Electric Power Systems Research 133 (2016) 160–172

Contents lists available at ScienceDirect

Electric Power Systems Research

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

Combined heat and power economic dispatch problem using gravitational search algorithm

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form 28 August 2015
Accepted 4 October 2015
Available online 12 January 2016

Keywords:
Combined heat and power economic dispatch (CHPED) problem
Gravitational search algorithm (GSA)
Optimization problem
Valve-point loading effect
Non-convex optimization

ABSTRACT

This paper presents the application of a novel optimization algorithm, namely gravitational search algorithm (GSA) to solve the non-convex combined heat and power economic dispatch (CHPED) problems. The proposed approach is based on the gravitational law and the law of particles motion. The effectiveness of the suggested algorithm is tested on study-cases which include modeling of valve-point loading effect and transmission losses. Results of GSA-based CHPED problem in terms of quality solution and computational performance are compared with various algorithms to show the ability of the introduced algorithm in finding an operating point with lower fuel cost.

1. Introduction

Optimal operation of a power system is one of the most important aspects of the power system operation and economy. In this regards, the objective of an economic dispatch (ED) problem is the optimal scheduling of power generation outputs subject to power balance equations and inequality constraints on the power system generation. Nowadays, in order to make a better use of fuel, combined heat and power production is largely utilized. This technology has been introduced to increase the thermal efficiency of the combined cycle plants, from 50–60% [1] to 90% [2,3] which is mainly due to a better use of low enthalpy heat. Furthermore, the CHP units, known as co-generation units, by recovering and using heat [1], can reduce the environment emissions of the generation sector by 13–18% [2].

The use of CHP units is strongly supported by the regulation in many countries because of the energy efficiency and environmental benefits. Its role in microgrids, energy hubs, and power parks is becoming more and more important in the need to disseminate power production and shorten the distance between locations where energy is converted and used. These technologies show their potentials in urban areas where the concern about environment is higher and a new urbanization of large cities is challenging energy needs.

In this scenario, this paper proposes a new approach for optimization when different energy carriers, in this case, power and heat, are involved. Although the power dispatch is a well-known problem, solved back in the 1930s the CHPED, but still presents some difficulties in the optimization process which needs further improvements.

In this paper, a metaheuristic approach is proposed to solve convergence difficulties due to the structure of the problem which cannot be overcome with more classical optimization algorithms (gradients-based, interior point, quasi-Newton methods, etc.). Furthermore, performances of different algorithms are compared mainly on the basis of the economical benefits which can be reached in searching the global optimum (or the less expensive solution) and its operating point costs. This characteristic is predominant in the power industry compared to timing performances. In fact, this

Abbreviations: ACPUT, absolute CPU time; ACSA, ant colony search algorithm; BCO, bee colony optimization; CHP, combined heat and power; CHPED, combined heat and power economic dispatch; CPSO, classic particle swarm optimization; DACE, design and analysis of computer experiments; DE, differential evolution; ED, economic dispatch; EDHS, economic dispatch harmony search; GA-PF, genetic algorithm based penalty function; GSA, gravitational search algorithm; HS, harmony search; IGA-MU, improved genetic algorithm with multiplier updating; LHS, Latin hypercube sampling; MADS, mesh adaptive direct search; NA, not available; NC, not calculable; PSO, particle swarm optimization; RCPUT, relative CPU time; SARGA, self-adaptive real-coded genetic algorithm; SPSO, selective particle swarm optimization; TVAC-PSO, time varying acceleration coefficients particle swarm optimization.

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http://dx.doi.org/10.1016/j.epsr.2015.10.007
0378-7796/

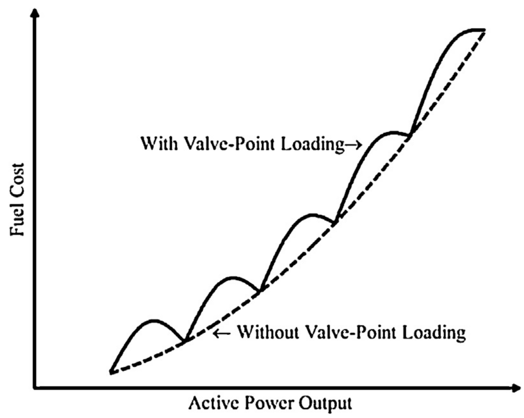

Fig. 1. Valve-point loading effect.

is an operational planning problem and, consequently, time constraints are weaker since computations need to be performed on the time scale of hours or in the worst case every 5–30 min.

More specifically, the CHPED problem refers to an optimization procedure in which the objective is the fuel cost minimization subject to all equality and inequality constraints related to power-only unit(s), co-generation (CHP) unit(s), and heat-only unit(s). As reported in the references, there are three challenges making the CHPED a complex problem:

1. Valve-point loading effects related to the power-only units: generally, the conventional fuel cost function of the thermal power generation units is expressed as a quadratic function of active power outputs. Multi-valve steam turbines in large steam turbine generators produce a rippling effect on the input–output characteristic which is known as "valve-point loading effect" [4]. Thus, the generation unit output is not always smooth as shown in Fig. 1.
2. System power losses: this term arises from power system resistances and is added to the power balance equation. Losses will play a major role when applying these techniques in the dispersed generation which refers to low and medium voltage grids.
3. Mutual dependency on the heat and power production related to the CHP units: in co-generation units, the power production capacity of most units depends on the heat generation and vice versa [1] (this concept is illustrated in Appendix A).

Consequently, the CHPED problem is a highly nonlinear, non-smooth, and non-convex one in which powerful optimization methods are required to solve it, to avoid trapping in local optimum solution and obtain the global system optimum point.

Typically challenges 1 and 2 have been widely treated in the literature whereas point 3 is quite a new problem which has some peculiarities which need more research efforts.

The CHPED problem attracted many researches around the world and different approaches have been applied to solve it.

Valve-point loading effects create multiple local minima. Gradient based classical methods usually find the local minima close to the starting point. So, in general, traditional mathematical programming approaches get trapped in the local optimum. Also, some nonlinear methods such as Lagrangian relaxation [5] and dual and quadratic programming [6] cannot take the non-convex problem into account. Alternatives to these approaches refer to evolutionary techniques. Vasebi et al. [3] and Decker and Brooks [7] applied HS algorithm to the constrained CHPED problem in which the fuel cost function of the power-only units is modeled as a quadratic form without considering the valve-point loading effect. An improved MADS is proposed in [8] which use different search algorithms such as DACE surrogate algorithm, PSO, and LHS. Another approach, namely PSO algorithm, is used in [9] to find the optimal heat and power generations of the multi-objective CHPED problem. The research work reported in [10] proposed an IGA-MU to solve the nonlinear problem. ACSA and SARGA as two stochastic search algorithms are applied to the CHPED problem in [11,12], respectively. Ramesh et al. [13] suggested a SPSO which provides a better solution than PSO algorithm. One of the main drawbacks of the mentioned approaches is that they do not consider the valve-point loading effects and network losses in the CHPED problem. Improved versions of PSO, namely TVAC-PSO in [14], DE in [1] and BCO in [15] are suggested to solve the CHPED problem considering the transmission losses and the valve-point loading effect.

Recently, a novel heuristic search algorithm based on the gravitational law and laws of motion has been proposed by Rashedi et al. [16], namely GSA. This new algorithm has been successfully applied to the various nonlinear functions and results demonstrated that it has high performance and is flexible enough to enhance exploitation and exploration abilities. Because of its characteristics, this new approach seems to be a good candidate to solve difficulties linked to the real world CHPED problems and as long as authors know it has not been tested on this kind of problems before.

In this paper, a new algorithm based on the GSA to solve CHPED problem is proposed and different test systems are selected to verify the accuracy and efficiency of the proposed method.

The main feature of the proposed approach is its ability in solving quite large CHPED problems yielding economical benefits with regard to the other tested algorithms reaching a better optimum solution with good convergence characteristics and a computational time fully compatible with operational planning time requirements. It should be noted that the contribution in this area derives from the capability of the algorithm in being robust, i.e. always capable of finding a good quality solution without convergence problems and mostly yielding a better optimum which results in economical benefits which is our main performance indicator.

The rest of this paper is organized as follows: CHPED problem, in terms of the objective function and the constraints, is described in Section 2. The GSA structure is presented in Section 3. The proposed GSA-based CHPED problem is introduced in Section 4. The effectiveness of the suggested approach is shown by comparisons with various algorithms in Section 5. The computational performance is presented in Section 6. Finally, we will draw the conclusions.

2. CHPED mathematical formulation

Generally, the CHP problem contains the objective function and several constraints as follows:

2.1. Objective function

The CHP objective is to minimize the fuel cost function of power-only units, CHP units, and heat-only units as follows:

$$\text{Minimize} \quad \sum_{i=1}^{N_p} C_i(P_i^p) + \sum_{j=1}^{N_c} C_j(P_j^c, H_j^c) + \sum_{k=1}^{N_h} C_k(H_k^h) \tag{1}$$

where

$$C_i(P_i^p) = \alpha_i \left(P_i^p\right)^2 + \beta_i P_i^p + \gamma_i$$

$$C_j(P_j^c, H_j^c) = a_j \left(P_j^c\right)^2 + b_j P_j^c + c_j + d_j \left(H_j^c\right)^2 + e_j H_j^c + f_j P_j^c H_j^c$$

$$C_k(H_k^h) = \alpha_k \left(H_k^h\right)^2 + \beta_k H_k^h + \gamma_k$$