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A modified honey bee mating optimization algorithm for multiobjective placement of renewable energy resources

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ABSTRACT

Electrical generators of renewable electricity resources are quiet, clean and reliable. Optimal placement of renewable electricity generators (REGs) results in reduction of objective functions like losses, costs of electrical generation and voltage deviation. Because of recent technology developments of photovoltaic units, wind turbine and fuel cell units, only these generators are considered in this paper. This work presents a multiobjective optimization algorithm for the siting and sizing of renewable electricity generators. The objectives consist of minimization of costs, emission and losses of distributed system and optimization of voltage profile. This multiobjective optimization is solved by the Improved honey bee mating optimization (HBMO) algorithm. In the proposed algorithm, an external repository is considered to save non-dominated (Pareto) solutions found during the search process. Since the objective functions are not the same, a fuzzy clustering technique is used to control the size of the repository within the limits. This algorithm is executed on a typical 70-bus test system. Results of the case study show the proper siting and sizing of REGs are important to improve the voltage profile, reduce costs, emission and losses of distribution system. The main feature of the algorithm refers to its accuracy and calculation speed.

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1. Introduction

Using renewable electricity generators (REGs) impose a different set of operating factors on distribution network such as reverse power flow, voltage rise, decreasing fault level and reduction of power losses, harmonic distortion and stability problems [1,2]. The impacts of REG depend on the several factors such as REG location, technology and capacity. Optimal REG placement aimed to find the optimal REG location and size of the REG in order to maximize or minimize a specific objective function subject to the operating constraints [3–5]. It is noted that these impacts in some cases have conflicting manner which persuades system operators to trade-off among these operating factors. In this regard, using multiobjective optimization framework can provide flexible tool for system operators who are responsible for decision making.

In Ref. [6], the idea of distribution systems reinforcement planning using REGs is clearly formulated. The authors have discussed the possibility to consider REG as a feasible alternative for traditional reinforcement planning. The authors of Ref. [7] have developed a method for generating combination of several construction plans of distribution systems, considering the yearly increase of network loads, but they do not consider the installation of REG units. In many other papers, pros and cons of the installation of REG units are considered and all the technical aspects of this problem are examined [8,9]. The optimal siting and sizing of REG units on the distribution system has been continuously studied in order to achieve different aims. The optimization problem objective can be the minimization of the active losses of the feeder [10,11]; or the minimization of the total network supply costs, which includes generators operation and losses compensation [12–14]. In Refs. [15,16] the objective function is optimization of voltage profile. All the mentioned objective functions are single-objective and in this paper all of them are considered with together as the multiobjective optimization algorithm. Various methods are used for solving the optimization problem. In Refs. [17,18] genetic algorithm (GA) and in Ref. [19] dynamic ant colony search algorithms are used to cope with the optimization problem. The authors of Ref. [20] have presented analytical methods to determine the optimal location to place a REG in radial networked systems with respect to the power losses. Refs. [21,22] present power flow algorithms to find the optimal size of REG at each load bus in a network assuming that every load bus can have a REG source. Placement and penetration of distributed generation with the objective of generation cost minimization is proposed in Ref. [23]. Ref. [24] applied Monte Carlo method and Refs. [25,26] used Tabu Search algorithm to find optimal REG siting. Many algorithms tend to drive toward local minima instead of a global minimum, i.e.

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early convergence. One of the recently proposed evolutionary algorithms that have shown great potential and good perspective for the solution of various optimization problems is honey bee mating optimization (HBMO). The HBMO algorithm has remarkable accuracy and calculation speed to deal with the optimization problem. Advantages of the HBMO algorithm are presented in Refs. [27–29]. Refs. [30,31] have used the HBMO algorithm for solving optimization problems on two separate applications. In this paper, a multi-objective optimization is used for the placement and sizing of REGs by the improved HBMO algorithm. Original HBMO often converges to local optima. In order to avoid this shortcoming, in this paper a new mating process is proposed for rising accuracy of the algorithm. The objectives consist of minimization of the total network supply costs, emission and real power losses of distributed system and optimization of voltage profile. In the proposed algorithm, several queens have been considered as a set of non-dominated solutions. An external memory has been used for the storage of non-dominated solutions found along the search process. Since the objective functions have competing nature, a fuzzy clustering algorithm is utilized to control the size of the external memory.

For the better illustration, the contributions of the paper can be summarized based on their importance order as follows:

- Optimal siting and sizing of renewable electricity generators (REGs) in the distribution systems using multiobjective framework. In the proposed placement scheme, generation costs, emission and losses of distributed systems and optimization of voltage profile are treated as competing objective functions.
- Improved HBMO algorithm equipped with a fuzzy decision making tool has been used to cope with the Pareto-based multiobjective optimization problem.
- Original HBMO often converges to local optima. In order to avoid this shortcoming, the new mating process is proposed.

The reminder of the paper is organized as follow: the problem formulation is presented in Section 2. Section 3 shows the proposed algorithm descriptions. Simulation results are presented in Section 4 and finally some relevant conclusions are drawn in Section 5.

2. Problem formulation

The main goal of the proposed algorithm is to determine the best location and size of new distributed generation resources by minimizing different objective functions. This section proposes four types of objective functions and their practical constraints in distributed system.

2.1. Objective functions

2.1.1. Minimization of cost

Generally, cost per kW h electrical energy produced by REGs is a function of the capital cost, fuel cost, and the operation and maintenance cost [23]. Table 1 shows these economic specifications. According to this table the function of cost is modeled as:

$$C(p) = a + b \times p \tag{1}$$

where a and b are:

$$a = \frac{\text{Capital cost } (\$/\text{kW}) \times \text{Capacity (kW)} \times Gr}{\text{Life time (Year)} \times 365 \times 24 \times LF} \tag{2}$$

$$b = \text{Fuel cost } (\$/\text{kW h}) + \text{O \& M cost } (\$/\text{kW h}) \tag{3}$$

LF is the load factor, Gr is the annual interest rate and the O & M cost is the operation and maintenance cost. Minimizing cost function can be modeled as follows:

$$f_1(X) = \sum_{i=1}^{N_{fc}} C_{fc}(P_{fc}) + \sum_{i=1}^{N_{wind}} C_{wind}(P_{wind}) + \sum_{i=1}^{N_{pv}} C_{pv}(P_{pv}) + Cost_{sub}$$

$$Cost_{sub} = P_{sub} + Q_{sub}$$

$$F_1(X) = \min[f_1(X)] \tag{4}$$

where P_{fc}, P_{wind} and P_{pv} are power generated by the fuel cell units, wind units and the photovoltaic units, respectively. P_{sub} is substation power rating. N_{fc}, N_{wind} and N_{pv} are the numbers of the fuel cell units, wind units and the photovoltaic units, respectively. Q_{sub} is the cost of installation of substation. X is the vector that will be defined in Section 3.4 and shows the location and the power of fuel cell units, wind units and the photovoltaic units. $f_1(X)$ is the first objective function that should be minimized.

2.1.2. Minimizing the deviation of the bus voltage

Bus voltage is one the most significant security and power quality indices, which can be described as follows:

$$f_2(X) = \sum_{i=1}^{N_{bus}} \frac{|V_{Rating} - V_i|}{V_{Rating}}$$

$$F_2(X) = \min(f_2(X)) \tag{5}$$

where N_{bus} is the total number of the buses. V_i is the real voltage of the ith bus and V_{Rating} is the nominal voltage [28].

2.1.3. Minimization of power losses

Minimizing the real power loss is selected as the third objective function for the placement of REGs. Reducing the real power loss of the distribution feeders is an important purpose of implementing REGs. The minimization of total real power losses of feeders over 10 years study period can be calculated as follows:

$$f_3(X) = \sum_{t=1}^{N_d} \sum_{i=1}^{N_{br}} (R_i \times |I_i|^2 \times \Delta t)$$

$$F_3(X) = \min(f_3(X)) \tag{6}$$

where R_i and I_i are the resistance and the actual current of the ith branch, respectively. N_{br} is the number of the branches, Δt is time step that in this study equals to one year and N_d is the number of years that in this study equals to 10 [32].

Table 1
Economic specification of REG.

REG type	Rated capacity (kW)	Capital cost ($/kW)	Fuel cost ($/kW h)	Operation & maintenance cost ($/kW h)	Life time (year)
Fuel cell with CHP	200	3674	0.029	0.01	10
Photovoltaic	100	6675	0	0.005	20
Small wind turbine	10	3866	0	0.005	20
Big wind turbine	1000	1500	0	0.005	20

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