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An inexact cost-risk balanced model for regional energy structure adjustment management and resources environmental effect analysis-a case study of Shandong province, China

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ABSTRACT

Energy structure adjustment is a significant way to resolve constrained resources and environment, improve the security of energy supply, and achieve sustainable development, which is a complicated itself but further challenged by existence of uncertainties. In this study, an inexact multistage stochastic cost-risk balanced programming model is developed for energy system management under considering the policies of coal-consumption control and pollutants emission reduction. The method is an integration of inexact multistage stochastic programming and a risk management tools from modern financial theory, and could tackle uncertainties described as interval values and probability distributions. The method could reflect energy system dynamic characteristic in a multi-period problem, and provide an effective linkage between conflicting economic cost and the system stability. The proposed method is applied to a real case of planning electric power structure adjustment in Shandong province, China, where the energy system is faced with lots of difficulties complexities in electric power structure adjustment. The impact of coal-consumption control level and pollutants emission reduction scenarios on energy system structure adjustment, and resources and environmental effect were compared and analyzed. The results are valuable for supporting the adjustment or justification of the existing power generation schemes of the complicated regional energy system.

1. Introduction

Energy structure adjustment under an energy supply security premise is an urgent task for dealing with traditional energy shortages, climate change, and deterioration of environmental quality [1,2]. Especially for countries such as China, rapid growth of power demand and energy consumption mainly based on thermal power has greatly affect the social, economic and environmental dimensions of sustainable development, and leads to major challenges requiring regional electric power structure adjustments. In addition, various uncertainties and complex relationships exist in regional electric power system, such as the distribution of future load demands, the conflicting bidding on power net of different activities, and the interactions of various factors and information [3–5]. These uncertainties would decrease the robustness of energy system management strategy about electric power supply/demand, energy system safety, and pollutants mitigation obtained by quantitative system management models. Therefore, effective robust optimization model for electric power structure adjustment management with a risk-aversion attitude is desired under various uncertainties.

Previously, a number of inexact optimization methodologies were developed for addressing the above-mentioned difficulties and helping energy system structure adjustment in a more sustainable pattern [6–16]. Many practices have been enforced in Saskatchewan, Ontario, Toronto-Niagara Region, Beijing, Shanghai, British Columbia and other regions through using interval-parameter programming, fuzzy mathematical programming, stochastic mathematical programming, and theirs hybrid optimization methods that successively be proposed for reflecting different forms of uncertain information [17–22]. Among them, an effective

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approach for dealing with uncertainties in energy system management is the stochastic mathematical programming (e.g. inexact two-stage stochastic programming and inexact multistage stochastic programming). The stochastic programming is to construct a set of scenarios about the future values of uncertain parameters with certain probabilities, such as the values of available resource and load demand for each future planning period [23]. The optimized decision schemes for each scenario and the sensitivity of these decisions could be obtained through the scenarios analysis method. Considering the energy system dynamic characteristic in a multi-period problem, the inexact multistage stochastic programming can be a useful technique and applied in regional energy system planning and structure adjustment. For example, Luo and Zhou presented a recourse-based multistage interval-stochastic programming model for long-term hydropower planning, where the uncertainties associated with random inflows and intervals information was reflected [24]. Li et al. developed an inexact fuzzy-stochastic energy model for energy and environmental systems management under multiple uncertainties, where the random electric power demand, air pollutants mitigation level, and dynamic characteristics for installed capacity expansion in a case study were expressed by the interval fuzzy linear programming, and multistage stochastic programming, and mixed-integer linear programming framework [25]. Rocha and Kuhn proposed a multistage stochastic mean–variance optimization model for hedging portfolio management of electricity derivatives from the viewpoint of a price-taking retailer that procures electric energy to satisfy its customers' electricity demand [26]. Amirahmadi and Foroud proposed a stochastic joint energy and spinning reserve market clearing model based on a multi-objective mixed integer nonlinear programming under considering minimizing the total expected load not supplied of the power system, maximizing the post-contingency expected social welfare associated with the spinning reserve scheduling, and the pre-contingency offered cost [27]. Xie et al. developed an inexact multistage stochastic model for regional energy system management in Jining City, China, where the model could effectively deal with the random and interval information in the system, and three scenarios about the electric power structure adjustment, clean power generation, and the emission reduction target were designed in order to search a reasonable development mode [28].

Many case studies have shown that the inexact multistage stochastic programming provides a powerful mechanism for modeling the energy system dynamic and addressing the uncertain random information expressed as multi-period probabilistic distributions with the stochastic nature of electric power demand. However, it fails to capture the following important aspects of energy system management: (i) the method may be possible to identify a decision policy that is relatively stable with respect to scenarios, especially when the scenarios do not differ drastically from one another [29,30]. (ii) the optimization methods aimed at minimizing expected costs or maximizing the system benefit without accounting for risk and managers behavior are now redundant, and this could lead to the problems of low system stability and unbalanced system development risk [31,32]. (iii) the traditional electric power management model mainly investigated the sensitivity of structure adjustment with respect to single factor analysis (e.g. pollutants mitigation, reduction level of coal-fired power generation), and the comparison of two or multi polices (especially resources consumption control and pollutants mitigation) effect for power generation management on the base of taking the dynamic and randomness into account has received little attention.

Therefore, the objective of this study is developed an inexact multistage stochastic cost-risk balanced programming (IMSCBP) method for regional electric power system structure adjustment management under considering the policies of coal-consumption control and pollutants emission reduction. The model is based on the recourse-inexact multistage stochastic programming, and developed by introducing a risk management tools from modern financial theory into a general framework with the minimum cost objective in regional energy system management problem under uncertainties. Moreover, the developed model will be applied to regional electric power system planning and management in Shandong province, China, where faces a more difficulties and complexities in energy structure adjustment. A deep compare for the effect of coal-consumption control and pollutants emission reduction on energy system structure adjustment, and the resources and environmental resources and environmental effects were analyzed. Furthermore, the model will be shown how it can be used to generate power generation schemes under a given risk level, as well as determine which of these designs can most efficiently lead to the optimized system objectives.

2. Methodology

Fig. 1 shows the general framework of the inexact multistage stochastic cost-risk balanced programming, which is based on IPP, MSP, and variance analysis techniques. Each technique has its unique contribution in enhancing the novel method capacities for tackling the uncertainties and system risk. For example, the probability distributions and system dynamic characteristics were handled through MSP; the uncertainties information presented as discrete intervals were reflected through IPP; and the variance analysis techniques was used for addressing the risk that introduced by the system randomness. The modeling framework would offer feasible and reliable solutions under different scenarios of energy generation targets, which are helpful for decision makers.

2.1. Inexact multistage stochastic programming

In general, each scenario of an inexact multistage stochastic

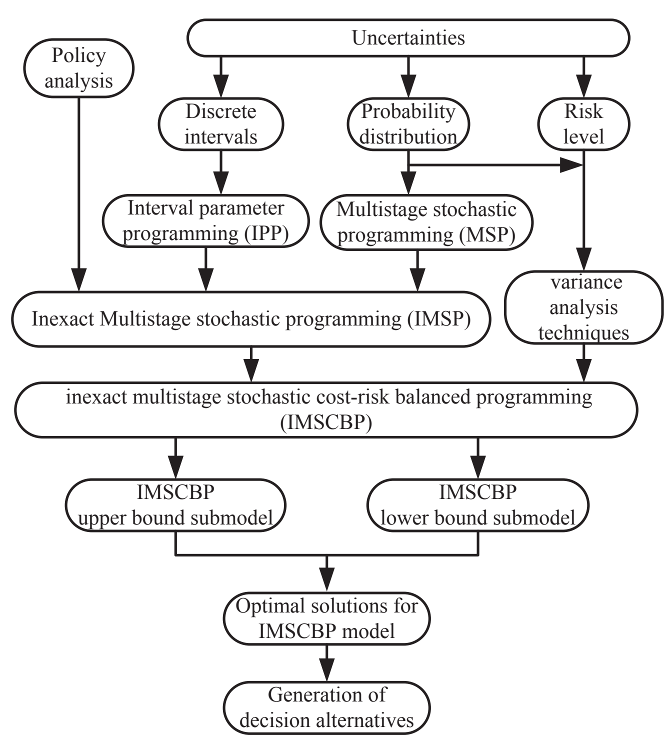

Fig. 1. Framework of the IMSCBP model.