

Research on solving the optimal sizing and siting of distributed generation

Bo Wang

Shandong Appraisal Centre for Environment and Engineering, Jinan, 250012, China

E-mail: eia001@126.com

Abstract. In this paper, a distributed network planning model is proposed with the goal of minimizing the sum of distributed power investment cost, network loss and interruption cost. In order to compare the performance of differential evolution algorithm (DE) and genetic algorithm (GA) in solving the optimal sizing and siting of distributed generation in distribution networks, the two algorithms were adopted to optimize the capacities and positions of DGs. Through analysis on a 10-bus test system, the study results show that the proposed model and algorithm can get reasonable planning scheme. And in solving simple optimization problems, both GA and DE Algorithms can get good results, but compare to DE, GA is of slow convergence speed and the convergence process is not quite stable.

1. Introduction

The optimal access problems of the distributed power, as a tool to promote the development of intelligent power grid, are gaining more and more attention from experts and scholars [1-2]. Distributed generation (DG), a supplement to centralized generation, mainly includes wind power and solar power, small hydropower and miniature gas turbine, etc [3-4]. The combination of distributed generation and centralized generation can leverage their advantages. In fact, if DG is properly placed in a distribution network, it can reduce distributed power investments power losses and interruption cost for network enforcing. But, if it is not correctly applied, it can cause degradation of power quality and reliability, increase in system losses and costs [5]. The problem of DG sizing and siting is of great importance, for that reason, optimization methods capable of indicating the best solution for a given distribution network have been extensively studied [6-7].

So far, many methods for solving the problem of DG optimization exist in literature. Examples of those methods include Lagrange multiplier [8], genetic algorithm [9], the improved differential evolution algorithm [10], tabu search algorithm [11] and etc. Also, definitions of optimization vary among authors' opinions. The objectives can be the minimization of the system operation cost [8], maximization of the benefit/cost ratio [9], or minimization of network loss [11].

Differential evolution algorithm (DE) and genetic algorithm (GA) are presented in this paper as the optimization techniques for the sizing and siting of DG in distribution network. In order to reduce cost in distribution network, distribution network planning model based on distributed power investment cost, network loss and the interruption cost is developed. Section 4 presents a brief introduction about load flow calculation issues. At last, an IEEE 10-bus application system is used to test our model, and the study results show that the proposed model and algorithms can get reasonable planning scheme, and the advantages and disadvantages of the two algorithms are discussed.



2. Genetic algorithm in DG siting and sizing problem

GA is a search heuristic that mimics the process of natural evolution. In a genetic algorithm, to an optimization problem, a population of strings, which encode candidate solutions, evolves toward better solutions. The evolution usually starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population based on their fitness, and modified to form a new population. The new population is then used in the next iteration of the algorithm. This generational process is repeated until a termination condition has been reached. Then a satisfactory solution has been reached. GA has the features of implied parallelism, global searching capability, simple encoding and implementation, and is not limited by constraint conditions. It is commonly used to solve an optimal problem [12-16]. The flow chart of GA to solve the DG siting and sizing problem is given in figure 1. [17-19]

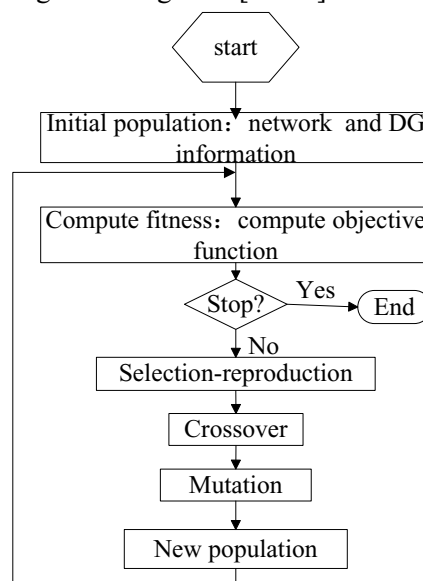


Figure1. Proposed Flow Chart

3. Differential evolution algorithm in DG siting and sizing problem

DE is also a search heuristic that mimics the process of natural evolution. It is a method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Also, DE generates new points that are perturbations of existing points, but these deviations are neither reflections, nor samples from a predefined probability density function. Instead, DE perturbs vectors with the scaled difference of two randomly selected population vectors. To produce the trial vector, DE adds the scaled, random vector difference to a third randomly selected population vector. In the selection stage, the trial vector competes against the population vector of the same index. The select-and-save step in which the vector with the lower objective function value is marked as a member of the next generation. DE works like GA [20].

DE can be used for problems whose objective functions are non-continuous, non-linear, multi-dimensional, non-differentiable, noisy or flat, etc. Or DE can be used to find approximate solutions to such problems. It has been found that DE is more accurate and efficient than controlled random search and another GA in some problems.

4. Distribution network planning model

The objective function was developed for the DG sizing and siting in distribution network is to decrease the costs of DG investment, the losses of network and the costs of interruption [21-24].

$$\min f = \sum_{i=1}^{n_{DG}} (K_{DG_i} C_{DG} S_{DG_i} + C_r E_{DG_i} r) + C_{pu} \Delta P T_{max} + C_Q \sum_{i=0}^{n_{DG}} \sigma_i T_i (P_{load_i} - S_{DG_i}) \quad (1)$$

Where K_{DG_i} presents coefficient of the i th yearly DG investment cost, C_{DG} presents yearly DG investment cost (\$/KW), C_r presents yearly DG operating cost (\$/KW), S_{DG_i} stands for the capacity limit of DG i (MW), E_{DG_i} stands for power generated from DG i in a year (MWh), r stands for the discount rate, C_{pu} stands for electricity market price (\$/MWh), ΔP is the network losses (\$), T_{max} is maximum load loss hours, C_Q is Economic loss because of unit power lack (\$/KWh), σ_i is weight coefficient of the load i , T_i is the island running time of the load, P_{load_i} is the load of node i in network, f is the objective function (\$).

The optimization of above objective function is done by considering the following limitations:

(1) The line power flows

$$\begin{cases} P_{DG,j} - P_{L,j} = U_j \sum_{i \in J} U_i (G_{ji} \cos \theta_{ji} + B_{ji} \sin \theta_{ji}) \\ Q_{DG,j} - Q_{L,j} = U_j \sum_{i \in J} U_i (G_{ji} \sin \theta_{ji} + B_{ji} \cos \theta_{ji}) \end{cases} \quad (2)$$

(2) The maximum flow capacity of buses in network

$$0 \leq I_i \leq I_i^{\max} \quad i = 1, 2, 3, \dots, n_b \quad (3)$$

(3) The permissible voltage amplitude

$$U_i^{\min} \leq U_i \leq U_i^{\max} \quad i = 1, 2, 3, \dots, n_n \quad (4)$$

(4) The permissible DG power

$$0 \leq P_{DG_i} \leq P_{DG_i}^{\max} \quad i = 1, 2, 3, \dots, n_D \quad (5)$$

Where $P_{DG,j}$ is the injected DG active power to node j , $Q_{DG,j}$ is the injected DG reactive power to node j , $P_{L,j}$ is the injected active load to node j in network, $Q_{L,j}$ is the injected reactive load to node j in network, G_{ji} is conductivity value, B_{ji} is electricity value, θ_{ji} is voltage phase Angle, I_i^{\max} is maximum acceptable flow in path I , n_b is the number of total path, U_i^{\min} is minimum voltage amplitude of i in network, U_i^{\max} is maximum voltage amplitude of i in network, n_n is the number of total node, $P_{DG_i}^{\max}$ is maximum acceptable DG capacity, n_D is the number of candidate node.

5. Power flow calculation

According to the radial structure and ring opening operation characteristic of distribution network, backward / forward sweep method for power flow calculation is presented [25].

Let us consider a radial network, as in Figure 2. the backward/forward sweep method for the power-flow computation is an iterative method in which, at each iteration, some computational stages are performed [26]:

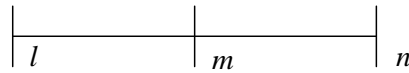


Figure 2. the wiring diagram of feeder

$$\begin{cases} \Delta P_{lm}^{(n)} = \frac{r_{lm} [(\sum_{p \in c_m} P_{mp}^{(n)} + P_{L,m})^2 + (\sum_{p \in c_m} Q_{mp}^{(n)} + Q_{L,m})^2]}{(U_m^{(n-1)})^2} \\ \Delta Q_{lm}^{(n)} = \frac{x_{lm} [(\sum_{p \in c_m} P_{mp}^{(n)} + P_{L,m})^2 + (\sum_{p \in c_m} Q_{mp}^{(n)} + Q_{L,m})^2]}{(U_m^{(n-1)})^2} \end{cases} \quad (6)$$

$$\begin{cases} P_{lm}^{(n)} = \Delta P_{lm}^{(n)} + P_{L,m} + \sum_{i \in c_i} P_{mp}^{(n)} \\ Q_{lm}^{(n)} = \Delta Q_{lm}^{(n)} + Q_{L,m} + \sum_{i \in c_i} Q_{mp}^{(n)} \end{cases} \quad (7)$$

$$I_{lm}^{(n)} = \frac{P_{lm}^{(n)} - jQ_{lm}^{(n)}}{(U_{lm}^{(n-1)})^*} \quad (8)$$

$$U_m^{(n)} = U_l^{(n)} - I_{lm}^{(n)}(r_{lm} + jx_{lm}) \quad (9)$$

Where, $\Delta P_{lm}^{(n)}$ is active network loss, $\Delta Q_{lm}^{(n)}$ is reactive network loss, $P_{L,m}$ is active load to node m in network, $Q_{L,m}$ is reactive load to node m in network, $\sum P_{mp}^{(n)}$ is active power flow in path mp, $\sum Q_{mp}^{(n)}$ is reactive power flow in path mp, $U_m^{(n)}$ is the node voltage, $r_{lm} + jx_{lm}$ is impedance of line lm, $I_{lm}^{(n)}$ is flow in path lm.

6. Example analysis

The studying distribution system in this project is IEEE 10-bus network (figure 3.). It is 10kV voltage grade for distribution network and the system total load is 7.5MW and 5.625 Mvar.

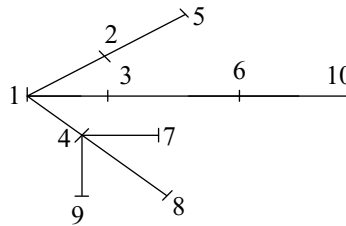


Figure 3. IEEE 10-bus system

In order to test the proposed methodology DG units have been considered, 100 KW .The number of node, to install, is 9. The maximum level of DG penetration admitted for the study is 20% of total load. The cost of Yearly DG investment has been taken as 2039.7\$ /KW. The cost of Yearly DG operating has been taken as 0.005\$/(KWh).Electricity market price has been assumed 0.078\$/(KWh) .Economic loss has been assumed 15.7\$/KWh .The period taken into consideration for the planning study is 20 years long.

Based on past experience, as well as the results of the experiment, the size of population has been assumed 50 and the maximum iteration 300.

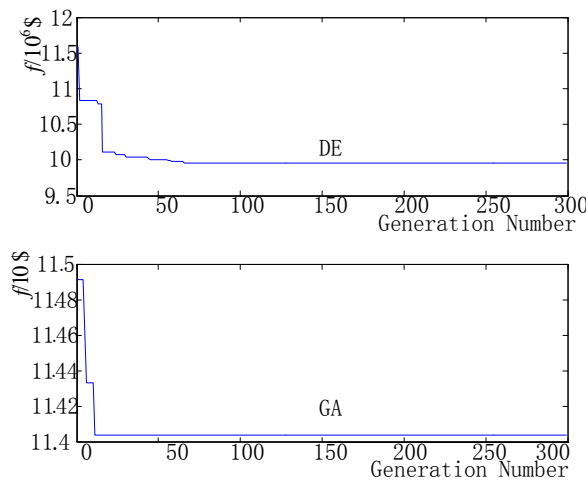


Figure 4. simulation process

Figure 4. shows iterative process of GA and DE methods to reach the optimization answer. By observing the figure, based on the network, GA and DE methods in DG siting and sizing problem in distribution network are efficient in reaching the closely optimization answer. But DE has better speed and is more stable.

Table 1. DG's capacity and position

	capacity and position of DG (kw)
Optimizing by DE Method	400(2),400(3),400(5),200(8)
Optimizing by GA Method	300(2),300(3),200(4),300(5),200(8),200(10)

Table 2. Results by using GA and AC methods

	Optimizing by DE method	Optimizing by GA method	Without DG
Investment cost of DG(\$)	2,517,987	2,697,843	
Network loss(\$)	352	347	450
Interruption cost(\$)	97,057,399	111,344,399	162,683,399
Total(\$)	99,575,740	114,042,591	

Table 1 shows the capacity and position of DG and table 2 shows the results of investment cost of DG, network loss, and interruption cost ,in this network ,by using DE and GA .It can be found that network loss and interruption cost have decreased after installing DG.

7. Conclusion

DG will play more and more important role in the electric power system. In order to let the application of DG get the best result from DG techniques, researches on an optimization method capable of indicating the best solution for a given distribution network will be extensively conducted. In this paper, distribution network planning model based on distributed power investment cost, network loss and the interruption cost is developed. GA and DE algorithms were proposed to optimize the capacities and positions of DG based on the model. By observing the figure and the table, based on the network, following results obtained:

(1) The distribution network planning model based on distributed power investment cost, Network loss and the interruption cost, in this paper, is very efficient.

(2)Both GA and DE methods in DG siting and sizing problem in distribution network are efficient in reaching the closely optimization answers.

(3)For DG siting and sizing problem , compare to GA,DE has better speed and is more stable to reach the optimization answer

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