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Group search optimization for combined heat and power economic dispatch

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ABSTRACT

This paper presents group search optimization to solve the complex non-smooth non-convex combined heat and power economic dispatch (CHPED) problem. Valve-point loading and prohibited operating zones of conventional thermal generators are taken into account. The effectiveness of the proposed method has been verified on four test systems. The results of the proposed approach have been compared with those obtained by other evolutionary methods. It is found that the proposed group search optimization based approach is able to provide better solution.

Introduction

The energy efficiency of the most modern combined cycle plants is about 60%. Most of the energy wasted in the conversion process is heat. But the efficient utilization of flue gas condensation, the total efficiency [8] of combined heat and power generation unit can be in the range of 80–111%. Also combined heat and power generation unit has less green house gas emission as compared with the other forms of energy supply. The principle of combined heat and power, known as cogeneration, is to recover and make beneficial use of this heat and as a result the overall efficiency of the conversion process is increased. Cogeneration units play an increasingly important role in the utility industry. For most cogeneration units, the heat production capacity depends on the power generation and vice versa. This introduces complexity due to the non-separable nature of electrical power and heat in the combined heat and power unit. The mutual dependencies of heat and power generation initiate a complication in the incorporation of cogeneration units into the power economic dispatch. Therefore, combined heat and power economic dispatch (CHPED) is a nonlinear and highly constrained optimization problem. The introduction of valve-point loading effect and prohibited operating zones of conventional thermal generators makes the CHPED problem into nonlinear nonsmooth nonconvex and highly constrained optimization problem.

Non-linear optimization methods, such as dual and quadratic programming [1], and gradient descent approaches, such as Lagrangian relaxation [2], have been applied for solving combined heat and power economic dispatch (CHPED). However, these methods cannot handle nonsmooth nonconvex fuel cost function of the conventional thermal generator.

The advent of stochastic search algorithms has overcome this problem for solving CHPED problem. Improved ant colony search algorithm [3], evolutionary programming [4], genetic algorithm [5], harmonic search algorithm [6], multi-objective particle swarm optimization [7], self adaptive real-coded genetic algorithm [8], novel selective particle swarm optimization [9], mesh adaptive direct search algorithm [10], particle swarm optimization with time varying acceleration coefficients [11] and oppositional teaching learning based optimization [12] have been applied to solve CHPED problem.

Group search optimization (GSO) is a biologically realistic algorithm. Inspired by the animal (such as lions and wolves) searching behavior, He et al. [13] proposed GSO in 2006, and discussed the effects of designed parameters on the performance of GSO in 2009 [14]. GSO employs a special framework, under which individuals are divided into three classes and evolve separately. This framework is proved to be effective and robust on solving multimodal problems [14]. Shen et al. [15] investigated the performance of GSO and concluded that GSO is an alternative for constrained

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optimization. GSO is simple and easy to implement. GSO has a superior search performance for uni-modal and multimodal functions.

Due to its high efficiency, GSO has been applied in many fields. Continuous quick group search optimizer [16] has been applied to solve non-convex economic dispatch problems. Dynamic economic emission dispatch problem is solved by using group search optimizer with multiple producers [17]. Binary group search optimization [18] has been applied to distribution network reconfiguration.

GSO has been applied here to solve the complex non-smooth/non-convex combined heat and power economic dispatch (CHPED) problem considering the various constraints. Valve-point loading and prohibited zones of conventional thermal generators has been considered. Transmission loss is accounted for through the use of loss coefficients. To illustrate the performance of the proposed method, four test systems are used. The test results are compared with those obtained by other evolutionary methods reported in the literature. It is found that the proposed GSO based approach provides better solution.

The remainder of the paper is organized as follows: Section 'Problem formulation' describes problem formulation. Section 'Group search optimization' deals with group search optimization. Application of the proposed method is presented in Sec tion 'Application of the proposed method'. The last section describes conclusion.

Problem formulation

The system under consideration has conventional thermal generating units, cogeneration units, and heat-only units. Cogeneration is the simultaneous production of heat and power and this concept has been used for a long time in various industries. Fig. 1 [2] shows the heat–power feasible operation region of a combined cycle co-generation unit. The feasible operation is enclosed by the boundary curve ABCDEF. Along the boundary curve BC, the heat capacity increases as the power generation decreases, the heat capacity declines along the curve CD.

The power output of the conventional thermal generating units and the heat output of heat units are restricted by their own upper and lower limits. The power is generated by conventional thermal generating units and cogeneration units while the heat is generated by cogeneration units and heat-only units. The CHPED problem is to determine the unit power and heat production so that the system's production cost is minimized while the power and heat demands and other constraints are met. The objective function and constraints of CHPED problem are described as follows:

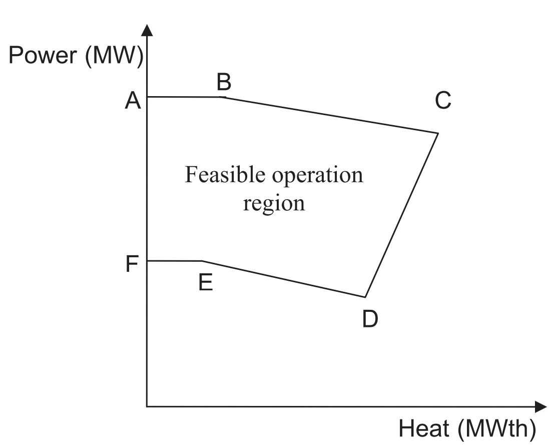

Fig. 1. Heat–power feasible operation region for a cogeneration unit.

Objective

The cost function of conventional thermal generating unit is obtained from data points taken during "heat run" tests, when input and output data are measured as the unit is slowly varied through its operating region. Wire drawing effects, occurring as each steam admission valve in a turbine starts to open, produce a rippling effect on the unit curve. In reality, a sharp increase in fuel loss is added to the fuel cost curve due to wire drawing effects when steam admission valve starts to open. This procedure is named as valve point effect. To model the effect of valve-points, a recurring rectified sinusoid contribution is added to the quadratic function [21], such as the one shown in Fig. 2.

The total heat and power production cost [2] can be expressed as

$$
\begin{aligned}
C_T &= \sum_{i=1}^{N_t} C_{ti}(P_{ti}) + \sum_{i=1}^{N_c} C_{ci}(P_{ci}, H_i) + \sum_{i=1}^{N_h} C_{hi}(H_{hi}) \\
&= \sum_{i=1}^{N_t}\left[a_i + b_i P_{ti} + d_i P_{ti}^2 + \left|e_i \sin\left\{f_i\left(P_{ti}^{\min} - P_{ti}\right)\right\}\right|\right] \\
&\quad + \sum_{i=1}^{N_c}\left[\alpha_i + \beta_i P_{ci} + \gamma_i P_{ci}^2 + \delta_i H_{ci} + \varepsilon_i H_{ci}^2 + \xi_i P_{ci} H_{ci}\right] \\
&\quad + \sum_{i=1}^{N_h}\left[\varphi_i + \eta_i H_{hi} + \lambda_i H_{hi}^2\right] \qquad (1)
\end{aligned}
$$

where C_T is the total production cost. C_{ti}, C_{ci}, C_{hi} are the respective fuel characteristics of the conventional thermal generating units, cogeneration units and heat-only units. P_{ti} is the power output of ith conventional thermal generating unit. $P_{ti}^{\min}$ and $P_{ti}^{\max}$ are the ith conventional thermal generating unit power capacity limits P_{ci} and H_{ci} are respectively the power output and heat output of ith cogeneration unit. H_{hi} is the heat output of ith heat-only unit. N_t, N_c and N_h are the numbers of conventional thermal generating units, cogeneration units and heat-only units respectively. a_i, b_i, d_i, e_i, f_i are the cost coefficients of ith conventional thermal generating unit. α_i, β_i, γ_i, δ_i, ε_i, ξ_i are the cost coefficients of ith cogeneration unit. $\varphi_i, \eta_i, \lambda_i$ are the cost coefficients of ith heat-only unit.

Constraints

Two types of constraints i.e. equality and inequality constraints are considered. Equality constraints are the power and heat

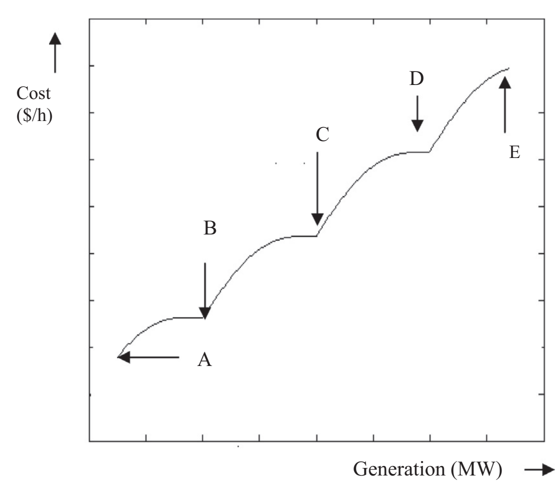

Fig. 2. Example of valve-point cost function with 5 valves A – primary valve, B – secondary valve, C – tertiary valve, D – quaternary valve, E – quandary valve.