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Multistage stochastic inexact chance-constraint programming for an integrated biomass-municipal solid waste power supply management under uncertainty

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In this study, a multistage stochastic inexact chance-constraint programming (MSICCP) model is developed for power supply management under uncertainties. In the MSICCP model, methods of multistage stochastic programming (MSP), interval-parameter programming (IPP), and chance-constraint programming (CCP) are introduced into a general optimization framework, such that the developed model can tackle uncertainties described in terms of interval values and probability distribution s over a multistage context. Moreover, it can reflect dynamic and randomness of energy resources during the planning horizon. The developed method has been applied to a case of managing the process of power supply in an integrated biomass-municipal solid waste power plant. Useful solutions for the power supply management have been generated. Interval solutions associated with different risk levels of constraint violation have been obtained. The generated solutions can provide desired energy resource allocation with a minimized system cost, maximized system reliability and a maximized energy security. Tradeoffs between system costs and constraint-violation risks can also be tackled. Higher costs will increase system stability, while a desire for lower system costs will run into a risk of potential instability of the management system. They are helpful for supporting (a) adjustment or justification of allocation patterns of energy resources, and (b) analysis of interactions among economic cost, environmental requirement, and power supply security.

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1. Introduction

With the rapid economic development and the improvement in people's living level, the demand for energy resources increases

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significantly [1]. As a main fuel for power generation, coal has been consumed in large amount. For example, in 2010, China's coal consumption in power generation industry has reached 0.91 billion metric tonnes, which accounts for 62.23 percent of the total amount of steam coals. In addition, it is estimated that it would exceed 1.4 billion metric tonnes in 2015. Besides, environmental pollution associated with the consumption of coal has a serious pressure on ecosystem and human health [2]. Therefore, it is extremely urgent to look for renewable energy resources which are favorable to environment protection and sustainable development, such as biomass and municipal solid waste (MSW).

However, considering the biomass or MSW utilization, a number of impact factors, such as low-density of biomass materials, low heating value, and low thermal efficiency and increasing energy demand, lead to an increasing consumption of energy resources. This would inevitably result in conflicts among economic objective, energy demand/supply, and environmental requirement. Therefore, several authors developed innovative systems or optimization techniques to take full advantage of biomass or MSW previously. For example, combining a biomass gasification power plant, a gas storage system and stand-by generators, Pérez-Navarro et al. [3] proposed an innovative hybrid wind-biomass system to stabilize a generic 40 MW wind park. A biogas, solar and a ground source heat pump greenhouse heating system (BSGSHPGHS) with horizontal slinky ground heat exchanger was designed innovatively by Esen and Yuksel [4] to meet the required heating load. Anderson et al. [5] developed a multi-objective evolutionary algorithm (specifically MOGA) to optimize the operation of a generic waste incineration plant in terms of economic and environmental goals, and operational constraints.

During the last decade, in order to promote the development of renewable energy resources in China, the investment in new energy is substantially on the rise, especially in biomass power industry. Based on the medium- to long-term development planning of renewable energy, Chinese Central People's Government has proposed the development goals for biomass power generation: by 2015, its installed capacity would be 13 GW (equivalent to generating capacity of 64.5 billion kWh); by 2020, its installed capacity will be 30 GW (equivalent to generating capacity of 148.8 billion kWh) [6]. Moreover, as a promising alternative way, the practice of MSW incineration for power generation is presently spreading in China, especially in cities where the economy is relatively more developed and landfill sites are difficult to locate [7].

In fact, with respect to biomass or MSW power generation, a variety of uncertain factors that should be considered by decision makers, including the acquisition of straw and stalks which are rather seasonal, the MSW generation rates, dynamics of system conditions, as well as the associated economic and technique parameters. In addition, many processes are linked to power generation, such as processing/conversion, transmission/storage, and supply/demand of electricity, further complicating the complexities in decisions making. Such uncertainties and complexities would affect the optimization process of MSW and biomass power generation and the generated decision schemes [8,9]. Above all, they could not effectively be addressed by the conventional deterministic optimization models. Therefore, it is desired to develop robust methods to deal with these uncertainties and complexities.

More recently, a number of inexact optimization techniques were developed to deal with such uncertainties and complexities in electric power and waste management systems. For instance, Li et al. [10] proposed a multistage interval-stochastic regional-scale energy model (MIS-REM) for supporting electric power system (EPS) planning under uncertainty. Li and Huang [11] presented a multistage interval-stochastic integer programming model for planning electric-power systems, where solutions of electricity-generation schemes under different GHG-mitigation options and electricity-demand levels were obtained. Li et al. [12] provided an interval-parameter two-stage stochastic mixed integer programming (ITMILP) model for waste management, which also could be used to analyze various policy scenarios that are associated with different levels of economic penalties when the promised policy targets are violated. Maqsood and Huang [13] introduced a two-stage interval-stochastic programming (TISP) model for the planning of solid-waste management systems, providing desired waste-flow patterns with minimized system costs and maximized system feasibility.

In general, the above discussion about electric power and MSW management systems mainly focus on several kinds of energy convention technologies (coal-fired power, wind power, biomass power, and solar power) and MSW management facilities (landfill, incineration, and composition). However, few studies were conducted on power supply management in a direct combustion biomass or MSW power plant, and hybridization of these two energy resources to adjust the power supply process on the base of taking the dynamic and randomness of biomass and MSW resources into account has received little attention. Moreover, although models mentioned above could effectively tackle uncertainties presented as both interval values and probabilistic distributions, they are incapable of accounting for the risk of violating uncertain system constraints, which means they can't support an in-depth analysis of the tradeoff between system cost and system-failure risk [14].

Thus, the objective of this study is to develop a multistage stochastic inexact chance-constraint programming (MSICCP) method and apply to a power supply management case with an integrated biomass-MSW power plant, reflecting the dynamic and randomness of energy resources. This is the first attempt that multistage stochastic programming (MSP), interval-parameter programming (IPP), and chance-constraint programming (CCP) methods are integrated into a general framework to manage the process of power supply under uncertainties and randomness presented as interval values and probabilities within a multi-stage context. A hypothetic case study was provided for demonstrating applicability of the developed method. The results can help decision makers identify the optimal power supply management strategies under uncertainty and gain a comprehensive tradeoff between system costs and constraint-violation risks. Moreover, to ensure the reliability and security of power supply, there are two types of power generation, including those utilizes biomass resources, as well as MSW-based backups [15].

2. Methodology

2.1. Multistage stochastic programming

In many real-world problems, uncertainties may be expressed as random variables, and the related study systems are of dynamic feature. Thus the relevant decisions must be made at each time stage under varying probability levels. Such a problem can be formulated as a scenario-based multistage stochastic programming (MSP) model with recourse. Uncertainties in MSP can be conceptualized into a multi-layer scenario tree (as shown in Fig. 1), with a one-to-one correspondence between the previous random variable and one of the nodes (state of the system) in each time stage (t) [16]. Generally, a multistage scenario-based stochastic linear programming model with recourse can be formulated as follows:

$$\max f = \sum_{t=1}^{T} \left(\sum_{j=1}^{n_1} c_{jt} x_{jt} - \sum_{j=1}^{n_2} \sum_{h=1}^{H_t} p_{th} d_{jth} y_{jth} \right) \tag{1a}$$