}$	The maximum fitness
$f_{\min}$	The minimum fitness

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