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Research Paper

Solving combined heat and power economic dispatch problem using real coded genetic algorithm with improved Mühlenbein mutation

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HIGHLIGHTS

- An improved Mühlenbein mutation is proposed for GA algorithm.
- Proposed algorithm is evaluated using different benchmark functions.
- The proposed algorithm has shown better convergence and constraint handling capability.
- Proposed algorithm found lower cost for CHPED problem in comparison with other algorithms.

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ABSTRACT

The combined heat and power economic dispatch (CHPED) is a complicated optimization problem which determines the production of heat and power units to obtain the minimum production costs of the system, satisfying the heat and power demands and considering operational constraints. This paper presents a real coded genetic algorithm with improved Mühlenbein mutation (RCGA-IMM) for solving CHPED optimization task. Mühlenbein mutation is implemented on basic RCGA for speeding up the convergence and improving the optimization problem results. To evaluate the performance features, the proposed RCGA-IMM procedure is employed on six benchmark functions. The effect of valve-point and transmission losses is considered in cost function and four test systems are presented to demonstrate the effectiveness and superiority of the proposed method. In all test cases the obtained solutions utilizing RCGA-IMM optimization method are feasible and in most instances express a marked improvement over the provided results by recent works in this area.

1. Introduction

The most efficient combined cycle generation plants generate electric power at an efficiencies of between 50 and 60%. Heat is the most wasted energy in the conversion of fossil fuels into electricity. Combined heat and power (co-generation) recovers the heat wasted during such conversion. CHP production unit not only achieves energy efficiency as much as 90% [1], but also serves an important impress for reducing greenhouse gas emission around 13–18%, which is considered as an environmental advantage [2]. Due to its energy saving and environmental advantages, CHP systems are considered as the main alternative for conventional systems [3,4]. CHP economic dispatch involves the utilization optimizing of the heat and power units with minimum cost of generation to meet the heat and power demands considering operational constraints [2]. Mutual dependency of multiple demand (heat and power) and heat–power capacity of the co-generation units present complexity for solving the optimization problem [5]. CHPED problem will be more complicated while considering several constraints which consist of valve-point loading, transmission losses, and prohibited operation zones of conventional thermal generators. For solving CHPED problem, which has attracted attention of researchers in recent years, in prior approaches, nonlinear optimization algorithm such as dual and quadratic programming [6], and gradient decent methods, such as Lagrangian relaxation [7], have been employed. However, non-convex fuel cost function of the generating units were not considered for solving the problem.

In reference 8, differential evolution with Gaussian mutation (DEGM) is introduced for solving CHPED problem considering valve-point loading and prohibited operating zones of conventional thermal generators. Implementation of Gaussian mutation to DE optimization method resulted to better search efficiency and providing the global optimal solution with high probability. The performance of Lagrangian relaxation in solution to CHPED problem is improved in reference 9 by utilization of surrogate subgradient multiplier updating procedure. An optimization method based on benders decomposition (BD) has been employed in reference 10 for solving the CHPED problem, where non-convex feasible operation region

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of co-generation units has been taken into account. The CHPED problem is solved by proposing a hybrid optimization tool based on harmony search (HS) and genetic algorithm (GA) in reference 11. The authors recommended to utilize HSGA which encompass the advantages of adaption and parallelism of GA and inferior individuals identification of HS, in order to obtain the global optimum with high probability. The authors utilized time varying acceleration coefficients PSO (TVAC-PSO) in reference 12 for the solution of CHPED problem, considering valve-point loading, system losses and capacity limits. The proposed optimization algorithm in this reference has been implemented on a large test system in which the valve point effect has been taken into account. The capability of obtaining the optimal feasible solution by employing the proposed method has been ensured in this reference. Self-adaptive real-coded genetic algorithm has been employed for solving the CHPED problem in reference 13, considering the optimization problem with equality and inequality constraints. Simulated binary crossover (SBX) is applied for achieving self-adaptation. In reference 14 HS algorithm as a new optimization technique has been implemented for obtaining the optimal solution of the CHPED problem. Optimal solution of CHPED problem by applying invasive weed optimization (IWO) procedure is presented in reference 15. A solution for CHPED problem in large scale power systems has been introduced in reference 16 by proposing an improved group search optimization procedure (IGSO) but the obtained results for system 4 are not feasible in which the minimum obtained cost for this test instance is 58,049.019 $.

In this paper a novel real coded genetic algorithm (RCGA) with an upgraded mutation process is employed for solving CHPED optimization problem. Valve point effects and system transmission losses are taken into account for the solution of the problem. Benchmark test cases and test systems have been utilized to prove the effectiveness of the proposed method. The proposed RCGA-IMM has the capability for dealing with CHPED problem considering valve-point loading effect and transmission losses. The obtained solutions for generation of system units by implementing the proposed RCGA-IMM show feasibility and better solution in terms of total cost, compared with reported studies in this area.

The rest of this paper is organized as follows: Section 2 represents the mathematical formulation of the CHPED problem, in which valve point effects and transmission losses are taken into account. Section 3 provides the brief description and basic aspects of GA and a detailed description of the proposed RCGA-IMM. Section 4 expresses the implementation of the proposed procedure to four test instances and provides a comparison of the obtained optimal results with the recent researches in the area of CHPED problem. The paper conclusions are presented in Section 5.

2. Formulation of the CHPED problem

The CHPED is stated to obtain the minimum operation cost of heat and power units, satisfying the heat and power demands. The objective function of the CHPED problem considering conventional thermal units, combined heat and power units and heat-only units is formulated as (Eq. 1):

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

In which C is the total production cost. N_p, N_c and N_h are the respective number of conventional thermal units, co-generation units, and heat-only units. The heat and power output of the unit are defined by H and P, respectively. i, j and k are utilized for indicating the above mentioned units. The production cost of different unit types can be stated as follows:

$$C_i\left(P_i^p\right)=\alpha_i\left(P_i^p\right)^2+\beta_iP_i^p+\gamma_i\,(\$/h) \quad (2)$$

$$C_j\left(P_j^c,H_j^c\right)=a_j\left(P_j^c\right)^2+b_jP_j^c+c_j+d_j\left(H_j^c\right)^2+e_jH_j^c+f_jH_j^cP_j^c\,(\$/h) \quad (3)$$

$$C_k\left(H_k^h\right)=a_k\left(H_k^h\right)^2+b_kH_k^h+c_k\,(\$/h) \quad (4)$$

where $C_i\left(P_i^p\right)$ is the respective fuel cost of conventional thermal unit i for producing P_i^p MW for 1 hour period. The cost function of conventional thermal units are modeled by utilization of quadratic function approximation (Eq. 2) [14,17,18]. $C_j\left(P_j^c,H_j^c\right)$ is utilized to define the co-generation unit j and a_j, b_j, c_j, d_j, e_j and f_j are the cost coefficients of this unit. The cost function of the co-generation unit is convex in both power output P^c and heat output H^c, which can be observed from Eq. (3).

The cost of heat-only unit k is defined by $C_k\left(H_k^h\right)$ which is considered for producing H^h MWth heat. a_k, b_k, and c_k are the cost coefficients of kth heat-only unit.

In order to obtain the optimal solution of the objective function (Eq. 1), the following constraints should be taken into account:

- Power production and demand balance

$$\sum_{i=1}^{N_p}P_i^p+\sum_{j=1}^{N_c}P_j^c=P_d \quad (5)$$

- Heat production and demand balance

$$\sum_{j=1}^{N_c}H_j^c+\sum_{k=1}^{N_h}H_k^h=H_d \quad (6)$$

- Capacity limits of conventional units

$$P_i^{pmin}\le P_i^p\le P_i^{pmax}\quad i=1,\ldots,N_p \quad (7)$$

- Capacity limits of CHP units

$$P_j^{cmin}\left(H_j^c\right)\le P_j^c\le P_j^{cmax}\left(H_j^c\right)\quad j=1,\ldots,N_c \quad (8)$$

$$H_j^{cmin}\left(P_j^c\right)\le H_j^c\le H_j^{cmax}\left(P_j^c\right)\quad j=1,\ldots,N_c \quad (9)$$

where $P_j^{cmin}\left(H_j^c\right)$ and $P_j^{cmax}\left(H_j^c\right)$ which are functions of generated heat H_j^c represent minimum and maximum power limits of jth CHP unit respectively. Heat generation limits are identified by $H_j^{cmin}\left(P_j^c\right)$ and $H_j^{cmax}\left(P_j^c\right)$ which are functions of generated power P_j^c. It should be mentioned that there are dependency between limitations of the CHP units power production and unit heat production plus limitations of the heat production and unit power production.

- Production limits of heat-only units

$$H_k^{hmin}\le H_k^h\le H_k^{hmax}\quad k=1,\ldots,N_h \quad (10)$$

2.1. Valve point impact consideration

Most of the reported studies have implemented quadratic and cubic cost function [17,19]. When steam admission valve starts to open, because of the wire drawing impacts, a ripple is created in the production cost. A sinusoid term has been added to the production cost of the generation units for modeling this impact [20,21]. Valve-point effects is utilized to express this ripple in the production cost, which is taken into account in the proposed work, making the optimization problem non-convex and non-differentiable. The fuel cost function with the consideration of valve-point effects can be stated as:

$$C_i\left(P_i^p\right)=\alpha_i\left(P_i^p\right)^2+\beta_iP_i^p+\gamma_i+\left|\lambda_i sin\left(\rho_i\left(P_i^{pmin}-P_i^p\right)\right)\right| \quad (11)$$

In which λ_i and ρ_i are the valve-point effects cost coefficients. The unit fuel cost by consideration of valve-point effects is shown