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Economic emission dispatch problems with stochastic wind power using summation based multi-objective evolutionary algorithm

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A B S T R A C T

In recent years, renewable energy sources such as wind energy have been used as one of the most effective ways to reduce pollution emissions. In this paper, a summation based multi-objective differential evolution (SMODE) algorithm is used to optimize the economic emission dispatch problem with stochastic wind power. The Weibull probability distribution function is used to model the stochastic nature of the wind power and the uncertainty is treated as the system constraints with stochastic variables. The algorithm is integrated with the superiority of feasible solution constraint handling technique. To validate the effectiveness of the proposed method, the standard IEEE 30-bus 6-generator test system with wind power (with/without considering losses) is studied with fuel cost and emission as two conflicting objectives to be optimized at the same time. Besides, a larger 40-generator system with wind farms is also solved by the proposed method. The results generated by SMODE are compared with those obtained using NSGAII as well as a number of techniques reported in literature. The results reveal that SMODE generates superior and consistent solutions.

1. Introduction

In electrical power systems, environmental concern is considered as one of the most important factors because of the fossil fuel fired electric generators exacerbate global warming. On the other hand, economic dispatch is another essential objective in order to ensure economic operation. For the traditional environmental economic dispatch (EED) problem, the purpose is to allocate the active power output from various generators in the system to minimize the total operating cost and pollution emissions, while fulfilling the load demand as well as the system constraints.

In the recent decades, increasing concern over environmental protection especially after the amendments of the clean air act in 1990 makes the EED problem as one of the active research areas in the operation of power system [19]. EED is a multi-objective problem with two conflicting objectives which are the minimization of cost and the minimization of the emission of pollution subjected to the practical constraints. Various approaches have been proposed in the literature to find

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an optimal dispatch scheme which can minimize emission and cost [37]. In [5,6], emission was treated as a constraint of the model and the power was dispatched by minimizing the cost as a single objective. The constrained emission approach was also considered by Granelli et al. to solve the dynamic power dispatch problem [14]. The problem was changed to a single objective optimization problem by using the weighted sum technique to combine the two objectives in [9]. Farag et al. [12] applied a linear programming based technique which considered one objective at a time. In the past few years, with the development of efficient evolutionary algorithms [28,20], especially multi-objective evolutionary algorithms, the research focus has switched to handling both objectives separately at the same time without combining them into a single weighted objective. In [1–4], Abido applied Niched Pareto Genetic Algorithm (NPGA), Non-dominated Sorting Genetic Algorithm (NSGA), Multi-objective Particle Swarm Optimization (MOPSO) and Strength Pareto Evolutionary Algorithm (SPEA) to solve EED problems. Hota et al. [16] used a Fuzzy based Modified Bacterial Foraging Algorithm (MBFA) to solve the EED problems. Robert et al. [31,32] successfully applied an elitist multi-objective evolutionary algorithm called NSGAII to solve the EED problems. The problem was also solved by using a Fuzzy Clustering based Particle Swarm Optimization algorithm (FCPSO) by Shubham et al. [33]. Qu et al. [30] proposed a Fast Multi-objective Evolutionary Programming (FMOEP) method to tackle the nonlinear multi-objective EED problems while Zhang et al. [38] used an improved quantum-behaved particle swarm optimization technique. In [13], Gong et al. introduced a hybrid multi-objective optimization algorithm based on particle swarm optimization and differential evolution and proved its efficiency in solving IEEE 30-bus 6 generator test system.

To reduce the emissions of the power plants, besides finding an optimal power dispatch strategy using the techniques mentioned above, connecting certain renewable energy such as wind power to the power system is another effective approach. Wind energy is clean and renewable energy which is increasingly used in many countries. It has become the world's fastest growing energy source [23]. However, the stochastic nature or uncertainty of the wind speed is considered as a major drawback in using this clean energy source. Integration of wind power also makes the EED problems much more complicated, as it will change the allocation of active power output for the thermal generators. In recent years, some works have been reported for solving the EED problems incorporating wind power generation [17,18,21,27,36,39]. In [36], the EED problem considering wind power and carbon tax was solved by applying the quantum-inspired particle swarm optimization. A single objective model was used by Jadhav et al. to express the operation cost of thermal and wind generation while the emission was also converted to the cost by using the carbon tax price [17]. In [39], a multi-objective evolutionary algorithm based on decomposition was used to handle the wind power EED problems without considering the losses of the system.

In this paper, the EED problems with a stochastic wind power model was established and solved by using a summation based multi-objective differential evolution algorithm (SMODE). The stochastic wind power was modeled as the system constraints by using the stochastic variables and applying the probability theory. The standard IEEE 30-bus 6-generator system was used as the basic system to inject the wind power. The system was solved excluding/including the losses as two separate cases. Moreover, a lossless 40 generator system with wind power was examined to demonstrate the effectiveness of solving large system by using the proposed method. The results were compared with the benchmark multi-objective optimization algorithm NSGAII and some other methods that have already been proven to be efficient for solving the EED problems. The main contributions of this paper contain three points. First, the SMODE algorithm is modified to remove the user defined parameter *P* and the performances are also improved for the tested EED problems. Second, IEEE 30-bus 6-generator system including the transmission losses considering wind power (Case 2B of Section 5.1) is introduced in this paper. Lastly, the proposed algorithm is able to generate better results than the compared algorithms.

The rest of the paper is organized as follows. Section 2 describes the concept of multi-objective optimization as well as the proposed summation based MODE. Section 3 outlines the mathematical model of the EED problems with stochastic wind power. In Section 4, the constraint handling method and the implementation of the algorithm are presented. Section 5 presents the experimental setup, results and discussions. Section 6 concludes the paper.

2. Constrained multi-objective optimization and summation based MODE

2.1. Constrained multi-objective optimization

Many real-world optimization problems involve constraints as well as more than one objective conflicting with each other. These problems are classified as constrained multi-objective optimization problems. A representative constrained multi-objective optimization problem can be modeled as:

Maximize / Minimize:

$$f_m(x) = f_m(x_1, x_2, \ldots, x_n), m = 1, 2, \ldots, M \quad (1)$$

Subject to:

$$h_k(x) = h_k(x_1, x_2, \ldots, x_n) = 0, k = 1, 2, \ldots, K \quad (2)$$

$$g_j(x) = g_j(x_1, x_2, \ldots, x_n) \geq 0, j = 1, 2, \ldots, J \quad (3)$$

$$x_i^{\mathrm{L}} \leq x_i \leq x_i^{\mathrm{U}}, i = 1, 2, \ldots, n \quad (4)$$

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