EasyChair Preprint

№ 8869

Optimal DG Placement in Distribution Networks Using Shuffled Frog Leap Algorithm

Askar Bagherinasab, Saifulnizam Abdul Khalid, Hadi Jahangere,
Mohammadjavad Kiani, Mahmod Zadebagheri and
Alireza Yousefpour

September 23, 2022

Optimal DG placement in distribution networks using Shuffled Frog Leap Algorithm

Askar bagherinasab, Saifulnizam Abdul Khalid, Hadi jahangere,Mohammad javad kiani,Mahmoud zadebagheri Alireza Yousefpour,
Faculty of Computer Science and Information System, UTMuniversity, Malaysia
DEP.Electrical Engineering. Islamic Azad University Mardashte
The corresponding author should be addressed to Askar bagherinasab: Askar.bagheri@yahoo.com

Abstract

Recent technological advancements in the field of renewable energy sources along with a significant rise in need to clean energy have led to increasing inclination to distributed generation (DG). Placement of DG in distribution networks leads to the system stability, increasing reliability, reducing losses, voltage profile improvement and decreasing final generation costs if it is conducted properly and accurately. In this study, Frog Leaping Algorithm is used for the optimal placement and determining the optimal amount of DG units to minimize costs. The suggested method is tested on an IEEE 70-bus system to determine the optimal place and capacity of the generators. Due to a large number of system buses it is a time-taking to reach the answers and the obtained results are indicative of the fact that optimal and proper placement of DG units can lead to significant reduction of the total costs.

Key words: Distributed generation, Shuffled Frog Leap Algorithm, Optimization of distribution networks

Introduction

Today, the majority of power plants is so big and with 250-1000 MW capacity due to economic reasons. It is obvious that such big power plants need is required to have large economic investment, large number of staff, big place as well as powerful and long power transmission lines leading to increasing costs a time of designing, installation, operation and maintenance [1]. On the other hand, such the big structure such plants make them more fragile against natural disasters. Such issues as well as environmental problems have raised the inclination to the new methods. Distributed generation which is defined as generating in small scale to be used on-site or nearby [2] mainly takes advantage of renewable sources such as wind, photo-voltaic energy, geothermal energy and ocean waves etc. In some cases, small diesel generators are used as the source of distributed generation. On the other hand, DG has been highly welcomed in the present competitive market due to its short time of designing and installation as well as its low cost of operation and maintenance. Recently, using DG has gathered momentum in the developing and developed countries. Studies conducted by EPRI shows that 25% of the total generated electricity in the whole world will belong to DG by the year 2012 [3]. There are numerous methods for placement and determining optimal capacity of distributed generations such as genetic algorithms, fuzzy logic, ant colony algorithm, analytical and mathematical methods or a combination of these methods [4,5]. In this study benefits from Frog Leaping Algorithm as one of the convenient and fast methods of optimization adopted from the natural behavior of frogs searching for food.

Shuffled Frog Leaping Algorithm (SFLA)

SFLA is a meta-heuristic approach to solve combinatorial problems of optimization. SFLA is a population-based algorithm used for heuristic search. This algorithm starts with a virtual sample of leaping frogs searching for an optimal place for food. This algorithm does not consider each single frog, but the population of frogs is of high consideration. Imagine a group of frogs leaping in a swamp in which there are some discontinuous rocks with specified amount food on each rock. Now, the goal is searching for the rock with the highest amount of food. Thus, the frogs should search for the optimal route to reach the food. In this algorithm, there is the relationship between the frogs and, so they can benefit from each other's information. As a result, each frog can improve its status in each step using its own and other frogs' information.

Mathematical Expression of SFLA

The following 10 steps present mathematical expression of SFLA. It is worth mentioning that SFLA can be used in the single-variable or multi-variable optimization problems. Like this study which focuses on combinatorial optimization, other combinatorial optimization problems can also be solved using SFLA. The steps to implement SFLA can be presented as follows:

1- Selecting m, the number of memeplexes
2- Selecting the number of frogs in each memeplex
3- Determining the number of iterations in each memepolex
4- Determining the total number of iterations in the whole solution
5- Generating the required population through random generation
6- Evaluating the fitness of each frog
7- Each of the following 5 steps is implemented for each memeplex separately

a) Determining the best frog performance (X_b) and the worst frog performance (X_w)

b) Improving the worst frog position through the following formula.
$(D_i) = \text{rand}\,() \times (X_b - X_w)$ (1)

In formula (1), D_i is the extent to which the worst frog position should be modified in the memeplex. The new position of the frog is updated though the following formula:

$$X_w = X_w(\text{old}) + D_i \qquad (2)$$
$$D\max \geq Di \geq D\min$$

c) Repeating step a for a specified number of iterations initially determined.

d) After completing the maximum iterations, the best output must be saved.

8) Implementing step 7 for all memplexes
9) Since only one answer is saved as the best answer in each memeplex, the optimal answers will be as many as the memeplexes among which only one answer is selected as the final answer.
10) Printing the results and exiting the program

The system under study

This study uses SFLA for optimal placement of DGs and determining place, capacity and number of them. The cost function is calculated using Fuzzy functions and minimization is conducted using FLA. In order to simulate the algorithm, a 70-bus radial distribution system has been used. This system has the nominal voltage of 11-KV. This system provides two-sided feeding and has 4 feeders and 74 branches. Figure 1 shows the 70-bus system under investigation. In addition, the complete information about the system including information about all branches and loads is available in Appendix A. It is worth mentioning that the common methods used for load distribution studies in power systems such as Gose-Sidel and Newton-Raphson cannot be used due to the large number of memeplexes and branches and high R/X ratio of lines as compared to power systems. In addition, since majority of the distribution systems have single-phase, two-phase and three-phase lines and loads, network-based topology method was used to calculate load distribution of the system.

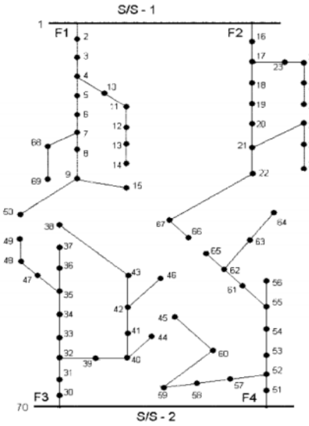

Fig1. shows the 70-bus system under investigation

Studying load distribution in distribution systems

In network-based typology method, load distribution calculations of each transmission line are expressed through a 4×4 matrix including impedance of each load and ground system as well as mutual impedance of each load with the ground system. Figure 2 presents the equivalent circuit of the three-phase four-wired line between the buses i and j.

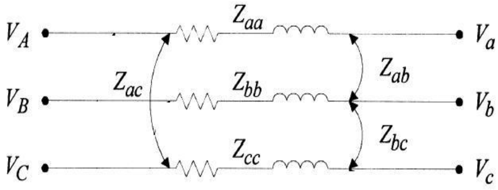

Fig.1. Equivalent circuits of three-phase lines

In distribution systems nicely connected to the ground, Vn and V_N can be assumed equal to 0. With reference to this assumption, impedance of each three-phase four-wired line can be expressed in a 3×3 matrix equation (3) as follows:

$$Z = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \qquad (3)$$

Now, absence of one phase on line L will make the related row and column equal to 0.

In the next stage, each radial network memeplex under investigation will undergo layered numbering.

After numbering the above node is completed, distribution is considered an infinite bus (with a given magnitude and phase) and at the beginning of the calculations, the initial voltage of all nodes are considered equal to voltage of infinite bus. Then, for example in Kth stage, iterative algorithm is used through the three following stages.

Calculating the nodes current

$$\begin{bmatrix} I_{ia} \\ I_{ib} \\ I_{ic} \end{bmatrix}^{(k)} = \begin{bmatrix} (\mathrm{S_{ia}}/\mathrm{V_{ia}^{(k-1)}})^* \\ (\mathrm{S_{ib}}/\mathrm{V_{ib}^{(k-1)}})^* \\ (\mathrm{S_{ic}}/\mathrm{V_{ic}^{(k-1)}})^* \end{bmatrix} - \begin{bmatrix} Y_{ia}^* & & \\ & Y_{ib}^* & \\ & & Y_{ic}^* \end{bmatrix} \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix}^{(k-1)} \qquad (4)$$

And in equation (4):

Iia, Iib and Iic: Injected currents into different phases of the node i and in the load have constant power (or admittance connection in parallel elements). *Sia, Sib and Sic*: Given injected power into the node i. *Yia, Yib and Yic*: Admittances of all parallel connected to the node i. (4) The target function and using fuzzy functions to evaluate the target function

Backward sweeping movement

This stage starts from the last layer of the given current of stage 1 toward the first layer of current of all routes based on the following equation:

$$\begin{bmatrix} J_{ia} \\ J_{ib} \\ J_{ic} \end{bmatrix}^{(k)} = \begin{bmatrix} I_{ja} \\ I_{jb} \\ I_{jc} \end{bmatrix}^{(k)} + \sum_{m \in M} \begin{bmatrix} J_{ma} \\ J_{mb} \\ J_{mc} \end{bmatrix}^{(k)} \qquad (5)$$

In which *Jia, Jib and Jic*: flowing currents in components of line L and Mare sum of the components connected to the node i.

Forward sweeping movements

By starting from the first layer and using the following equation, voltage of nodes in different layers is calculated:

$$\begin{bmatrix} V_{ja} \\ V_{jb} \\ V_{jc} \end{bmatrix}^{(k)} = \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix}^{(k)} - \begin{bmatrix} Z_{aa,i} & Z_{ab,i} & Z_{ac,i} \\ Z_{ba,i} & Z_{bb,i} & Z_{bc,i} \\ Z_{ca,i} & Z_{,cbi} & Z_{cc,i} \end{bmatrix} \begin{bmatrix} J_{ia} \\ J_{ib} \\ J_{ic} \end{bmatrix}^{(k)} \qquad (6)$$

After these three stages and based on the obtained results, power discrepancy of nodes (calculated and real) is calculated using the following equations. If the losses exceed the previously determined limit, the above three stages are repeated.

$$\begin{aligned} \Delta S_{ia}^{(k)} &= V_{ia}^{(k)}\left(I_{ia}^{(k)}\right) - Y_{ia}^*|V_{ia}|^2 - S_{ia} \\ \Delta S_{ib}^{(k)} &= V_{ib}^{(k)}\left(I_{ib}^{(k)}\right) - Y_{ib}^*|V_{ib}|^2 - S_{ib} \qquad (7) \\ \Delta S_{ic}^{(k)} &= V_{ic}^{(k)}\left(I_{ic}^{(k)}\right) - Y_{ic}^*|V_{ic}|^2 - S_{ic} \end{aligned}$$

The method used in this study to introduce the network to load distribution algorithm is based on the two matrixes BIBC5 and BCBV6 and the equivalent injected currents.

Target functions and using fuzzy functions to evaluate the target function

The target function to be minimized in this study is a cost function and contains three parts including voltage deviation of all buses, generation cost of all DG units and the emissions generated by power production in the above bus as well as the emissions generated by power production of the DG units operating by internal combustion engines or micro-turbines. Voltage deviation is in the form of a total amount indicative of the total voltage deviation in all system buses and is calculated based on the equation number 8.

$$V_{\mathrm{e}} = \sum_{\mathrm{N=2}}^{\mathrm{N_b}} \frac{\mathrm{V(1)-V(N)}}{\mathrm{N_b}} \qquad (8)$$

In the above equation, V_{e} indicates sum of deviation of the total voltage of buses. N indicates the number of the bus and N_b indicates the total number of buses. DG costs include the initial cost, fuel, operation and maintenance. DG cost function is defined in the following way:

$$C(DG)= a + bp \qquad (9)$$

In this equation, P is the active power produced by DG and a and b are calculated through the following equations:

$$a = \frac{\text{capital cost}\left(\frac{\$}{\text{kw}}\right) \times \text{capacity(kw)} \times \text{Gr}}{\text{Life time(year)} \times 365 \times 24 \times \text{Lf}}$$

$$b=Fuel\ Cost(\$/kw)+O,MCost(\$/kw) \qquad (10)$$

In the above equations, Gr is annual profit rate, Lf is the load factor of DG which are considered equivalent to unit . The emissions generated by DG units operating on fossil fuel as well as the pollution caused by the production in the above distribution are the third quantity or amount that are supposed to be minimized. The total amount of pollution is calculated using the following equation:

$$Emission=0.3\times p(DG) + .7 \times P(substation) \qquad (11)$$

As shown in the above equation, only 30% of DG units operate on fossil fuel and P (DG) indicates the total amount of the power generated by all DG units and 70% of the power production units in the above distribution system operate on fossil fuel. In the above equation, P(substation) indicates the total power transmitted from the above substation distribution.

Using fuzzy functions to evaluate the target functions

Regarding the fact that the three discussed amount including voltage deviation, generation cost and rate of emission are of different kinds, they cannot be summed up. On the other hand, what was intended in the suggested algorithms was minimizing the three amounts simultaneously. In order to achieve this goal, each amount in the target function is expressed fuzzily as an amount between 0 and 1 through a special fuzzy function and the three final amounts will be summed up through fuzzy equation (9).

Figure (4) shows fuzzy membership function for voltage deviation, generation cost and rate of emission.

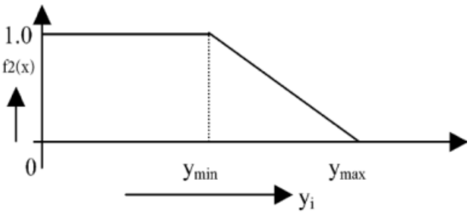

Fig 2. Fuzzy membership function

It is worth mentioning that Y_{max} and Y_{min} have been considred independently for each of the three situations. In each situation of system simulation through load distribution program and calculating the mentioned amount, Y_{min} is calculated in the absence of DG units and Y_{max} has been considered 1.5 times as much as Y_{min}.

Now, the output of voltage deviation (C1), generation cost (C2) and rate emission which are numbers between 0 and 1 are summed up through fuzzy equation.

$$C_{equal} = \frac{C_1 \times C_2 \times C_3}{C_1 + C_2 + C_3} \qquad (11)$$

In the above equation, Cequal indicates cost of each of the three amounts and it is aimed to minimize Cequal in the suggested algorithm.

Simulation results

This study tried to provide a software for optimal DG placement of a 70-bus sample network using programming language in MATLAB. This software is able to detect place and the capacity of the DG units based on Shuffled leaping Frog Algorithm (SFLA). In addition, the results obtained from the suggested method will be compared with the results of genetic algorithm. The comparison is conducted using a Pentium 4 computer equipped with a 2800 MH processor. The results obtained from optimization based on the suggested method and optimization based on the genetic algorithm are as follows.

Voltage of buses

Voltage of all buses has been presented in three different situations figure (3). Voltage of buses has been calculated in the absence of DG units in the first situation, in presence of DG units that their place and capacity have been obtained using the suggested method in the second situation and in presence of DG units that their place and capacity have been obtained using the genetic algorithm.

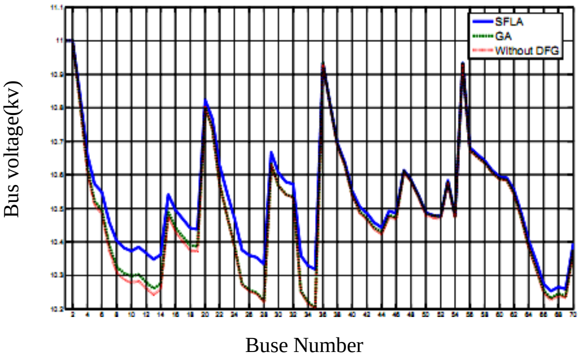

Fig 3. All of voltage in three different modes

based on the genetic algorithm, the variables are arranged in the following way using tool box of genetic algorithm software in MATLAB.

Population size= 100

Population type= Double vector

Crossover fraction= 0.8

Mutation function= Gaussian

A) Place and Capacity of DG units

The following table illustrates place and capacity of DG units based on SFLA and Genetic Algorithm.

Table 1: Place and capacity of DG units based on SFLA and GA

Location Installation SFLA	Capacity SFLA (KW)	Location GA	Capacity GA (KW)
4	*46.50*	*3*	*25.84*
7	*21.22*	*7*	*37.36*
11	*40.98*	*8*	*24.62*
12	*46.13*	*10*	*29.64*
15	*36.57*	*11*	*39.96*
26	*39.93*	*19*	*47.80*
28	*37.04*	*34*	*34.15*
30	*24.34*	*38*	*40.81*
33	*41.66*	*42*	*23.38*
35	*47.98*	*44*	*36.63*
42	*39.47*	*52*	*43.38*
55	*21.11*	*62*	*33.18*
65	*38.01*	*67*	*29.96*

It is worth mentioning that maximum power of DG units is considered equal to 50-KW in both of the methods, SFLA and GA. It takes 2:18:12 and 2:54:19 to reach the final answer in SFLA and GA respectively.

B) Voltage deviation, generation cost and rate of emission

Table 2 illustrates Voltage deviation, generation cost and rate of emission for both SFLA and GA.

Table 2: Voltage deviation, generation cost and rate of emission based on SFLA and GA

	SFLA	**GA**
Voltage deviation (V_e)	***0. 4733***	***0.5097***
Cost of production ($)	***6.5119*10^7***	***6.4223*10^7***
Pollution $(^{ton}/_{h})$	***4.3031*10^3***	***4.6240*10^3***

Conclusion

Results of this study are indicative of the fact that the lowest rate of network losses is achieved when feeding is done on-site. In fact, if any consumer can accompany a generation unit, network losses can be minimized. However, this goal cannot be achieved at least for the time being due to economic reasons. Moreover, precise placement of DG units plays an important role in minimizing losses, voltage deviation and rate of emission as the results of this study illustrate.

Refrence

[1] Th. Oo , Le. Van Phu. 2004. *“Distributed Generator Placement in power Distribution system using GeneticAlgorithm to Reduce Losses”* . Energy Program, Asian Institute of Energy, Vol: 9. No:3

[2] M.Rabinowitz. 2000. *“Power system of future”*. IEEE Power Engineering Review. Part 4.

[3] Th.Ackermann, G. Anderson, L. soder. 2001. *“Distributed Generation: A Electric efinition”.* Electric Power system Research, pages:195-204.

[4] E.B.Cano. 2007. *“Utilizing Fuzzy Optimization for Distributed Generation Allocation”* . IEEE Trans. On power system, Vol:6. No:3.

[5] T.Griffin, et al. 2000. *“Placement of Dispersed Generation system for Reduced Losses”*. 33rd Annu. Hawaii Int. conf. on system sciences. Maui, HI.

[6] C.Yang, etal. 2008. *“A combination of Shuffled frog Leaping Algorithm and Genetic Algorithm FOR Genetic selection”*. Journal of Advanced computational Informatics. Vol:12. No:3.

[7] D. DAS. 2006. *“A fuzzy Multiobjective Approach for Network Reconfiguration of Distribution system”*. IEEE Trans. On Power Delivery. Vol:21. No:1.

[8] J-H. Teng. 2000. *“A Network Topology based Three phase load flow for Distribution system”*. proc. Natl. Sci. counc. Roc(A) Vol:24. No:4. Pp:259-264.

[9] A.G.Bhutad. S.V.Kulkarni, S.A.Khapurave. 2003. *“Three phase load flow Method for Radial Distribution Networks”*. Power Transmission and Distribution \785, TENCON 2003\784 .