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Regional heuristic interval recourse power system analysis for electricity and environmental systems planning in Eastern China

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ABSTRACT

In some cases such as the power grid in eastern China, a regional power system analysis is confronted with multiple challenges: dynamics of electricity demands, nonlinearity of the relationship between these demands and influencing factors, fluctuation of system features, risks of resource unavailabilities, spatial heterogeneities of power supplies and demands, dynamical diversity and interactions of system components, and the multi-layer interactions of these challenges. In order to address these challenges, a regional heuristic interval recourse power system analysis (RHIRPSA) method is developed in this study and applied to electricity and environmental systems planning in eastern china. RHIRPSA can predict electricity demands effectively, and allow for incorporation of interval uncertainties into the optimization process and solutions in electricity systems. The objective is to maximize system profits under constraints of resources availability and environmental regulations. Three scenarios are considered to reflect the influence of different emission reduction policies on power generation and power dispatching. The results indicate that reasonable decision alternatives are generated. This study is helpful for (a) facilitating electricity consumption estimation, (b) providing reliable electricity systems management schemes to guide activities such as electricity-conversion technological development, capacity expansion and electricity allocation, (c) mitigating conflicts and interactions among economic profits, electricity generation patterns, air pollution emission control and system reliability, and (d) identifying the desired strategies for improving air quality in eastern China through optimizing the economic and environmental protection measures under policies of air pollution emission reduction.

1. Introduction

In the past decades, electricity supply and demands have been steadily increasing to support population growth, economic development and life standard improvement throughout the world (Cai et al., 2009). For China, the annual growth rates in the gross domestic product (GDP), population and per capita electricity consumption from 2010 to 2014 were 11.8%, 0.4%, and 5.8%, respectively (National Bureau of Statistics of the People's Republic of China, 2015). At the same time, insufficient supplies, ineffective pollutant treatment, and unreasonable production practices have become major obstacles to electricity systems management. Power generation is an important source of air pollution in China since it is mostly from coal-fired powerplants (Zhao et al., 2013; Hu et al., 2016; Huang et al., 2016). For instance, power generation coming from fossil fuels accounted for 76.96% of the total electricity generation in 2014 in China (Sina Finance, 2015). Approximately 45% of the anthropogenic SO_2 and NOx emissions are contributed by fossil-fuel combustions in thermal power plants (Editorial office of China Electric Power, 2014). Moreover, these existing problems will worsen in the following decades due to the economic growth in spite of the increasing fuel prices and energy efficiency improvement (Lin and Ouyang, 2014). Lack of scientific management schemes on electricity and environmental systems (EES) leads to a series of problems, such as energy resources shortage, serious environment pollution and even threat to human life and health.

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Therefore, EES planning in a municipal, regional, or national level is required for supporting socio-economic and environmental management from a long-term point of view by scientific methods.

Previously, a number of optimization models were developed for facilitating electricity management systems and controlling the associated environmental emissions. For example, Kwaczek et al. (1996) developed an optimization model to analyze economic impacts of various emission-reduction strategies on energy activities in Saskatchewan, Canada. Khella (1997) analyzed policies associated with energy utilization and environmental externality costs. Loulou and Kanudia (1998) analyzed marginal costs related to green-house-gas (GHG) mitigation in provinces of Ontario, Quebec, and Alberta, Canada, which might give rise to shift from fossil fuels to renewable energy resources in these areas. Iniyan and Sumathy (2000) developed a linear programming model for minimizing cost/efficiency ratio of energy consumptions and determining optimal patterns of renewable energy allocation in India. Zhang et al. (2001) analyzed relationships between global warming and structural changes in the power-generation sector in Guangdong Province, China. Ramanathan (2005) analyzed relationships between energy consumptions and carbon dioxide emissions in countries of the Middle East and North Africa. Jebaraj and Iniyan (2006) reviewed a number of energy models and their effectiveness to support decision making and policy formulation. Srivastava and Misra (2007) employed multi-pronged strategies to support operation of energy systems encompassing softer options in South Asia sub-regional. Dicorato et al. (2008) presented an energy flow optimization model to analyze the contribution of distributed power generation technologies in improving energy utilizing efficiencies. Deshmukh and Deshmukh (2009) developed a multi-objective goal programming for analyzing energy consumption patterns in Rajasthan of India and determining optimal energy allocations among a number of end-users in the region.

Though great efforts have been dedicated, most of the previous studies focused on identification of energy technologies based on the assumption that the associated parameters such as costs and efficiencies were simplified as deterministic values (Dong et al., 2012). However, EES planning is challenged by multiple system complexities. Generally, many factors are involved in EES such as energy supplies and demands, pollution emission standards, and power generation types, which are uncertain and have influence on imbalance between power generation and consumption in a region. The complexities are further multiplied by not only complex interactions among multiple uncertain parameters, but also their spatial and temporal variations, which are difficulty to formulate relevant policies and strategies by decision makers (Cai et al., 2009; Dong et al., 2011). Therefore, programming methods were developed for dealing with various uncertainties in EES planning. For example, Liu et al. (2000) developed an interval-parameter chance-constrained method for nonrenewable energy resources management under uncertainty. Mavrotas et al. (2003) proposed a fuzzy linear programming model to handle uncertainties in energy costs presented as fuzzy sets. Liu et al. (2008) developed an integrated fuzzy-possibilistic joint-probabilistic mixed-integer programming model for the expansion planning of power generation under uncertainty. Lin and Huang (2008) introduced an interval-parameter linear programming approach to develop an interval-parameter energy systems model (IPEM) for supporting effective regional energy systems planning under uncertainty. Zhou et al. (2013) developed a fractile-based robust stochastic programming method for tackling uncertainties expressed as possibilistic and probabilistic distributions in constraints and objective function in electric power systems planning. Piao et al. (2014) developed a stochastic simulation–optimization model for planning electric power systems under uncertainty.

At the same time, power consumption is part of the inputs of EES optimization models. Inaccurate prediction may lead to unreliability of EES optimization practices and results. In order to deal with dynamic changes of power consumption, many approaches including Engineering Method, Statistical Method and Artificial Intelligence (AI) Method were proposed (Zhao and Magoulès, 2012a,b; Yao and Steemers, 2005; Pan et al., 2007; Lam et al., 2010; Cho et al., 2004; Azadeh et al., 2008; Dong et al., 2005; Lai et al., 2008; Wong et al., 2010; Hou et al., 2006; Guo et al., 2011). For instance, Yao and Steemers (2005) proposed a simple method of predicting a daily energy consumption profile for the design of a renewable energy system for residential buildings. Pan et al. (2007) summarized the calibrated simulation as one building energy analysis method and applied it for analyzing the energy usage of a high-rise commercial building. Lam et al. (2010) used principle component analysis to develop a climatic index Z to investigate whether energy use in buildings from simulation could be correlated with a new composite climatic index. Cho et al. (2004) developed a regression model on 1-day, 1-week, 3-month measurements, leading to the prediction error in the annual energy consumption of 100%, 30% and 6%, respectively. Azadeh et al. (2008) predicted long-term annual electricity consumption in energy intensive manufacturing industries. Dong et al. (2005) first introduced SVMs to predict the monthly electricity consumption of four buildings in the tropical region. Lai et al. (2008) applied SVMs on one year's electricity consumption of a building.

However, most of the previous studies were conducted for describing interactions among energy, economy, and environment, energy and environmental policy on energy activities for a particular target (such as capacity expansion, energy stability and minimal economic costs) in optimization models of EES planning (Cai et al., 2009). There was lacking of studies that could systematically reflect electricity and environmental implication of power dispatching and transmission among these regions (Su et al., 2016). Most of the previous studies in EES planning focused on interval linear programming (ILP) and integration of ILP and other methods on uncertain parameters of energy model expressed as intervals, but the solution of ILP can hardly reflect constraint-violation risks of energy model with system optimality, which cannot reflect the optimal planning of the energy system (Cheng et al., 2015a,b,c). In electricity consumption forecasting, Engineering Method has difficult to apply it practically and lack of input information, and the Statistical Methods has been found to have lack of accuracy and not flexible (Zhao and Magoulès, 2012a,b). SVMs has higher computational burden for the constrained optimization programming (Ahmad and Hassan, 2014). In order to remedy these shortages, interval recourse linear programming (IRLP) and ANN can be integrated into a general optimization framework for supporting the planning of regional electricity systems and air pollution alleviation (Zhang et al., 1998).

Therefore, the objective of this study is to develop a regional heuristic interval recourse power system analysis (RHIRPSA) approach to support regional power systems planning and environmental management under uncertainty. RHIRPSA will be a hybrid method, which will incorporate ANN and IRLP to tackle dynamics of energy activities, constraint-violation risks and uncertainties presented as intervals. At the same time, a variety of energy resources and technologies, power dispatching/transportation activities, and environmental pollution control measures, as well as their interactions will be effectively reflected within a large-scale context. A real case study of eastern China electric power systems will be provided for demonstrating availability of the developed RHIRPSA and identifying the optimal EES planning.