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Using the modified shuffled frog leaping algorithm for optimal sizing and location of distributed generation resources for reliability improvement

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Abstract

Restructuring the recent developments in the power system and problems arising from construction as well as the maintenance of large power plants lead to increase in using the Distributed Generation (DG) resources. DG units due to its specifications, technology and location network connectivity can improve system and load point reliability indices. In this paper, the allocation and sizing of distributed generators in distribution electricity networks are determined through using an optimization method. The objective function of the proposed method is based on improving the reliability indices, such as a System Average Interruption Duration Index (SAIDI), and Average Energy Not Supplied (AENS) per customer index at the lowest cost. The optimization is based on the Modified Shuffled Frog Leaping Algorithm (MSFLA) aiming at determining the optimal DG allocation and sizing in the distribution network. The MSFLA is a new mimetic meta-heuristic algorithm with efficient mathematical function and global search capability. To evaluate the proposed algorithm, the 34-bus IEEE test system is used. In addition, the finding of comparative studies indicates the better capability of the proposed method compared with the genetic algorithm in finding the optimal sizing and location of DG's with respect to the used objective function.

Keywords: *Distributed Generation, Reliability, Optimization, Modified Shuffled Frog Leaping Algorithm, Optimization.*

1. Introduction

Due to restructuring and competition in power systems and changes in management and ownership of electricity industry, the role of DGs is expected to increase in future. Also, some factors, such as environmental pollution, problems due to establishment of new transmission lines, increase the use of these DGs. Although, the use of DGs in the distribution electricity networks can lead to have lower loss, higher reliability, etc, it can also apply a high capital cost to the system. This demonstrates the importance of finding the optimal size and placement of DGs. In the recent years, several studies have been carried out to locate optimally the DG units on distribution systems [1]-[9]. The improvement of system characteristics is the focus of most papers and is the main objective of DG placement. Virtually most of the DGs related papers have studied loss minimization and voltage profile improvement [2], [9] and a few papers have investigated the role DGs for improving the reliability [1, 10]

In [1], Wang and Sing applied Ant Colony algorithm to determine the optimal DG allocation and they study the impact of DG placement on the reliability indices. In [2], Wang and Nehrir presented analytical approaches for determining optimal location of DG to minimize the power losses. Celli et al in [3] proposed a multi-objective formulation for the DG placement in distribution feeders for minimization the objective programming and decision theory to find the best plan for distribution system with DG. Hedayati et al in [5] presented a method for optimal DG placement in order to reduce the power losses and improve voltage profile. Their method was based on the analysis of power flow continuation and determination of most sensitive buses to voltage collapse. In [6], Borges and Falcao proposed a

method for optimal DG placement for minimizing the network l and guaranteeing acceptable reliability level and voltage profile. Haghifam et al in [7] presented a method to locate DG units in the distribution networks in an uncertain environment for minimizing monetary cost index, technical risks (including risks of voltage and loading constraints) and an economic risk. They employed fuzzy numbers to model uncertain environment. In [8], Hyoung Lee et al apply Kalman filter algorithm to find an optimal placement of DG in order to minimize the losses of network. Popovic et al in [9] used a sensitivity analysis for DG placement in the network with respect to security constraints.
From the reliability aspect, considering load shedding results in more realistic optimization method. As an example, in [18], it is assumed that if the total DGs rating in an island are less than the total loads located in that island, then no loads can be served and all those loads are shed untill the feeder under fault is repaired.
Because allocation and sizing of distributed generation units have a discrete natures of the…??, it encounters a number of local minima. To overcome this issue, a reliable optimization algorithm should be used. The optimization approaches are mostly divided into analytical and heuristic approaches. In the non-smooth functions, the heuristic methods have higher accuracy compared with the analytical approaches. In the analytical methods, the optimization may be trapped in a local minimum [12]. In the literature, several optimization techniques have been applied to the DG placement issue, such as Ant Colony algorithm [1], genetic algorithm [3], [6], [7], [9], Kalman Filter Algorithm [8] and analytical based methods [2, 4, 5].
The SFLA in this paper is used to achieve an optimal response. To accelerate the algorithm convergence and to prevent the algorithm from converging it to a wrong answer, a new parameter is added to the original formulation to create a Modified Shuffled Frog-Leaping (MSFL) algorithm [26].
This paper focuses on the following sections. The effect of DG on system reliability and reliability assessment is introduced in the next section. In section III, formulation of problem is presented and a composite reliability index is also defined. In section IV, the proposed method for optimal DG placement by shuffled frog leaping algorithm is detailed. Simulation results and conclusion are discussed in sections V and VI, respectively.

2.Distribution system reliability assessment

Reliability evaluation of distribution electricity network has received a great attention of many researchers and the numerous papers have published in this case. However, evaluation methods distribution electricity network need more development [10], [11]. In this paper, the failure impact of each element on load points is considered as well as the average failure rate of the element. Then, the interruption frequency and duration at each load point are calculated to eventually compute the system reliability indices. The important issue focuses on the effect of network structure, switches, supply ability of loads from the main source of power or other resources. Islanding of DGs should be modeled suitably in each error simulation. More explanation is about a distribution system is provided in Figure 1 that is supplied by DG units. For example, if in this figure a fault occurs in first section (ab), with no DG connected to feeder, all load points service must be interrupted during repair operation, but with DG connected (bus c), some load points, due to DG capacity can be restored via DG source. So, DGs can decrease the duration of outage and as a result, system reliability is increased.

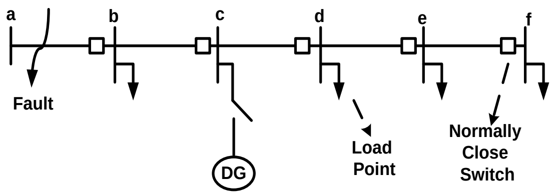

Figure 1. A radial feeder with one DG

The DG has a positive effect on distribution system on blackouts of the supply [11], [13].
In this paper, the difference between reliability of distribution system with and without DG in failure rate and outage time index is calculated. The distributed generation is represented by four-state Markov process as depicted in Figure 2, where λ and μ respectively, are bus/DG failure and repair rates.

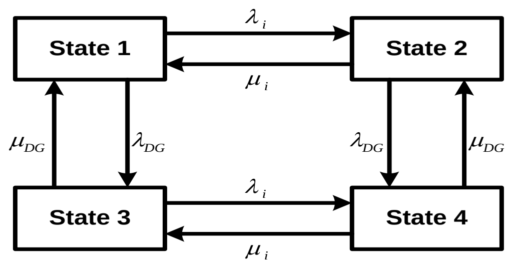

Figure 2. A four state representation for typical distribution system with one DG.

Direction shown in Figure 1 shows the transition between modes. DG and busi is in normal condition.

In the first state, DG and busi are in the normal condition. In the second state, error occurred in the system and bus connection is interrupted The DG interrupted in the third state, but the bus is not connected yet. In fourth state, DG and transmission has been interrupted and bus is isolated. For our four-state system, matrix P is given by:

$$P = \begin{bmatrix} 1-(\lambda_i+\lambda_{DG}) & \lambda_i & \lambda_{DG} & 0 \\ \mu_i & 1-(\mu_i+\lambda_{DG}) & 0 & \lambda_{DG} \\ \mu_{DG} & 0 & 1-(\lambda_i+\mu_{DG}) & \lambda_i \\ 0 & \mu_{DG} & \mu_i & 1-(\mu_i+\mu_{DG}) \end{bmatrix} \tag{1}$$

The matrix P is known as the stochastic transitional matrix [14], [15]. It represents the transitional probabilities between states for one step of the Markov chain. The limiting probabilities pi corresponding to each state can be evaluated from (2) and (3).

$$p_i = \begin{bmatrix} \frac{\mu_i\mu_{DG}}{L} & \frac{\lambda_i\mu_{DG}}{L} & \frac{\mu_i\lambda_{DG}}{L} & \frac{\lambda_i\lambda_{DG}}{L} \end{bmatrix} \tag{2}$$

$$L = (\lambda_i+\mu_i)(\lambda_{DG}+\mu_{DG}) \tag{3}$$

Finally, bus failure rate and repair rate, connected to DG can be evaluated from (4) and (5).

$$\lambda_i^{bus} = \frac{p_2\lambda_{DG}+p_3\lambda_i}{p_1+p_2+p_3} \tag{4}$$

$$U_i^{bus} = p_4 \tag{5}$$

3.Problem formulation

The objective of DGs placement in a radial feeder is to maximize the distribution network reliability under certain constraints at the lowest cost. The standard reliability indices are used in this paper [16]: System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Average Energy Not Supplied per customer index (AENS). They are defined as follows:

$$SAIFI = \frac{\sum \lambda_i . N_i}{\sum N_i} \tag{6}$$

Where N_i is the number of customers of load point i and λ_i is the failure rate.

$$SAIDI = \frac{\sum u_i N_i}{\sum N_i} \tag{7}$$

where u_i is the outage time.

$$AENS = \frac{\sum L_{a(i)} u_i}{\sum N_i} \tag{8}$$

where $L_{a(i)}$ is the average load connected to load point i.

For the purpose of optimization, the proposed objective function is expressed in Equation (9), which includes composite reliability indices and DG cost through the weighted aggregation of these indices.

$$OBF = w_{SAIFI}.\frac{SAIFI}{SAIFI_T} + w_{SAIDI}.\frac{SAIDI}{SAIDI_T} + w_{AENS}.\frac{AENS}{AENS_T} + w_{C_{DG}}.\frac{C_{DG}}{C_{DGT}} \tag{9}$$

where the weighting coefficients represent the relative importance of the objectives and the subscript T indicates the target value.

These reliability indices are the most widely used indices to perform the reliability assessment in the distribution network. In this formulation, we incorporate the desired values and these reliability indices are empirically justified [10].

The DG cost is formulated as:

$$C_{DG} = C_{Install} + \left(\sum_{t=1}^{T_{yr}} C_{O\&M} \frac{(1+IF)^t}{(1+IR)^t}\right) \tag{10}$$

where C_{INSTAL} is the total installation cost for DGs, $C_{O\&M}$ is the total operation and maintenance cost for DGs, IR is the interest rate, IF is the Inflation rate and T_{yr} is the number of years in the study timeframe.

4.Implementation of SFLA

The SFLA originally developed as a population-based meta-heuristic by M. Eusuff and K. Lansey in 2003 performed an informed heuristic search using any mathematical function to find a solution of optimization problem [22]. It combines the benefits of both the genetic-based memetic algorithm and the social behaviour-based PSO algorithm [23].

This algorithm has been inspired by the frog's life as a group when the frogs are in search of food. A shuffling strategy allows for the exchange of information between local groups to move toward a global optimum point [24]. The description and comments of algorithm implementation are presented as follows.

Step 1: Coding

Each possible size and location for DG placement needs to be integrated into each population. In this method, eight bits encode each solution. From the first to fourth bits indicate the locations for DG placement. The rest of the bits show the capacity of the installed unit.

The bits and their corresponding information for one candidate location are shown in Figure 3.

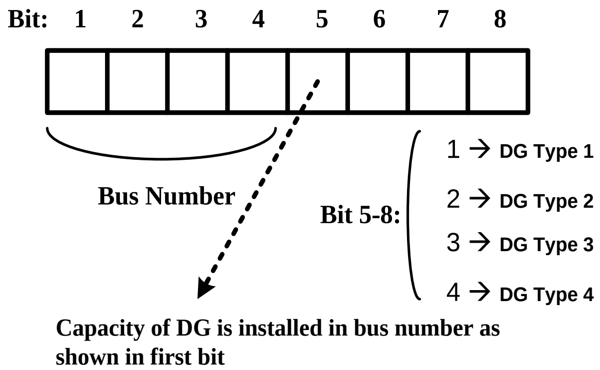

Figure 3. Bit information for each candidate location of DG.

Step 2: Initializing the population and partition frogs into memeplexes

An initial population of P frogs in the marsh is created randomly. Then, the frogs are arranged in a descending order according to their fitness. Then, the P frogs are partitioned into m memeplexes, each containing n frogs (P = m × n). In this procedure, the first frog moves to the first memeplex, the second frog moves to the second memeplex and the mth frog moves to the mth memeplex, then (m + 1)th frog goes back to the first memeplex and so on.

Step 3: Local exploration

In each memeplex, the frogs with the best and the worst fitness are determined and named as X_b and X_w, respectively. Also, the position of frog with the global best fitness among the memeplexes is identified as X_g. Then, in each memeplex, the frogs with the worst fitness (not all frogs) apply a process (move toward to X_w) to improve their memes.

Regarding the selection of the X_w, it is not always desirable to use the best frog, because the frog's tendency would be to concentrate around the frog, which may be local optimum. So, to avoid trapping in local optima, a submemeplex is constructed in each memeplex, which consists of frogs chosen on the basis of their corresponding fitness. Probabilistic roulette wheel is used to select submemeplex in each memeplex. This selection strategy is to give higher weights to frogs that have higher fitness values and togive less weight to those with lower fitness values.

A triangular probability distribution is used to assign this weight:

$$P_k = \frac{2(n+1-k)}{n(n+1)} \quad k = 1,\ldots,n \qquad (11)$$

where P_k is the probability of the k_{th} frog being selected to form a submemeplex, and n is the number of frogs in a memeplex. In each memeplex, the frog with the best performance has the highest probability $p_1 = 2/(n+1)$ and the frog with the worst performance has the lowest probability $p_n = 2/n(n+1)$ of being selected for the submemeplex [25].

The best global frog's position is represented by X_{sg}. The best and the worst frog's position are represented by X_{sb} and X_{sw} respectively in each submemeplex. The worst frog's position in the submemeplex is updated as follows (as shown in Figure 4):

$$D_i = round\,(rand \times (X_{sb} - X_{sw})) \qquad (12)$$

$$X_w(new) = X_w(old) + D_i \qquad (\text{-}D_{max} \le D_i \le D_{max}) \qquad (13)$$

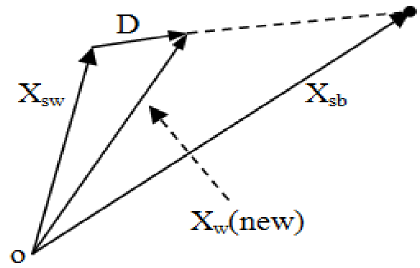

Figure 4. The original of the frog leaping rule.

Where D_{max} is the maximum allowed change in position of frog in each leaping and rand is a random number between 0 and 1. If this process produces a better solution, X_w (new) replaces the worst frog's position (X_w (old)). Otherwise, the calculations in Equations (12) and (13) are repeated with replacement of X_{sb} by X_{sg}. If no improvement is achieved in this case, then a new solution is randomly generated to replace the worst frog (X_{sw}). These calculations continue in a memeplex for a specific number of iterations [23].

Step 4: Check convergence criteria

If the defined convergence criteria are satisfied or the output does not change for a specific number of iterations, the program will be terminated and the results will be printed, and the rest of the program goes to Step 3.

4.1.Modified Shuffled Frog Leaping Algorithm (MSFLA):

As explained in the previous section, in each submemeplex, the worst frog corrects its position towards the best frog's position or the global best position in the same submemeplex. But according to Equations (12) and (13) and Figure 4, the possible new position of the worst frog is limited in the line segment between its current position (X_{sw}(old)) and the best frog's position (X_{sb}). Also, the worst frog will never jump around this line or over the best one (see Figure 5). This limitation leads to slow down the speed of optimization convergence. This leads to the issue that the algorithm converges to the wrong answers. In order to solve this limitation, the use of new equations are employed instead of using the Equations (12) and (13) as explained in [26]:

$$D_i = round\,(rand \times C\,(X_b - X_w) + W) \qquad (14)$$

$$W = \left[r_1 w_{1,\max}, r_2 w_{2,\max}, \ldots, r_{NF} w_{NF,\max}\right]^T \qquad (15)$$

$$X_w(new) = \begin{cases} X_w + D & \text{if } |D| \le D_{\max} \\ X_w + \dfrac{D}{\sqrt{D^T D}} D & \text{if } |D| \ge D_{\max} \end{cases} \qquad (16)$$

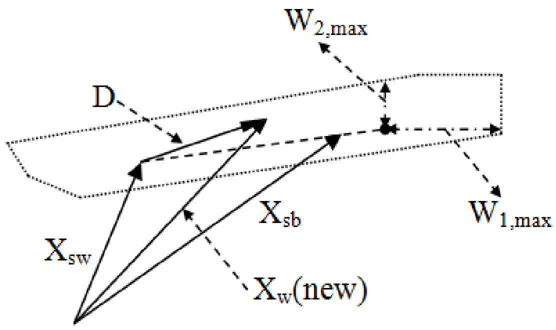

Figure 5. The modification of the frog leaping rule.

Where rand is a random number between 0 and 1, C is a constant chosen in the range between 1 and 2, r_i are random numbers between -1 and 1, $w_{i,\max}$ are the maximum range that frog sees in the i_{th} dimension of the search space and D_{max} is the maximum allowed change in position of frog in each leaping.

5. Simulations Results

To validate the proposed method, the 34-bus IEEE test system, as shown in Figure 6, is studied. The system is modeled with all of its detailed parameters using MATLAB2009b software. The system is divided into four zones for reduce number of customer that are affected blackouts.

The reliability index weights are chosen as follows:

WSAIFI = 0.30, WSAIDI = 0.30, WAENS = 0.33 and WPDG = 0.07. The target values of the reliability indices are set as follows: SAIFIT = 10, SAIDIT = 100, AENST = 300 and CDGT = 10000000. They are empirically selected and show the reasonably level of reliability [10]. The interest rate (r), the Inflation rate and the number of years in the study timeframe (Tyr) are chosen 0.1, 0.18 and 20 respectively [7]. The specifications lines and loads of the test system are shown in Table 3, 4 [13], [17].

The MSFLA parameters that are used to tune the performance of the MSFLA allocation, as follows:

Population size: 100 individuals

Number of memeplexe: 20

Number of submemeplex for each memeplex: 3

The variable c: 1.8

The variable wi, max: [0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1]

The variable Dmax: 10

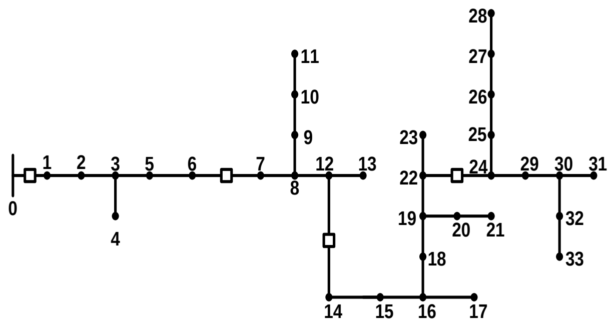

Figure 6. Test system

The DG types available for the tests and the corresponding investment, maintenance, operating cost are shown in Table 1. The cost of DG unit, DG site, construction and survey fees, diagnostic and protection equipment, and fuel delivery equipment are included in the investment cost. The maintenance costs are annual mechanical and electrical inspection and recondition cost. The operating cost includes labor cost for service, taxes and fuel cost. Those cost related data is mainly based on the book of Willis and Scott [19], [20].

Table 2 shows the main system reliability indices prior to DG installation and the reliability indices considering the DG placement are obtained by the method. Three places after the implementation of MSFLA for distributed generation units are proposed (The bus 18, 25 and 28, respectively with capacities of 700, 500 and 1000 kW). It can be observed that the system average interruption duration and system average interruption frequency and energy not supply indices improve the DG installation. Figure 7 shows the convergence process of the MSFLA when used to optimize DGs placement in 34-bus IEEE test system.

Table 1. The cost for dg types

Type	*DG Specification*	*Investment cost ($)*	*Maintenance cost ($/yr)*	*Operating cost ($/yr)*
1	300 kW mini Gas turbine	182000	11630	78000
2	500 kW mini Gas turbine	330000	21140	142000
3	700 kW mini Gas turbine	410000	27310	178000
4	1000 kW mini Gas turbine	550000	32240	237000

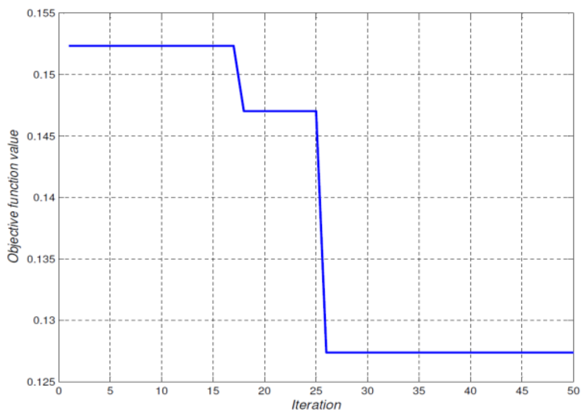

Figure .7. Convergence curves for the objective function with MSFLA

Next, we compare the MSFLA with the GA algorithm. The convergence process and the reliability indices are obtained by GA method shown in Table 2 and Figure 8, respectively. This method purposes four places for distributed generation units. The buses are 16, 19, 25 and 28, with capacities of 700, 500,300, 1000 kW, respectively.

Table 2. Comparison of outputs before and after installation of dgs

		SAIFI	SAIDI	AENS	C_{DG} (M$)	C_{INT} (M$)
Without DGs		8.7	92.4	461.4	-------	361.39
With DGs	GA	1.31	9.91	49.57	9.0166	38.792
	MSFLA	1.36	8.65	43.27	7.9049	33.838

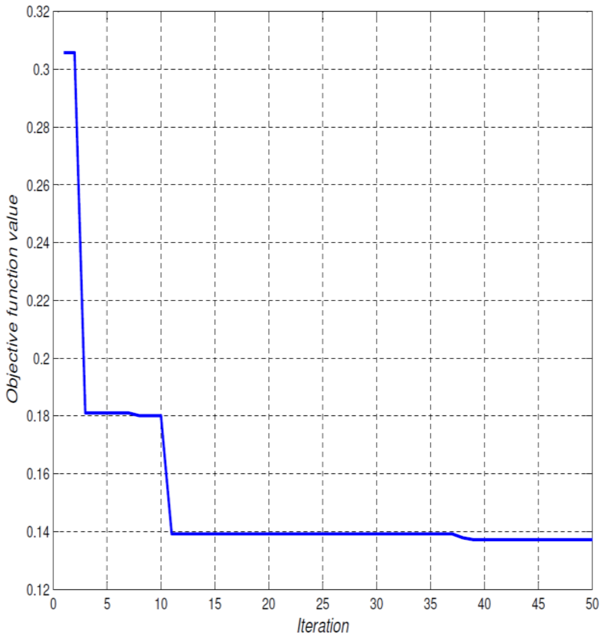

Figure 8. Convergence curves for the objective function with Genetic Algorithm.

The last element in Table 2 can be identified with SAIDI, which is the average interruption duration per year per customer. The interruption cost is obtained by using Equations (12) [12].

$$C_{INTERRUPTION} = (\sum_{t=1}^{20} NC \times SAIDI \times CI \times \frac{(1+IF)^t \times (1+IG)^t}{(1+IR)^t}) \qquad (12)$$

where NC is the number of customers, CI is the cost of interruption per hour for a customer and IG is the Load Growth rate.

The number of customers is 354 in the test system, the cost per 1 minute interruption is assumed 7$ and load growth rate is chosen 0.1 [21]. As observed in Table 2, after installation of DGs, interruption cost decreases. The proposed method is based on MSFLA, and total cost decreases from M$ 361.39 to M$ 33.838. This difference, M$ 327.552, is much more than the total cost of DGs, M$ 7.9049.

As shown in Figure 7, Figure 8 and Table 2, objective function value for the proposed MSFLA method is less than the GA method. It means that better locations are found for achieving higher system reliability through the proposed MSFLA. The proposed method is based on MSFLA will converge in the 26th generation, whereas the method based on GA in 37th is converged. The difference and potential advantage of the MSFLA over genetic algorithms is that information is spread among all individuals in the population, whereas in a GA only parent or their siblings are allowed to interaction. Therefore, Modified

Shuffled Frog Leaping Algorithm in convergence speed and computation time and memory use is superior to the Genetic Algorithm.

Table 3. Loads specification of the test system

BUS No.	No . Customers	Q KVAR	P KW	BUS No.	No . Customers	Q KVAR	P KW
1	0	0	0	18	1	2	4
2	0	0	0	19	0	0	0
3	11	29	55	20	0	0	0
4	0	0	0	21	0	0	0
5	3	8	16	22	90	225	450
6	0	0	0	23	3	7	15
7	0	0	0	24	1	1	2
8	0	0	0	25	6	7	23
9	0	0	0	26	0	0	0
10	0	0	0	27	83	20	414
11	7	17	34	28	9	23	45
12	27	70	135	29	17	393	83
13	1	2	5	30	41	121	206
14	8	20	40	31	16	43	82
15	1	2	4	32	13	41	67
16	10	23	52	33	0	0	0
17	0	0	0	34	6	14	28

Table 4. Loads specification of the test system

Line No.	From Bus	To Bus	λ(f/yr)	Line No.	From Bus	To Bus	λ(f/yr)
1	34	1	0.983	18	16	18	14.035
2	1	2	0.65	19	18	19	0.04
3	2	3	12.282	20	19	20	1.98
4	3	4	2.212	21	20	21	4.024
5	3	5	14.291	22	19	22	1.867
6	5	6	11.33	23	22	23	0.617
7	6	7	0.04	24	22	24	2.221
8	7	8	0.118	25	24	25	0.107
9	8	9	0.651	26	25	26	0.512
10	9	10	18.349	27	26	27	1.387
11	10	11	5.236	28	27	28	0.202
12	8	12	3.891	29	24	29	0.77
13	12	13	1.154	30	29	30	1.021
14	12	14	0.32	31	30	31	0.328
15	14	15	7.789	32	30	32	0.106
16	15	16	0.198	33	32	33	1.85
17	16	17	8.891				

6. Conclusion

In this paper, a new objective function is introduced for the placement and sizing of DGs optimally with respect to the reliability indices improvement. To evaluate the proposed algorithm, the 34-bus IEEE test system, is used. The results are finally compared with the no DG condition and it shows that reliability indices especially ENS has improved remarkably with optimal placement of distributed generation. The test results show that this proposed method is capable to improve service reliability, reduces the customer outage costs and decreases the power cost. In addition, the result demonstrated the better characteristics of the MSFLA in comparison with the GA especially in terms of solution quality and number of iterations.

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