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Short-term hydro-thermal-wind complementary scheduling considering uncertainty of wind power using an enhanced multi-objective bee colony optimization algorithm

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ABSTRACT

This paper presents a short-term economic/environmental hydro-thermal-wind complementary scheduling (HTWCS) system considering uncertainty of wind power, as well as various complicated non-linear constraints. HTWCS system is formulated as a multi-objective optimization problem to optimize conflictive objectives, i.e., economic and environmental criteria. Then an enhanced multi-objective bee colony optimization algorithm (EMOBCO) is proposed to solve this problem, which adopts Elite archive set, adaptive mutation/selection mechanism and local searching strategy to improve global searching ability of standard bee colony optimization (BCO). Especially, a novel constraints-repairing strategy with compressing decision space and a violation-adjustment method are used to handle various hydraulic and electric constraints. Finally, a daily scheduling simulation case of hydro-thermal-wind system is conducted to verify feasibility and effectiveness of the proposed EMOBCO in solving HTWCS problem. The simulation results indicate that the proposed EMOBCO can provide lower economic cost and smaller pollutant emission than other method established recently while considering various complex constraints in HTWCS problem.

1. Introduction

With increasing seriousness of energy crisis and global warming, high-efficiency utilization for clean and renewable energy sources such as wind and hydro power, as well as reduction of pollutant emission from fossil fuels, have been paid more attention and become a hot research issue. For instance, in China, accelerating the energy structure transition of power system with clean-energy economies have been taken into consideration, which indicates that the society will need sufficient and stable electricity not only at lowest price, but also has lower emission rate. Therefore, the optimization operation of power system considering economic/environmental have been widespread concerned recently [1]. Generally, several ways can be taken to decrease the pollutant emission and usage of primary energy sources. The first way focuses on how to effectively decrease emission level by means of improving the existing power dispatch strategies in the power system that fossil-fuel is dominant [2]. The related research mainly involve the dynamic economic dispatch (DED) [3], economic emission dispatch (EED) [4–6] and hydrothermal economic/environmental dispatch (HEED) problem [7–9] with the purpose of optimizing generation cost and emission level, simultaneously. The second approach we generally used is to exploit renewable energy such as wind energy, which can effectively decrease our dependence on fossil fuels. As one of the clean and renewable energy sources, wind power has gained wide attention due to its advantage with low operation cost and zero emission, and EED models including wind power have been established to obtain feasible scheduling schemes by researchers [10–12].

However, wind energy resources have characteristics of unpredictability and uncontrollability, which leads to uncertainty, intermittency and volatility of its outputs [13]. Therefore, the large-scale wind power integration will affect the reliable operation of power system and increase the operational risks, which makes the EED problem more complicated. Several methods have been proposed to deal with the EED problem considering uncertainty of wind power. Among them, in Ref. [14], the cumulative density

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function (CDF) and probability density function (PDF) of wind power are described by two-parameter Weibull distribution and the modeling approach based on chance-constrained programming method is used to handle constraints with stochastic variables. By analyzing history data and the stochastic characteristic of wind speed, Ref. [15] presents a scenarios generation method based on Markov chains to generate predictive values of wind power with numerous scenarios, and impacts of stochastic constraints under different confidence levels of wind fluctuation on system operation are analyzed. Ref. [16] presents a probabilistic approach based on 2 m point estimated method to analyze uncertainties of load demand and wind speed which are considered as random input variables of wind-thermal system. Moreover, Ref. [17] proposes a closed-form in terms of the incomplete gamma function (IGF) to represent the effect of wind power, and the extra cost of reserve and electricity dissipation in power system caused by wind power overestimation and underestimation are formulated, respectively. These papers are mainly aimed to realizing joint operation of wind power and thermal power, but the integration of wind power with hydrothermal power system is rarely reported in literature. Therefore, HTWCS is a problem that is worth discussing, and the related work are also carried out in succession recently [18–20].

In this paper, to take full advantages of complementary property among hydro, thermal and wind power, a short-term economic/environmental hydro-thermal-wind complementary scheduling (HTWCS) system is established, while considering uncertainty of wind power. The HTWCS problem is a complex, multi-objective, multi-stage, and multi-constraint optimization problem, which aims to reasonably arrange power outputs of hydro plants, thermal and wind generators to meet load demands while minimizing the total generation cost and pollutant emission, simultaneously. For such a complex multi-objective problem, optimizing algorithms that based on traditional mathematical programming [21–23] may be unable to converge to the global optimal solution and coordinate the conflicting relationship among multiple objectives. These disadvantages motivate the requirement for seeking alternative methods based on evolutionary mechanism. Multi-objective evolutionary algorithms (MOEAs) are heuristics stochastic methods for solving multi-objective problems. Recently, inspired by the famous non-dominated sorting genetic algorithm-II (NSGA-II) [24], some MOEAs, such as multi-objective differential evolution (MODE) [4,25], multi-objective particle swarm optimization (MOPSO) [26], multi-objective gravitational search algorithm (MOGSA) [27], multi-objective artificial bee colony optimization (MOABC) [11], multi-objective ant colony optimization (MOACO) [28], have been proposed to deal with the complex multi-objective dispatch problems with practical modeling of operation constraints efficiently. However, the premature convergence caused by sharply decrease of the population diversity during evolutionary process, as well as shortcomings in balancing global exploration and local exploitation still exist in these stochastic searching algorithms. Therefore, it is worthwhile to develop new efficient algorithms to solve the multi-objective problems precisely.

Inspired by the foraging behavior of honey bee colonies, Karaboga [29] firstly proposed the Bee colony optimization algorithm (BCO) in 2005. Compared with other swarm based metaheuristic algorithms, the optimization mechanism and coding form of BCO are more simple and efficient as it needs to set less control parameters. Therefore, it has been applied to handle various complex power system optimization problems [3,30–32], and we also attempt to use it for solving HTWCS problem in our work. However, BCO still needs further improvements for following reasons. Firstly, BCO is originally designed for solving single objective problems, it lacks of ability for dealing with the multiple conflictive objectives, simultaneously. Furthermore, BCO often suffers premature convergence and easily be trapped in local optimum, and it has no ability of handling complicated constraints effectively. Therefore, we propose an enhanced multi-objective bee colony optimization algorithm (EMOBCO) to solve the HTWCS problem with optimization of economic and environmental dispatching objectives, in which Elite archive set and adaptive mutation/selection mechanism based on crowding distance, non-dominated relationship and feasibility method are introduced into BCO. To avoid premature convergence and lose diversity, as well as balance the abilities of exploration and exploitation, a local searching (LS) method is proposed to guide the behavior of a scout in BCO. Especially, the heuristic constraints handling strategy with compressing decision space and the violation adjustment method are applied to handle various time-related and space-coupled constraints of HTWCS problem, then the feasibility of solutions and the computation efficiency are guaranteed. Finally, to verify the feasibility and effectiveness of the proposed EMOBCO method, a daily scheduling simulation of hydro-thermal-wind system with four hydro plants, three thermal units and two wind generators is established and the Pareto solutions are obtained by EMOBCO. The obtained results prove that EMOBCO can provide lower economic cost and smaller pollutant emission than other method established recently, and it presents a better performance in convergence properties and distribution diversity for solving HTWCS problem while considering various complex constraints, which can be a promising alternative for solving HTWCS problem.

The paper is organized as follows: Section 2 introduces the uncertainty description of wind power. Section 3 presents the formulation of HTWCS problem. In Section 4, we give a brief description about the Standard BCO algorithm. Section 5 and Section 6 present the proposed methodology of EMOBCO and the practical the solving procedure for HTWCS problem, respectively. In Section 7, the proposed method is applied to a hydro-thermal-wind complementary scheduling test system and the optimization results are compared with HMOCA. Section 8 outlines the conclusions followed by acknowledgement.

2. The uncertainty description of wind power

2.1. The probability distribution of wind power

To solve HTWCS problem, we should firstly focus on how to deal with uncertainty of wind power. Generally, the Weibull probability density function (PDF) method [17] is commonly used to describe the stochastic characteristic of wind speed profile, then its PDF can be formulated as follows:

$$f_v(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \cdot \exp\left(-\left(\frac{v}{c}\right)^k\right), \quad (v > 0) \tag{1}$$

where $c > 0$ and $k > 0$ are the scale factor and shape factor, respectively. v denotes the current wind speed. Based on the PDF of wind speed, the cumulative density function (CDF) can be obtained:

$$F_v(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^k\right) \tag{2}$$

Wind power output is determined by wind velocity, and some researchers [33,34] adopt a linear model to characterize their relationship, which is presented as follows:

$$w = \begin{cases} 0 & (v < v_{in} \text{ or } v \geqslant v_{out}) \\ \frac{w_r(v - v_{in})}{v_r - v_{in}} & (v_{in} \leqslant v < v_r) \\ w_r & (v_r \leqslant v < v_{out}) \end{cases} \tag{3}$$

where v_r, v_{in} and v_{out} are the rated, cut-in and cut-out wind speeds, respectively. w_r is rated power of wind turbine. $w \in [0, w_r]$ denotes wind power output.