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Modulated particle swarm optimization for economic emission dispatch

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ABSTRACT

The economic emission dispatch (EED) problem of thermal generating units is a highly complex combinatorial multi-constraint, non-convex optimization problem with conflicting objectives. This paper presents a Modulated Particle Swarm Optimization (MPSO) method to solve the EED problem of thermal units. The conventional PSO is modified by modulating velocity of particles for better exploration and exploitation of the search space. The modulation of particles' velocity is controlled by introducing a truncated sinusoidal constriction function in the control equation of PSO. The conflicting objectives of the EED problem are combined in fuzzy framework by suggesting adjusted fuzzy membership functions which is then optimized using proposed PSO. The effectiveness of the proposed PSO is tested on three standard test generating systems considering several operational constraints like valve point effect, and prohibited operating zones (POZs). The application results and their comparison with other existing methods show that the proposed MPSO is promising for EED problem of thermal generating units.

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Introduction

The economic dispatch (ED) aims at determining the optimal scheduling of thermal power generating units so as to minimize the total fuel cost while satisfying various operational and power system network constraints. The thermal power plants based on fossil fuels releases significant amount of harmful pollutants such as oxides of carbon, sulfur and nitrogen, which not only affect human, animals and plant lives but also contribute toward alarming global warming. This has forced the electric utilities all over the world to reduce the plant emission level below certain specified limits. Therefore, economic emission dispatch (EED) is an attractive alternative where both economy of fuel cost and reduction of pollutant emission addressed simultaneously, though the cost and emission functions are of conflicting nature. The EED problem becomes more complex due to the practical constraints such as prohibited operating zones (POZs), ramp rate limits and valve-point loading effect. The POZs causes discontinuities in higher order nonlinear generator's cost function. In addition, the valve-point loading effect causes non-convex characteristic with multiple minima in the generator cost functions and thus imposes challenges to obtain the global optima. Due to complexity of the problem, conventional methods such as gradient method and Lagrange relaxation method are not suitable. The dynamic programming [1] can solve such type of problems, but it suffers from the curse of dimensionality [2].

In the last two decades, modern stochastic based meta-heuristic optimization techniques have received more attention by the researchers due to their ability to obtain global or near global solution. Several evolutionary and swarm based computational techniques have been attempted EED problems and some of them are mentioned here: genetic algorithm (GA) [3–5] has parallel search capabilities which imitate natural genetic operations. But, it has slow execution speed [6] and cannot assure constant optimization response times [7]; evolutionary programming (EP) [8–10] is similar to genetic programming, but the program structure is fixed. The main disadvantage of EP is its slow convergence [4,11–13], and is unable to explore the search space satisfactorily as initially the solutions move very fast toward the optimal point, but at the later half, when fine tuning is required, it is failed to give better performance [13]. Particle swarm optimization (PSO) has opened the gate way for swarm intelligence based computational techniques. In Ref. [11] authors attempted to improve the convergence of PSO by modifying cognitive and social behavior of the swarm. Hooshmand et al. [6] applied hybridized bacterial foraging with Nelder–Mead algorithm to cover a wide search region but has low convergence speed. Zhang et al. [14] proposed an enhanced multi-objective cultural algorithm (EMOCA) by combining PSO with cultural algorithm framework as CA needs modification to adapt to the mechanisms of multi-objective problems. Ghasemi

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[15] presented interactive honey bee mating optimization (IHBMO) algorithm that combines the original HBMO with the universal gravitation. Roy and Bhui [16] proposed quasi-oppositional teaching learning based optimization (QOTLBO) algorithm by suggesting an opposition-based learning concept in the standard TLBO to accelerate the convergence rate of optimization technique. Bhattacharjee et al. [17] proposed real-coded chemical reaction optimization (RCCRO) which is developed from CRO to makes it suitable for continuous optimization problems. The spiral optimization algorithm (SOA) is presented by Benasla et al. [18] where the multi-objective optimization problem is converted into a single objective function using a price penalty factor. Jeddi and Vahidinasab [19] proposed modified harmony search algorithm (MHSA) in which the process of generating random variables is adapted from the idea of mutation operator of GA. Shayeghi and Ghasemi [20] applied modified artificial bee colony (MABC) by employing chaotic local search to enhance the self-searching ability of the original ABC. However, these meta-heuristic methods are computationally demanding due to premature phenomena and trapping into local optimum especially for a large-scale problem [21]. Moreover, the quality of solutions obtained using these techniques may be affected by the tuning of their control parameters, and therefore it needs a thorough investigation. When the system has a highly epistatic objective function and number of variables to be optimized is large, then they have degraded efficiency to obtain global optimum solution [20].

Though PSO is the oldest swarm intelligence based techniques, but it has several advantages over other meta-heuristic techniques in term of simplicity, convergence speed, and robustness [22]. It provides convergence to the global or near global point irrespective of the shape or discontinuities of the cost function [23]. The potential of PSO to handle non-smooth and non-convex ELD problem was demonstrated by [24,25]. However, the performance of PSO greatly depends on its parameters and it often suffers from the problems such as being trapped in local optima due to premature convergence [12,26], lack of efficient mechanism to treat the constraints [27], loss of diversity and performance in optimization process [28], etc.

Several attempts have been reported in literature to enhance the performance of the PSO. The Improved PSO of [27] suggested chaotic inertia weight which decreases and oscillates simultaneously under the decreasing line in a chaotic manner. In this way, additional diversity is introduced but it requires tuning of chaotic control parameters. Roy and Ghoshal [29] proposed Crazy PSO where the particle velocity is randomized within predefined limits. The idea was to randomize the velocity of some of the particles, referred to as "crazy particles" by applying a predefined probability of craziness to maintain the diversity for global search and better convergence. However, the value of predefined probability of craziness can only be achieved after several experimentations. Chaturvedi et al. [30], dynamically controlled the acceleration coefficients within maximum and minimum bounds. However, the determination of limiting values of the acceleration coefficients is a difficult task as it needed many simulations. Coelho and Lee [31] randomized cognitive and social behavior of the swarm using chaotic sequences and Gaussian distribution respectively. Vlachogiannis and Lee [32] suggested new control equation in Improved Coordinated Aggregation PSO for better communication among particles to enhance local search. They allowed particles to interact with its own best experience along with all other particles have better experience on aggregate basis, instead of the global best experience. However, the authors' accepted that the performance of the proposed method is quite sensitive to various parameters setting and their tuning is essential. Selvakumar and Thanushkodi [33] proposed civilized swarm optimization (CSO), by combining Society-Civilization Algorithm with PSO to improve its communication. The proposed algorithm provides clustered search that results in better exploration and exploitation of the search space but needs several experimentations to determine the optimum values of the control parameters of CSO. Some researchers [34–36] suggested constriction factor in the velocity updating equation to assure convergence of PSO, but the exact determination of this factor is computationally demanding. Numerous other modified versions of PSO have been reported in literature, but most of them need experimentation for parameter settings and/or require some additional mechanism for better exploitation of the search space to avoid local trappings.

It is reported in [36] that for good convergence of PSO, the particles must fly with higher velocities during the early flights to enhance the global search (better exploration) and they should be gradually retarded during later flights of the journey to improve the local search (better exploitation). Therefore, there should be some mechanism to control the velocity of particles to achieve good convergence. In this paper, a Modulated Particle Swarm Optimization (MPSO) method is proposed to efficiently solve the complex EED problem of thermal units. The salient contributions of this paper may be listed as below:

1. The proposed MPSO employs a truncated sinusoidal constriction function to vary the velocities of the particles in a self-regulating mode to improve both global and local search ability of the standard PSO.
2. A new adjusted fuzzy membership function has been proposed to combine the economic and environmental objectives of the EED problem in order to ensure equal weightage for both the objectives.
3. A correction algorithm is suggested for repairing infeasible individuals whenever they appear during the computational process.

The applicability of the proposed method is investigated on three different standard test generating systems. The application results are presented and compared with other existing techniques.

Problem formulation

The EED is a multi-objective multi-constraint optimization problem solved to obtained the most compromizing generator schedule for simultaneously minimizing conflicting objectives of fuel cost and pollutants emission while satisfying several equality and inequality constraints. These objectives and constraints can be mathematically expressed as below:

Objectives

(i) Generator fuel cost function: The generator cost function is generally considered as quadratic when valve-point effects are neglected. The large turbine generators usually have a number of fuel admission valves which are operated in sequence to meet out increased generation. The opening of a valve increases the throttling losses rapidly and thus the incremental heat rate rises suddenly. This valve-point effect introduces ripples in the heat-rate curves and can be modeled as sinusoidal function in the cost function. Therefore, the generator cost function of EED problem may be stated as

$$F(P_G) = \sum_{i=1}^{N_G}(a_i + b_iP_{Gi} + c_iP_{Gi}^2) + |e_i \sin(f_i(P_{Gi\,min} - P_{Gi}))| \quad (1)$$

where a_i, b_i, c_i, are the cost coefficients of the ith generator, and e_i and f_i are the valve point effect coefficients, P_{Gi} is the

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