Research on Maximum Penetration of Microgrid Based on Artificial Bee Colony Algorithm

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Abstract. The paper builds a planning model with maximizing the penetration of microgrid as its aim to realize the maximum output of microgrid based on the planning problem of microgrid grid-connection in distribution network. Considering the impact of microgrid grid-connection on distribution network, power flow, power balance, bus voltage are taken as the constraint conditions. Optimal scheme of microgrid grid-connection is acquired by the application of Artificial Bee Colony algorithm and the results of simulation calculation using IEEE 39-bus test system verify the validity of the built model and better convergence of the adopted algorithm.

Introduction

With the limited conventional energy gradually depleted, countries in the world pay more attention to development and utilization of new energy sources. Grid-connection of various distributed generations (DGs), such as solar energy, wind energy, is considered by many experts as the major way to reduce energy consumption and improve the reliability and flexibility of power system. But high cost of DG access and difficulty in control pose significant effects upon the distributed network [1]. In order to coordinate the contradiction between the distributed network and DG, make full use of the value and benefits brought by DG to grid and users, the concept of microgrid emerged in the early 21st century.

Microgrid refers to small power generation and distribution system capable of providing power and heat to local loads, which consists of DG, energy storage device, load and monitor, protection device [2].When microgrid grid-connection runs, random nature of DG will severely affect the stability of power system. The problem attracted attention of domestic and foreign scholars who have done some research in this field and achieved certain results. In [3] Particle Swarm Optimization (PSO) and Craziness based Particle Swarm Optimization (CRPSO) are used to consider the location and size of single and two DGs to minimize the active power loss of distribution system. Considering the total costs offered by the distribution company and DG units as optimal problems, [4] solves the active and reactive power dispatch for the DG units in distribution networks through Fuzzy Adaptive Particle Swarm Optimization (FAPSO) method. A method called Harmony Search Algorithm is applied to minimize losses in [5]. Other methods used in DG planning are Hereford Ranch Algorithm (HRA) [6], Swine Influenza Model Based Optimization with Quarantine (SIMBO-Q) [7], Fuzzy Evolutionary Programming algorithm (Fuzzy-EP) [8], etc.

The researches all above treat DG as the main power source and consider the planning problem of DG grid-connection from various perspectives. [9] puts forward that when the microgrid is grid-connected, distributed system transfers its single role of power distribution to a new energy exchange system integrated collection, transmission, storage and distribution of electric energy into one. Meanwhile, the penetration from microgrid to distribution network will affect the stability of the distribution network in some degree which requires immediate conduct of the research on penetration of microgrid grid-connection. Under the circumstances of rare study on maximum penetration of microgrid grid-connection, the paper carried out study on the issue.

In this paper, Artificial Bee Colony (ABC) algorithm is used for optimization problems of maximum penetration of microgrid grid-connection in distribution system. The proposed method is tested on IEEE 39-bus test system. The result successfully obtained the maximum penetration of microgrid grid-connection under the selected system. It also reveals that the ABC algorithm is efficient and capable of handling complex optimization problems.

The paper is organized as follows: Section II presents the mathematical formulations of the problem; Section III explains the ABC algorithm and its use in microgrid grid-connection; Section IV includes results and discussion; Section V outlines conclusion and Section VI shows the other relevant information concerning the project.

Problem Formulation

To facilitate the study of power flow between microgrid and distribution network, the formula of microgrid penetration is defined as follow:

$$\lambda = P_m / P_s \tag{1}$$

where λ is the penetration of microgrid, P_m is exchanged power between microgrid and distribution network, P_s is total power of distribution network.

In order to improve the utilization efficiency of microgrid as far as possible, microgrid active power output should be maximized as much as possible under the permission of the distribution network. Combined with the penetration of microgrid, the objective function is shown as follow:

$$\min F = 1 - \frac{P_m}{P_s} = 1 - \lambda \tag{2}$$

The study on maximum penetration of microgrid can be explained to find the optimal placement and sizing of microgrid.

Constraints are defined as follows.

- Power flow equations constraint

$$\begin{aligned} P_{m,i} - P_{LD,i} - U_i \sum_{j=1}^{n} U_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) = 0 \\ Q_{m,i} - Q_{LD,i} - U_i \sum_{j=1}^{n} U_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) = 0 \end{aligned} \tag{3}$$

where n is the number of buses. $P_{m,i}$, $Q_{m,i}$ are active and reactive power of microgrid grid-connection in bus i. $P_{LD,i}$, $Q_{LD,i}$ are active and reactive power of load in bus i. U_i is the voltage magnitude of bus i. θ_{ij} is the voltage phase difference between bus i and j. G_{ij}, B_{ij} are the real and imaginary part of admittance between bus i and j.

- Power balance constraint

$$\sum_{k=1}^{N_g} P_k + P_m = P_{LD} + P_L \quad (4)$$

where N_g is the number of generators. P_k is active power output of k-th generator. P_m is active power input of microgrid. P_{LD} is total active power of loads. P_L is total system real power loss.

· Bus voltage magnitude

$$V_{min} \le V_i \le V_{max} \quad (5)$$

where V_{min}, V_{max} are min-max voltage of the bus voltage. The min-max voltage is $\pm 5\%$ of the nominal voltage that satisfies operating constraints.

Artificial Bee Colony Algorithm

The Artificial Bee Colony (ABC) algorithm is a swarm intelligent optimization algorithm proposed by the Turkish scholar Karaboga in 2005 [10], which is a nature-inspired and intelligent computation method that simulates foraging behavior of bees.

Three varieties of bees are involved in the ABC algorithm: employed bees, onlooker bees and scout bees. Employed bees search nectar position randomly and share the information of nectar position by dancing to onlooker bees waiting in the hive. The duration of dance is determined by the nectar amount. Onlooker bees watch the dance and choose good nectar position by the quality of nectar. Employed bees abandoning the old nectar become scout bees searching another new nectar position.

In ABC algorithm, the position of nectar, the amount of nectar, looking for nectar speed and maximum amount of nectar correspond respectively to a possible solution of optimization problem, a fitness value, optimal speed of a possible solution and final optimal solution.

In ABC algorithm, the number of employed bees equals to that of onlooker bees. In the initialization step, N initial population of scout bees is randomly generated, where N indicates the number of employed bees. All employed bees are scout bees at the beginning. Each solution x_i (i=1,2,...,N) is a D-dimensional vector. Here D is the number of optimization parameter. After initialization the nectar position is subjected to repeated search of the employed, onlooker, scout bees.

Employed bees produce new positions X'^{j}_{i} in neighboring regions by memory information, its expression is shown as follow:

$$X'^{j}_{i} = X^{j}_{i} + \text{rand}()(X^{j}_{i} - X^{j}_{k}) \quad (6)$$

where X^{j}_{i} is the j-th dimension solution of the i-th nectar position; $i \ne k$ and both $\in \{1,2,...,N\}$; $j \in \{1,2,...,D\}$; rand() is a random number between [-1,1].

Comparing the amount of nectar in new positions, employed bees will memorize the nectar position with the highest amount based on greedy criterion.

After all the employed bees complete the search process, they share the nectar information of nectar volume and their positions with onlooker bees on the dance area. Onlooker bees evaluate the nectar information brought by employed bees and choose a nectar position with a certain probability related to its nectar amount. The probability of a nectar chosen by onlooker bees is determined by the following expression:

$$P_i = \frac{fit_i}{\sum_{n=1}^{N} fit_n} \tag{7}$$

where fit_i is the fitness value of i-th solution; N is the number of nectar sources. It can be concluded that the higher fitness value of the nectar source, the greater probability of selection by onlooker bees .

When the same nectar has been searched for limit times and a better nectar haven't been found in its vicinity, this nectar will be abandoned. Then employed bees become scout bees looking for a new nectar position. The ABC algorithm repeats the process until the maximum cycle number is satisfied.

Results

To check the performance and validity of ABC algorithm, the IEEE 39-bus test system is adopted. The proposed ABC algorithm is implemented in MATLAB. The 39-bus test system data without microgrid is shown in table 1.

Table 1 Test system default case

	39-bus
Vmin(p.u.)	0.977
Vmax(p.u.)	1.063
Load(MW)	61.505

The ABC algorithm result is recorded in table 2 in which optimal placement, optimal size, ABC parameters and min-max voltage are shown. Simulation has been run 50 times.

Table 2 Simulation results for 39-bus system

	39-bus
Optimal placement	Bus 22
Optimal size(MW)	4.784
ABC parameters	CS=10, MCN=50
Vmax/Vmin(p.u.)	1.063/0.976

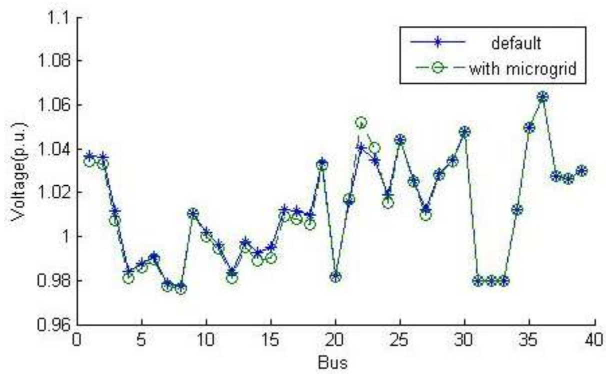

Fig. 1 Voltage profile of 39-bus system

During microgrid grid-connection, the voltage of injection bus increases due to the injected power, but the voltages of several buses near the injection bus have been improved to varying degrees. The voltage profile of 39-bus system is shown in figure 1, which shows that all bus voltages satisfy the 5% limit except 36^{th} bus, 30^{th} to 39^{th} buses connect generators and that their voltages don't change after microgrid grid-connection.

It's obtained from the simulation analysis that the maximum penetration of microgrid grid-connection in 39-bus test system is 7.778%.

Conclusion

In this paper, a calculation method based ABC algorithm is proposed to solve the mixed nonlinear optimization problem. The objective function is to maximize the output of microgrid subject to equality and inequality constraints and the simulation is tested on IEEE 39-bus test system. As a result, the proposed ABC algorithm successfully achieves the optimal solution with its exact and strong robustness.

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