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Combined heat and power economic emission dispatch using nondominated sorting genetic algorithm-II

M. Basu *

Department of Power Engineering, Jadavpur University, Kolkata 700 098, India

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ABSTRACT

This paper presents nondominated sorting genetic algorithm-II for solving combined heat and power economic emission dispatch problem. The problem is formulated as a nonlinear constrained multi-objective optimization problem. Nondominated sorting genetic algorithm-II is proposed to handle economic emission dispatch as a true multi-objective optimization problem with competing and noncommensurable objectives. The proposed algorithm is illustrated for two test systems and the test results are compared with those obtained from strength pareto evolutionary algorithm 2.

1. Introduction

The conversion of fossil fuel into electricity is an inefficient process. Even the most modern combined cycle plants are between 50% and 60% efficient. Most of the energy wasted in the conversion process is heat. 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. Combined heat and power generation has higher energy efficiency and less green house gas emission as compared with the other forms of energy supply. Recently, cogeneration units have been extensively used in utility industry. The heat production capacity of most cogeneration units depends on the power generation and vice versa. The mutual dependencies of heat and power generation introduce a complication in the integration of cogeneration units into the power economic dispatch.

Nonlinear 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 nonconvex fuel cost function of the generating units.

The advent of stochastic search algorithms has provided alternative approaches for solving CHPED problem. Improved ant colony search algorithm [3], evolutionary programming [4] genetic algorithm [5], harmonic search algorithm [6] and multi-objective particle swarm optimization [7] have been successfully applied to solve CHPED problem. In [8] stochastic PSO-based method is used for solving CHPED problem including wind power and pollutant emissions constraints. In [9] artificial immune system has been used for solving CHPED problem. Chen et al. [10] have solved CHPED problem by using a novel approach based on the direct search method. Sashirekha et al. [11] have presented Lagrangian relaxation with surrogate subgradient multiplier updates to solve CHPED problem.

This paper incorporates the combined heat and power units into the economic emission dispatch problem which plays a vital role in the power system dispatch. The objective of the combined heat and power economic emission dispatch (CHPEED) is to find the optimal point of power and heat generation with optimum fuel cost and emission level simultaneously such that both heat and power demands and other constraints are met while the combined heat and power units are operated in a bounded heat versus power plane.

Over the past few years, several researches have been made on the development of multi-objective evolutionary search strategies. Strength Pareto evolutionary algorithm (SPEA) [12], nondominating sorting genetic algorithm II (NSGA II) [13], multi-objective evolutionary algorithm (MOEA) [14], multi-objective particle swarm optimization [15,16], fuzzy clustering-based particle swarm optimization (FCPSO) [17], etc., constitute the pioneering multi-objective approaches that have been applied to solve the economic environmental dispatch (EED) problem. These methods are population-based techniques and multiple pareto-optimal solutions can be found in one single run.

This paper proposes nondominating sorting genetic algorithm II (NSGA II) for solving the combined heat and power economic

* Fax: +91 33 23357254.
E-mail address: mousumibasu@yahoo.com

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emission dispatch (CHPEED) problem. Here, transmission loss is accounted for through the use of loss coefficients. This problem is formulated as a nonlinear constrained multi-objective optimization problem. Due to difficulties of binary representation when dealing with continuous search space with large dimensions, the proposed approach has been implemented by using real-coded genetic algorithm (RCGA) [18,19]. In order to show the validity of the proposed approach the developed algorithm is illustrated on two test systems. Results obtained from the proposed approach have been compared with those obtained from strength pareto evolutionary algorithm 2 (SPEA 2).

2. Formulation of CHPEED problem

The system under consideration has conventional thermal generators, cogeneration units, and heat-only units. Fig. 1 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 power units and the heat output of heat units are restricted by their own upper and lower limits. The power is generated by conventional thermal generators and cogeneration units while the heat is generated by cogeneration units and heat-only units. The CHPEED problem is to determine the unit power and heat production so that the system's production cost and emission level are optimized simultaneously while the power and heat demands and other constraints are met. It can be mathematically stated as

Objectives:

(i) *Cost*: The total cost can be expressed as

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

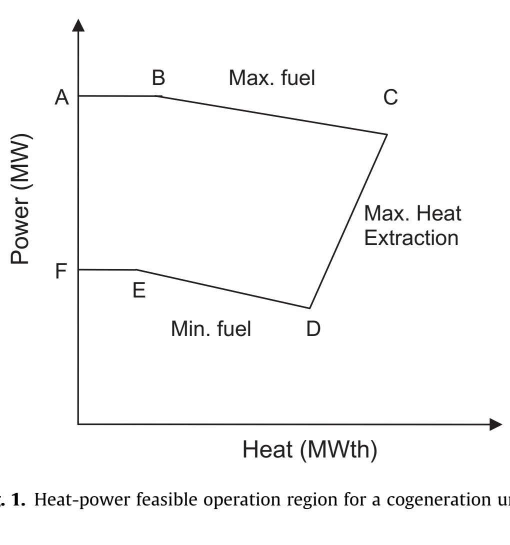

Fig. 1. Heat-power feasible operation region for a cogeneration unit.

(ii) *Emission*: The total emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) can be expressed as

$$\begin{aligned} E_T &= \sum_{i=1}^{N_P} E_{ti}(P_i) + \sum_{i=1}^{N_c} E_{ci}(O_i) + \sum_{i=1}^{N_h} E_{hi}(T_i) \\ &= \sum_{i=1}^{N_P} \left[\mu_i + \kappa_i P_i + \pi_i P_i^2 + \sigma_i e^{(\theta_i P_i)} \right] + \sum_{i=1}^{N_c} \tau_i O_i + \sum_{i=1}^{N_h} \rho_i T_i \end{aligned} \tag{2}$$

Subject to the equilibrium constraints of electricity and heat production, and the capacity limits of each unit.

Constraints:

$$\sum_{i=1}^{N_P} P_i + \sum_{i=1}^{N_c} O_i = P_D + P_L \tag{3}$$

$$\sum_{i=1}^{N_c} H_i + \sum_{i=1}^{N_h} T_i = H_D \tag{4}$$

$$P_i^{\min} \leqslant P_i \leqslant P_i^{\max} \quad i \in 1, 2, \ldots, N_P \tag{5}$$

$$P_i^{\min}(H_i) \leqslant P_i \leqslant P_i^{\max}(H_i) \quad i \in 1, 2, \ldots, N_c \tag{6}$$

$$H_i^{\min}(P_i) \leqslant H_i \leqslant H_i^{\max}(P_i) \quad i \in 1, 2, \ldots, N_c \tag{7}$$

$$H_i^{\min} \leqslant H_i \leqslant H_i^{\max} \quad i \in 1, 2, \ldots, N_h \tag{8}$$

The active power transmission loss P_L can be calculated by the network loss formula

$$\begin{aligned} P_L &= \sum_{i=1}^{N_P}\sum_{j=1}^{N_P} P_i B_{ij} P_j + \sum_{i=1}^{N_P}\sum_{j=1}^{N_c} P_i B_{ij} O_j + \sum_{i=1}^{N_c}\sum_{j=1}^{N_c} O_i B_{ij} O_j + \sum_{i=1}^{N_P} B_{0i} P_i \\ &\quad + \sum_{i=1}^{N_c} B_{0i} O_i + B_{00} \end{aligned} \tag{9}$$

where C_T and E_T are the total production cost and total emission level respectively. C_{ti}, C_{ci}, C_{hi} are the respective fuel characteristics of the conventional thermal generators, cogeneration units and heat-only units. E_{ti}, E_{ci}, E_{hi} are the respective emission characteristics of the conventional thermal generators, cogeneration units and heat-only units. P_i is the power output of ith conventional thermal generator. O_i and H_i are respectively the power output and heat output of ith cogeneration unit. T_i is the heat output of ith heat-only unit. N_P, N_c and N_h are the numbers of conventional thermal generators, 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 generator. α_i, β_i, γ_i, δ_i, ε_i, ξ_i are the cost coefficients of ith cogeneration unit. φ_i, η_i, λ_i are the cost coefficients of ith heat-only unit. μ_i, κ_i, π_i, σ_i, θ_i are the emission coefficients of ith conventional thermal generator. τ_i is the emission coefficient of ith cogeneration unit. ρ_i is the emission coefficient of ith heat-only unit. The operation ranges of conventional thermal generators and heat-only units are expressed in Eqs. (5) and (8) and those for cogeneration units are in Eqs. (6) and (7). The heat and power outputs of the cogeneration units are non-separable and one output will affect the other. H_D and P_D are the system heat and power demands respectively. B_{ij} is the loss coefficient for a network branch connected between generators i and j. $P_i^{\min}$ and $P_i^{\max}$ are the ith unit power capacity limits. $H_i^{\min}$ and $H_i^{\max}$ are the ith unit heat capacity limits. $P^{\min}(H)$, $P^{\max}(H)$, $H^{\min}(P)$ and $H^{\max}(P)$ are the linear inequalities that define the feasible operating region of the cogeneration units.