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Optimal Placement and Sizing of DG in Radial Distribution Networks Using SFLA

E. Afzalan[1], M. A. Taghikhani[2,*], M. Sedighizadeh[1,2]

[1]Department of Electrical and Computer Engineering, Saveh Branch, Islamic Azad University, Saveh, Iran
[2]Engineering Department, Imam Khomeini International University, Qazvin, Iran

Abstract Optimal placement and sizing of DG in distribution network is an optimization problem with continuous and discrete variables. Many researchers have used evolutionary methods for finding the optimal DG placement. This paper proposes a shuffled frog leaping algorithm (SFLA) for optimal placement and sizing of distributed generation (DG) in radial distribution system to minimize the total real power loss and to improve the voltage profile. The SFLA is a meta-heuristic search method inspired from the memetic evolution of a group of frogs when seeking for food. It consists of a frog leaping rule for local search and a memetic shuffling rule for global information exchange. The proposed SFL algorithm is used to determine optimal sizes and locations of multi-DGs. Test results indicate that SFLA method can obtain better results than the simple heuristic search method on the 33-bus radial distribution systems. Moreover, voltage profile improvement and branch current reduction are obtained.

Keywords Distributed Generation (DG), Shuffled Frog Leaping Algorithm (SFLA), Loss Reduction, Voltage Profile Improvement

1. Introduction

One of the most important motivation for the studies on integration of distributed resources to the grid is the exploitation of the renewable resources such as; hydro, wind, solar, geothermal, biomass and ocean energy, which are naturally scattered around the country and also smaller in size. Accordingly, these resources can only be tapped through integration to the distribution system by means of Distributed Generation. Distributed Generation (DG), which generally consists of various types of renewable resources, can be defined as electric power generation within distribution networks or on the customer side of the system[1].DG affects the flow of power and voltage conditions on the system equipment. These impacts may manifest themselves either positively or negatively depending on the distribution system operating conditions and the DG characteristics. Positive impacts are generally called 'system support benefits', and include voltage support and improved power quality; loss reduction; transmission and distribution capacity release; improved utility system reliability. On account of achieving above benefits, the DG must be reliable, dispatchable, of the proper size and at the proper locations[2],[3]. Distributed Generation (DG) is a small generator spotted throughout a power system network, providing the electricity locally to load customers. DG can be an alternative for industrial, commercial and residential applications. DG makes use of the latest modern technology which is efficient, reliable, and simple enough so that it can compete with traditional large generators in some areas[4],[5]. In fact, three types of DG are considered as follows: DG is capable of supplying only real power; DG is capable of supplying only reactive power; DG is capable of supplying real power but consuming proportionately reactive power. The methodology is proposed for optimal placement and sizing of only first type DG. Moreover, the heuristic search requires exhaustive search for all possible locations which may not be applicable to more than one DG. Therefore, in this paper, SFLA method is proposed to determine the optimal location and sizes of multi-DGs to minimize the total real power loss and improve the voltage profile of the distribution systems. The organization of this paper is as follows. Section 2 addresses the Load flow in radial distribution network. The problem formulation is in Section 3. The SFL algorithm is presented in Section 4. A SFLA computation procedure for the optimal placement and sizing of distributed generation problem is given in Section 5. Simulation result on the test systems are illustrated in Section 6.

2. Load Flow

On account of the some inherent features of distribution systems such as radial structure, unbalanced distributed loads, large number of nodes, a wide range of R/X ratios, the conventional techniques have been developed for transmis-

* Corresponding author:
taghikhani@ee.iust.ac.ir (M. A. Taghikhani)
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sion systems generally fail on the determination of optimum size and location of distributed generations. In this study, the proposed methodology is based on the equivalent current injection that uses the Bus–Injection to Branch-Current (BIBC) and Branch-Current to Bus-Voltage (BCBV) matrices which were developed based on the topological structure of the distribution systems and is implemented for the load flow analysis of the distribution systems. The methodology proposed here requires only one base case load flow to determine the optimum size and location of DG. Detailed description of BIBC and BCBV matrix's building algorithm is omitted due to the lack of space.

3. Problem Formulation

The problem is to determine allocation and size of the DGs which minimizes the distribution power losses and to improve the voltage profile for a fixed number of DGs and specific total capacity of the DGs.

3.1. Objective Function

In this paper the objective function for the optimal placement and sizing of DG in distribution network problem is to minimize the real power losses and improve the voltage profile, which is calculated as follows:

$$F_1(X) = P_L = \sum_{i=1}^{N_{br}} R_i \cdot \left|I_i\right|^2 \tag{1}$$

$$F_2(X) = \sum_{i=1}^{N_{bus}} \left|V_i - V_{i,ref}\right| \tag{2}$$

$$X = l_1, l_2, \ldots, l_{bus}, x_1, x_2, \ldots, x_{power\ limit} \tag{3}$$

Where, R_i and I_i are resistance and actual current of the ith branch, respectively. N_{br} is the number of the branches. V_i is the magnitude of bus voltage i. $V_{i,ref}$ is the magnitude of voltage of slack bus .X is the vector of control variables. l is the number of DG location candidates. x is the number of capacity types of DGs. The objective function of the placement and sizing is to minimize the real power loss and improve the voltage profile. Mathematically, the objective function can be written as:

$$F_{Total} = W_1 \cdot F_1 + W_2 \cdot F_2$$

$$\sum_{i=1}^{n} W_i = 1 \tag{4}$$

W_1 and W_2 are weight factor.

3.2. Constraints

The constraints are listed as follows:

a) Distribution line absolute power limits:

$$\left|P_{ij}^{Line}\right| \le P_{ij,max}^{Line} \tag{5}$$

$\left|P_{ij}^{Line}\right|$ and $P_{ij,max}^{Line}$ are the absolute power and its corresponding maximum allowable value flowing over the distribution line between the nodes i and j, respectively.

b) Bus voltage limit:

Bus voltage amplitudes are limited as

$$V_{min} \le V_i \le V_{max} \tag{6}$$

Where V_{min} and V_{max} are the minimum and maximum values of bus voltage amplitudes, respectively.

c) Radial structure of the network:

$$M = N_{bus} - N_f \tag{7}$$

Where M is the number of branches, N_{bus} is the number of nodes and N_f is the number of sources.

d) Power limits of DG:

$$P_{DGi}^{min} \le P_{DGi} \le P_{DGi}^{max}, Q_{DGi}^{min} \le Q_{DGi} \le Q_{DGi}^{max} \tag{8}$$

Where P_i and Q_i are the injected active and reactive power of DG components at the ith bus.

e) Subject to power balance constraints:

$$\sum_{i=1}^{N_{sc}} P_{DGi} = \sum_{i=1}^{N_{sc}} P_{Di} + P_L \tag{9}$$

Where N_{sc} is total number of sections, P_L is the real power loss in the system, P_{DGi} is the real power generation at bus i, P_{Di} is the power demand at bus i.

4. Shuffled Frog Leaping Algrithm (SFLA)

The SFL algorithm, in essence, combines the benefits of the genetic-based MAs and the social behavior-based PSO algorithms. In the SFL, the population consists of a set of frogs (solutions) that is partitioned into subsets referred to as memeplexes. The different memeplexes are considered as different cultures of frogs, each performing a local search. Within each memeplex, the individual frogs hold ideas, that can be influenced by the ideas of other frogs, and evolve through a process of memetic evolution. After a defined number of memetic evolution steps, ideas are passed among memeplexes in a shuffling process. The local search and the shuffling processes continue until defined convergence criteria are satisfied[6].As described in the pseudocode of Appendix A, an initial population of P frogs is created randomly. For S-dimensional problems (S variables), a frog i is represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{iS})$. Afterwards, the frogs are sorted in a descending order according to their fitness. Then, the entire population is divided into m memeplexes, each containing n frogs ($P = m \times n$). In this process, the first frog goes to the first memeplex, the second frog goes to the second memeplex, frog m goes to the mth memeplex, and frog m+1 goes back to the first memeplex, etc. Within each memeplex, the frogs with the best and the worst fitnesses are identified as X_b and X_w, respectively. Also, the frog with the global best fitness is identified as X_g. Then, a process similar to PSO is applied to improve only the frog with the worst fitness (not all frogs) in each cycle. Accordingly, the position of the frog with the worst fitness is adjusted as follows:

$$\text{Change in frog position}(D_i) = \text{rand}(\,) \times (X_b - X_w) \tag{10}$$

$$\text{New position } X_w = \text{current position } Xw + Di \tag{11}$$

$$D_{max} \ge Di \ge -Dmax$$

Where rand( ) is a random number between 0 and 1 and D_{max} is the maximum allowed change in a frog's position. If this process produces a better solution, it replaces the worst frog, otherwise the calculations in (10) and (11) are repeated but with respect to the global best frog (X_g replaces X_b). If no improvement becomes possible in this case, then a new solution is randomly generated to replace that frog. The calculations then continue for a specific number of iterations[6]. Accordingly, the main parameters of SFL are: number of frogs P, number of memeplexes, number of generation for each memeplex before shuffling, number of shuffling iterations, and maximum step size.

5. SFLA Procedure

The SFLA-based approach for solving the optimal placement and sizing of distributed generation problem to minimize the loss and improve the voltage profile takes the following steps:

In SFLA, each possible solution $X_i = (x_{i1}, x_{i2}, \ldots, x_{iS})$ that in this paper $X_i = l_1, l_2, \ldots, l_{bus}, x_1, x_2, \ldots, x_{power\ limit}$

Where, l is the number of DG location candidates and x is the number of capacity types of DGs are is considered as a frog. The steps of the algorithm are as follows**:**

Step 1: Create an initial population of P frogs generated randomly.

SFLA_Population $=[X_1, X_2, \ldots, X_p]_{p\times n}$

Where, P=m×n, N is the number of DG, m is the number of memplexes and n is the number of frogs in memplex**.**

Step 2: Sort the population increasingly and divide the frogs into m memplexes each holding n frogs such that P=m×n. The division is done with the first frog going to the first memplex, second one going to the second memplex, the mth frog to the mth memplex and the m+lth frog back to the first memplex. Fig.1 illustrates this memeplex partitioning process.

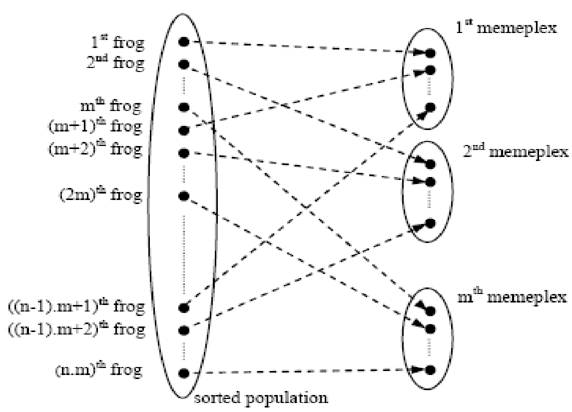

Figure 1. Memeplex partitioning process

Step 3: Within each constructed memeplex, the frogs are infected by other frogs' ideas; hence they experience a memetic evolution. Memetic evolution improves the quality of the meme of an individual and enhances the individual frog's performance towards a goal. Below are details of memetic evolutions for each memeplex:

Step 3-1: Set m_l=0 where m_l counts the number of memeplexes and will be compared with the total number of memeplexes m. Set y_l=0 where y_l counts the number of evolutionary steps and will be compared with the maximum number of steps (y_{max}), to be completed within each memeplex.

Step 3-2: Set $m_l=m_l+1$

Step 3-3: Set $y_l=y_l+1$

Step 3-4: For each memplex, the frogs with the best fitness and worst fitness are identified as X_w and X_b respectively. Also the frog with the global best fitness X_g is identified, and then the position of the worst frog X_w for the memplex is adjusted such as (10) and (11). Fig.2 demonstrates the original frog leaping rule.

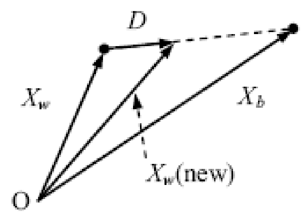

Figure 2. The original frog leaping rule

If the evolutions produce a better frog (solution), it replaces the older frog, otherwise X_b is replaced by X_g in (10) and the process is repeated. If no improvement becomes possible in this case a random frog is generated which replaces the old frog.

Step 3-5: If $m_l<m$, return to step3-2. If $y_l<y_{max}$, return to step 3-3, otherwise go to step 2.

Step 4: Check the convergence. If the convergence criteria are satisfied stop, otherwise consider the new population as the initial population and return to the step2. The best solution found in the search process is considered as the output results of the algorithm. The flowchart of the SFLA is illustrated in Fig. 3.

6. Simulation Results

The test system for the case study is radial distribution system with IEEE 33 buses as shown in Figure 4.The total loads for this test system are 3.72 MW and 2.3 MVR. The original total real power loss and reactive power loss in the system are 227.6934 KW and 150.1784 KVAR respectively. The substation voltage is 12.66 KV and the base of power is 10.00MVA.The current carrying capacity of branch No.1-9 is 400 A, and the other remaining branches including the tie lines are 200A. The minimum and maximum voltages are set at 0.95 and 1.05 p.u. respectively. The load data are given in Table A1 and branch data is in Table A2[7, 8]. For SFLA parameters, population size is 50. The maximum iteration for SFL algorithm is 5.The number of memplexes is 5. The number of frogs in memplex is 10.The number of iterations in each memeplexes is 5. The total number of algorithm iterations is 5.The maximum number of DG is 3. The maximum real power of DG is 1200KW. The improvement in the voltage profile after optimally placing the DGs is shown in Figure 5. Without DG, the bus no. 18 has the lowest voltage of 0.8889 p.u. and the bus voltage has improved to 0.9687 p.u. after installing DG. For the 33 bus systems, in table 1, the SFLA can obtain the same optimal size and location. For the 33bus system, first type DG can reduce the total real power loss by 48.09%. For two and three types DGs, they can further reduce the real power loss by 67.88% and 73.66%, respectively.

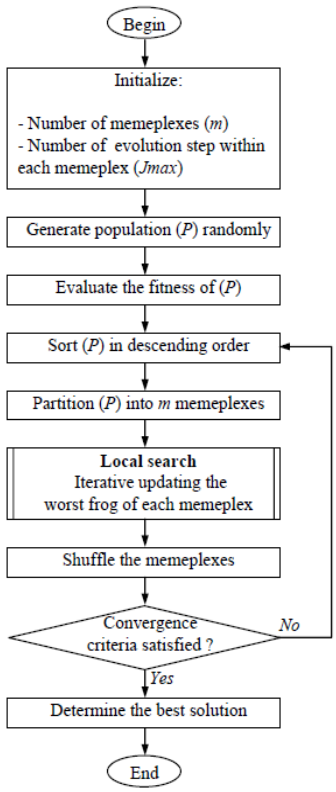

Figure 3. Flowchart of the SFLA

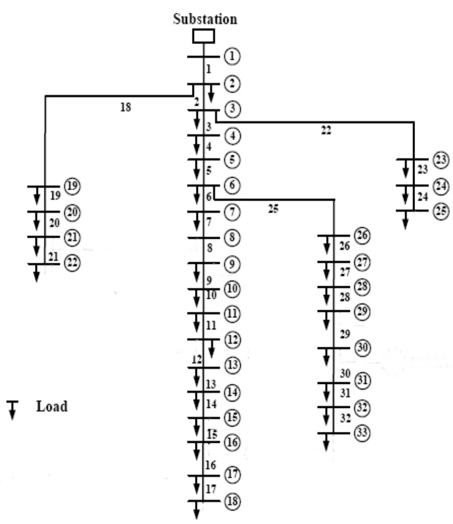

Figure 4. Single-line diagram of 33-bus radial distribution system

7. Conclusions

In this paper, a shuffled frog leaping algorithm (SFLA) for optimal placement and sizing of multi-DGs is efficiently minimizing the total real power loss and improve the voltage profile satisfying transmission line limits and constraints. The methodology is fast and accurate in determining the sizes and locations. DG regulating bus voltage will be considered in future research work.

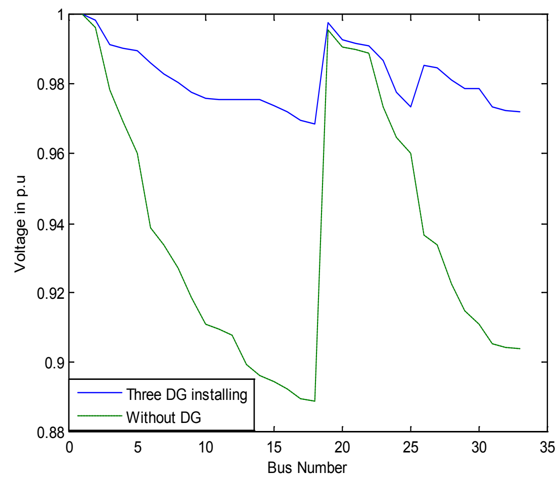

Figure 5. Bus voltage before and after DG Installation

Table 1. Optimal DG placement and sizing for DG

Method	Load flow analysis	SFLA		
Bus	---	30	30	14
DG_{size}(MW)	---	1.1999	1.0311	0.6022
Bus	---	---	9	30
DG_{size}(MW)	---	---	1.1623	0.7500
Bus	---	---	---	6
DG_{size}(MW)	---	---	---	1.0981
P_L(KW)	227.6934	118.1877	73.1137	59.9672
Real loss Reduction (%)	---	48.09	67.88	73.66

Appendix

Pseudocode for a SFL procedure:
Begin;
Generate random population of P solutions (frogs);
For each individual i∈P calculate fitness (i);
Sort the population P in descending order of their fitness;
Divide P into m memeplexes;
For each memeplex determine the best and worst frogs;
Improve the worst frog position using equations (10) or (11);
Repeat for a specific number of iterations;
End;
Combine the evolved memeplexes;
Sort the population P in descending order of their fitness;
Check if termination = true;
End;

Appendix

TableA1. Load data for 33-bus distribution system

Bus No.	P_L (kW)	Q_L (kVAr)	Bus No.	P_L (kW)	Q_L (kVAr)
2	100	60	18	90	40
3	90	40	19	90	40
4	120	80	20	90	40
5	60	30	21	90	40
6	60	20	22	90	40
7	200	100	23	90	50
8	200	100	24	420	200
9	60	20	25	420	200
10	60	20	26	60	25
11	45	30	27	60	25
12	60	35	28	60	20
13	60	35	29	120	70
14	120	80	30	200	100
15	60	10	31	150	70
16	60	20	32	210	100
17	60	20	33	60	40

TableA2. System data for 33-bus distribution system

Branch Number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.2512
3	3	4	0.3661	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	0.7115	0.2351
8	8	9	1.0299	0.7400
9	9	10	1.0440	0.7400

Table A2. (Continued)

Branch Number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
10	10	11	0.1967	0.0651
11	11	12	0.3744	0.1298
12	12	13	1.4680	1.1549
13	13	14	0.5416	0.7129
14	14	15	0.5909	0.5260
15	15	16	0.7462	0.5449
16	16	17	1.2889	1.7210
17	17	18	0.7320	0.5739
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3555
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3084
23	23	24	0.8980	0.7091
24	24	25	0.8959	0.7071
25	6	26	0.2031	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0589	0.9338
28	28	29	0.8043	0.7006
29	29	30	0.5074	0.2585
30	30	31	0.9745	0.9629
31	31	32	0.3105	0.3619
32	32	33	0.3411	0.5302
34	8	21	2.0000	2.0000
36	9	15	2.0000	2.0000
35	12	22	2.0000	2.0000
37	18	33	0.5000	0.5000
33	25	29	0.5000	0.5000

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