Neurocomputing 78 (2012) 55–63

Contents lists available at SciVerse ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Group search optimizer based optimal location and capacity of distributed generations

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ARTICLE INFO

Available online 26 August 2011

Keywords:
Distributed generations
Optimal location and capacity
Swarm intelligence
Improved group search optimizer

ABSTRACT

This paper presents a novel efficient population-based heuristic approach for optimal location and capacity of distributed generations (DGs) in distribution networks, with the objectives of minimization of fuel cost, power loss reduction, and voltage profile improvement. The approach employs an improved group search optimizer (iGSO) proposed in this paper by incorporating particle swarm optimization (PSO) into group search optimizer (GSO) for optimal setting of DGs. The proposed approach is executed on a networked distribution system—the IEEE 14-bus test system for different objectives. The results are also compared to those that executed by basic GSO algorithm and PSO algorithm on the same test system. The results show the effectiveness and promising applications of the proposed approach in optimal location and capacity of DGs.

1. Introduction

Distributed generation (DG) is a small generator or an electric power source scattering throughout a power system (connected directly to the distribution network or on the customer site of the meter) [1]. DG is expected to become more important in the future generation system. Due to locally available resources and the small scale, DG units are mostly installed in the demand system and directly connected to the distribution system. So far, DG has many types including wind turbines, photovoltaic, fuel-cells, biomass, micro turbines, small hydroelectric plant, etc. DG has different categories. For example, there are nonrenewable and renewable DG from the technological aspect; by rating of the generation source ranges, it can be divided into four levels including micro DG (1 W–5 kW), small DG (5 kW–5 MW), medium DG (5 MW–50 MW), and large DG (50 MW–300 MW).

The newly introduced DG units connected to local distribution systems have a significant impact on the power-flow, voltage profile, stability, continuity, and quality of power supply for customers and electricity suppliers [2]. Therefore, selection of optimal location and capacity of the DG is a necessary process to maintain the stability and reliability of existing system effectively before it is connected to a power grid. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. Even if the location is fixed due to some reasons, improper capacity would increase negative effect on the system beyond the case without DG. Optimal location and capacity depend on the type of DG as well. The selection of the best places for installation and the preferable capacity of the DG units in large distribution systems is a complex combinatorial optimization problem. For these reasons, the use of an efficient optimization method capable of indicating the best solution for a given distribution network can be very useful. Hence, in this paper, an attempt is to propose a population-based heuristic method for optimal location and capacity of DGs.

In power distribution systems, the optimal location and capacity of DG units is a significant project, which has been continuously studied in order to achieve different aims. To solve this planning problem, the optimal location of DG, and the optimal size of the DG for a given location are handled independently for radial feeders and networked systems, respectively [3,4]. The objective can be the reducing power loss of distribution network, the investment and operation cost, or improving the power quality including the voltage profile, etc. In tackling this problem, many approaches have been proposed in recent years, including the analytical approaches, second-order algorithm, linear programming, dynamic programming, ordinal optimization, simulated annealing, genetic algorithms, and meta-heuristics approaches [3–12]. Wang and Nehrir [3] present analytical methods to determine the optimal location to place a DG in radial as well as networked systems to minimize the power loss of the system. Hung et al. [5] propose analytical expressions for finding

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doi:10.1016/j.neucom.2011.05.030

optimal size of four types of DG units to achieve the highest loss reduction in distribution networks. Several artificial intelligence algorithms have been used to solve the problem. Nara et al. [6] employ the Tabu search method to optimize the placement of DGs. Singh et al. [7] use a genetic algorithm for optimal sizing and placement of DG to minimize system power loss; while Jeon et al. [8] adopt simulated annealing (SA). Jabr and Pal [9] present an ordinal optimization (OO) method for specifying the locations and capacities of distributed generation (DG) such that a trade-off between loss minimization and DG capacity maximization is achieved. In [10], ant colony search (ACS) algorithm is used to reduce losses for the purpose of network reconfiguration. Ding et al.[11] apply particle swarm optimization (PSO) to solve DG planning problem. Objective can also be the voltage profile improvement. Sedighizadeh and Rezazadeh [12] and Sedighi and Igderi [13] address GA algorithm and PSO algorithm to improve the voltage profile in power distribution network, respectively. Lalitha et al. [14] present a new methodology using fuzzy and artificial bee colony (ABC) algorithm for the placement of DGs in the radial distribution systems to reduce the real power losses and to improve the voltage profile.

In this paper, a novel population-based heuristic algorithm named group search optimizer (GSO) [15] is developed to find the optimal location and capacity of DGs in complex networked distribution systems. By incorporating particle swarm optimization (PSO) with group search optimizer (GSO), this paper proposed an improved group search optimizer (iGSO) model for optimal setting of DGs. We take power quality and economy objectives into account to define the optimization objectives in this paper, including power losses, voltage profile and fuel cost. The proposed approach is executed on the IEEE 14-bus test system with different type of DGs. The results are also compared to those executed by basic GSO algorithm and PSO algorithm on the same test system.

In the rest of the paper, we will first present the problem formulation of the optimal DG location and capacity in Section 2. Then we will propose an improved group search optimizer (iGSO) after brief introduction of the basic GSO algorithm in Section 3. The simulation of iGSO algorithm applied on IEEE 14-bus test system will be presented in Section 4, as well as the results comparison with PSO and GSO algorithm. The paper is concluded in Section 5.

2. Problem formulation

The problem investigated in this work is to find the optimal DG location and capacity for a distribution network, to achieve minimization of fuel cost, power loss reduction and voltage profile improvement.

2.1. System power flow

The goal of a power flow calculation is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions. Power flow calculation is a critical tool for planning future expansion of power systems, as well as in determining the best operation of existing systems, etc. In this paper, power flow calculation is also necessary to obtain the variation of power and voltage distributions when some DGs are installed into the system. It is a primary step to find an optimal programming scheme (optimal location and capacity) of DGs in a distribution network. The standard power flow or load flow problem involves solving for the set of voltages and flows in a network corresponding to a specified pattern of load and generation. A set of equations of power flow calculation is in the form of $g(x)=0$, constructed by expressing a subset of the nodal power balance equations as functions of unknown voltage quantities.

In the traditional formulation of power flow, the power balance equation in $g(x)=0$ is split into its real and reactive components, expressed as functions of the voltage angles θ, voltage magnitudes V_m, generator injections P_g and Q_g, where the load injections P_d and Q_d are assumed to be constant and given by

$$\begin{cases} g_P(\theta,V_m,P_g)=P_{loss}+P_d-P_g=0 \\ g_Q(\theta,V_m,P_Q)=Q_{loss}+Q_d-Q_g=0 \end{cases} \tag{1}$$

where P_{loss} and Q_{loss} are the active power loss and reactive power loss, respectively.

Generator injections P_g and Q_g are given as

$$\begin{cases} P_g=P_{SUB}+\sum_{i=1}^{N_{DG}} P_{DG_i} \\ Q_g=Q_{SUB}+\sum_{i=1}^{N_{DG}} Q_{DG_i} \end{cases} \tag{2}$$

where P_{SUB} and Q_{SUB} are the active and reactive power injection of substation, respectively, P_{DGi} and Q_{DGi} are the power injection of ith DG, and N_{DG} represents the number of DGs.

In this paper, the Newton method [16] is used to calculate the power flow. In general, distributed generations can be modeled as a voltage-controlled node (PV node) or as a complex power injection (PQ node) [17]. This gives flexibility in modeling various types of DGs. In this paper, proper models will be used due to special objective function.

2.2. Objective outlines

2.2.1. Optimization of active power loss

Considering only power loss-based objectives in optimization problem may result in a feasible solution that has unattractive fuel cost. In this case, a two-fold objective function is proposed in order to minimize both active power loss and the fuel cost.

$$OBJ_1 := f_1 = min(P_{loss}+Cost) \tag{3}$$

where P_{loss} is active power loss, which can be obtained with power flow calculation. To intuitively describe the problem, we directly represent it as $P_{loss}=\sum_{i=1}^{L}|I_i|^2\cdot R_i$, where L is the number of lines in the power system.

Cost is defined as total fuel cost given by $Cost=\sum_{i=1}^{NG}(a_i+b_iP_{Gi}+c_iP_{Gi}^2)(\$/\mathrm{h})$, where a_i, b_i, and c_i are three cost coefficient of the ith generator. The value of these coefficients depends on different power system and different generators. In this study, IEEE 14-bus test system is used. Therefore, the corresponding coefficients are given in Table 1. Other cost such as purchase and installment cost for DG is neglected.

Therefore, the objective function can be expressed as

$$f_1=min\left(\sum_{i=1}^{L}|I_i|^2\cdot R_i+\sum_{i=1}^{NG}(a_i+b_iP_{Gi}+c_iP_{Gi}^2)(\$/\mathrm{h})\right) \tag{4}$$

Subject to: power flow Eqs. (1), (2) and other constraints, such as permissible voltage limits at each bus defined as $V_{i\,min}\le V_i\le V_{i\,max}$, the maximum capacity of DGs in $P_{DGi\,min}\le P_{DGi}\le P_{DGi\,max}$, $Q_{DGi\,min}\le Q_{DGi}\le Q_{DGi\,max}$, etc.

Table 1
Generator cost coefficients.

	G_1	G_2	G_3	G_6	G_8	DG_i
a	0	0	0	0	0	0
b	20	20	40	40	40	40
c	0.043	0.25	0.01	0.01	0.01	0.01