Optimal installation of distributed generators based on an enhanced harmony search algorithm

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Abstract. The demand of reducing global greenhouse gas emissions and restructuring electricity market has led to an increase in the use of distributed generation. Distributed generators (DGs), which are being connected to utility distribution networks, can improve power supply reliability. This paper describes how an enhanced harmony search algorithm can be used to find the optimal number of distributed generators in a distribution network. Different system parameters and scenarios are chosen to run the algorithm. The results indicate the correctness and availability of the proposed algorithm.

1. Introduction
Distributed generation (DG) will become more and more important in the future electricity distribution system. This tendency is increased by the demand of protecting the environment, the liberalization of the energy market and restructuring electricity market. Recently, many distributed power generation systems have been installed in demand area, and have been directly connected to the distribution system, since there are many advantages such as substitution of large scale generators, extension of facility expansion schedule and loss reduction, etc. On the other hand, some complicated problems may occur in such a power distribution system: voltage increase at the end of a feeder, demand supply unbalance in a fault condition, power quality decline or voltage wave distort in demand side. Over the years, some papers which discuss about the optimal allocation and operation of the distributed generators have been published [1-4]. Das [5] has presented an algorithm based on the heuristic rules and fuzzy multi-objective approach for optimizing network configuration. The drawback with this algorithm is criteria for selecting membership functions for objectives are not provided. Borges and Falcao [6] have presented a technique to evaluate the impact of DG size and placement on losses, reliability and voltage profile of distribution networks. Wang and Nehrir [7] have proposed an analytical technique for optimally allocating distributed generation units in a radial distribution system that minimized power losses. The proposed technique considered different types of load profiles with varying time loads and distributed generation output while also took into account technical constraints, such as feeder capacity limits and voltage profile.

In this paper, a new distribution network planning method based on an enhanced harmony search algorithm to dispatch DGs has been presented. The planner counts on the distributed generators to compensate for the conventional power stations in preference to reducing polluting gases emissions. In
addition, the optimal numbers of DGs under the electricity demand of different scale cities are obtained.

2. Problem formulation
The problem is to determine allocation and size of DGs which minimize the pollution emissions under the condition that ensure regular power supply. We intend to acquire optimized amount of distributed power and traditional coal-fired power plant via an optimized model which focus on environmental factor.

The traditional harmony search algorithm includes procedures is listed below:

a. Initialization;
b. New vector generation;
c. Harmony memory update.

We improve harmony search algorithm by combining it with swarm pattern search algorithm. The improved harmony search algorithm overcomes local convergence while harmony updating process. Objective function:

\[ \text{Min } \rho = \rho(C) = \frac{\sum e_i C_i}{\sum e_0 C_0} \]  
\[ n_c = \frac{\sum C_i p_i}{p_0} \]  
\[ s.t. \sum N_i > 0, \sum N_i p_i > P_{LD} \]

\( C = [C_1, C_2, ..., C_n] \) is solution vector, \( C_i \) (i=0, 1, 2, ..., n) is number of each kind of power:

\( e_i \) (i=0, 1, 2...) is emission of each power source (traditional coal-fired power plant, wind power generator, fuel cells, photovoltaic cells, etc)

\( e_0 \): coal-fired power plant emission;

\( e_1 \): wind power generator emission;

\( e_2 \): fuel cells emission;

\( e_3 \): photovoltaic cells emission;

\( p_i \) (i=0, 1, 2...) is power contribution of each power source (traditional coal-fired power plant, wind power generator, fuel cell, photovoltaic cell, etc)

\( p_0 \): coal-fired power plant output power contribution;

\( p_1 \): wind power generator output power contribution;

\( p_2 \): fuel cells output power contribution;

\( p_3 \): photovoltaic cells output power contribution;

\( P_{LD} \) is the average electricity load of the city.

The main steps are as follows:

Step1, parameters initialization: supposing harmony memory is made up of solution vector \( \{N_i, (N_{1i}, N_{2i}, ..., N_{ni}) | N_i \in R^r, i=1, 2, ..., S \} \), \( N_i^{\text{best}} (p_{1i}^{\text{best}}, ..., p_{ni}^{\text{best}}) \) is the best iterative solution of \( N_i \).

\( s_{i_1, s_{12}, ..., s_{in}} \) is the best solution in harmony memory. \( H_{size} \) is harmony memory size. The maximum iterative time is \( I_m \), meanwhile, \( PAR \in (0,1) \) . \( W \) imply tuning parameter.

Step2, update all vectors in harmony memory utilizing pattern search formulations below:

\( N_i^{k+1} = N_i^k + h e_i \)

\( e_i \) is a randomly generated unit vector, \( h \) ranges (0.03,0.2).

If \( \rho(N_i^{k+1}) < \rho(N_i^k) \)

\( N_i^{\text{best}} = N_i^{k+1} \)
\[
N_{i}^{k+1} = N_{i}^{k} + \alpha(N_{i}^{best} - N_{i}^{k})
\]

If \( \rho(S_{i}^{cor}) < \rho(N_{i}^{best}) \)

\[
S_{i}^{best} = N_{i}^{best} \\
k = 1, 2, ... I_{m} \\
i = 1, 2, ... S \\
0.25 < \alpha < 0.5
\]

Step 3, tuning harmony memory vectors: producing two random variables \( R_{i} \) and \( R_{w} \), \( r \in (0, 1) \). If \( R_{i} < PAR \),

\[
N_{i}^{k+1} = N_{i}^{k} + R_{i} \cdot W
\]

Otherwise,

\[
N_{i}^{k+1} = N_{i}^{k} + R(N_{i}^{best} - N_{i}^{k})
\]

Step 4, terminal condition: If \( I_{m} \) reaches certain amount the previously set, end the iterative process; or else return to step 2.

3. Numerical examples

In this section, the algorithm is tested by using an example distribution system model in which traditional coal-fired power plant (CF), photovoltaic cells (PV), wind power generation systems (WP) and fuel cells (FC) coexist to meet the electricity demand of different scale cities. The DGs’ optimal placement is determined in order to reduce polluting gases emissions. Finally, we get the optimal number of the DGs in distribution network under the electricity demand of different scale cities.

The parameters for DGs and coal-fired power plant are shown in Table 1, and electricity demand of different scale cities is shown in Table 2.

| The types of DGs | Average output power | Polluting gases emissions |
|------------------|----------------------|--------------------------|
| PV               | 1.2 kW               | 335 m$^3$/year           |
| WT               | 1.5 MW               | 123.5 m$^3$/year         |
| FC               | 200 kW               | 1350 m$^3$/year          |
| CF               | 60 MW                | 1490000 m$^3$/year       |

| City scale | Average power load | City scale | Average power load |
|------------|--------------------|------------|--------------------|
| 100,000    | 95,000 kW          | 3,000,000  | 4,690 MW           |
| 500,000    | 650,000 kW         | 10,000,000 | 9,820 MW           |
| 1,000,000  | 1,570 MW           | 20,000,000 | 17,600 MW          |
Fig. 1 shows polluting gases emissions of distribution network with DGs are less than traditional coal-fired power plant distribution network. From the figure, it can be found that introduce of DGs is beneficial for the environment. The calculation results of the DGs’ optimal numbers under the electricity demand of different scale cities are shown in table 3.

![Figure 1. Comparison of polluting gases emissions of distribution network with and without DGs. (Red circle represents original pollution emission when power grid just contains coal-fired power plant, and black dot represents optimized pollution emission when power grid contains both coal-fired power plant and distributed power sources)](image)

| City scale  | PV   | WT  | FC  | CF  |
|-------------|------|-----|-----|-----|
| 20,000,000  | 25,005 | 1,590 | 430  | 246 |
| 10,000,000  | 16,050 | 803  | 201  | 120 |
| 3,000,000   | 6,015  | 397  | 69   | 65  |
| 1,000,000   | 3,105  | 165  | 35   | 31  |
| 500,000     | 1,700  | 103  | 19   | 22  |

4. Conclusion
In this paper, a new distribution network planning method based on an enhanced harmony search algorithm to dispatch DGs has been illustrated. It is found that introduce of DGs is beneficial for the environment. The planner counts on the distributed generators to compensate for the conventional power stations in preference to reducing polluting gases emissions. The proposed scheme is quite useful for the network planning, which can obtain the optimal numbers of DGs to achieve the minimum polluting gases emissions under the electricity demand of different scale cities.
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