Electric Power Systems Research 80 (2010) 1394–1405

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Multi-period multi-objective electricity generation expansion planning problem with Monte-Carlo simulation

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ARTICLE INFO

Article history:
Received 18 December 2008
Accepted 19 May 2010
Available online 7 July 2010

Keywords:
Generation expansion
Generation planning
Multi-objective optimization
Monte-Carlo simulation

ABSTRACT

A new approach to the electricity generation expansion problem is proposed to minimize simultaneously multiple objectives, such as cost and air emissions, including CO_2 and NO_x, over a long term planning horizon. In this problem, system expansion decisions are made to select the type of power generation, such as coal, nuclear, wind, etc., where the new generation asset should be located, and at which time period expansion should take place. We are able to find a Pareto front for the multi-objective generation expansion planning problem that explicitly considers availability of the system components over the planning horizon and operational dispatching decisions. Monte-Carlo simulation is used to generate numerous scenarios based on the component availabilities and anticipated demand for energy. The problem is then formulated as a mixed integer linear program, and optimal solutions are found based on the simulated scenarios with a combined objective function considering the multiple problem objectives. The different objectives are combined using dimensionless weights and a Pareto front can be determined by varying these weights. The mathematical model is demonstrated on an example problem with interesting results indicating how expansion decisions vary depending on whether minimizing cost or minimizing greenhouse gas emissions or pollutants is given higher priority.

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1. Introduction

The electricity generation expansion planning (GEP) problem involves the selection of generation technology options to be added to an existing system, and when and where they should be constructed to meet the growing energy demand over a planning horizon time. The GEP problem is well studied, with many of the studies focus on finding the least cost expansion plan. However, there are many conflicting objectives in the GEP problem such as environmental impact, reliability, imported fuel, safety and so on. Moreover, there are uncertainties associated with the input data such as demand forecasts, water flows to reservoirs, input fuel prices, system component failure and others. Therefore, a multi-objective, stochastic optimization method is desirable to solve the GEP problem.

In this study, we use multi-objective optimization to minimize the cost, and to minimize the environmental impact, namely to minimize the CO_2 and NO_x emissions. The CO_2 and SO_2 emissions are largely generated from coal burning. Therefore the SO_2 emission is highly and positively correlated with the CO_2 emission. Even though we did not consider the SO_2 emission explicitly, we implicitly consider minimizing the SO_2 emission by minimizing CO_2 emission. The availability of the system components is explicitly considered as a part of expansion planning problem. Monte-Carlo simulation is used to generate scenarios based on the uncertainty of availability of the system components. Then, a two-stage stochastic programming model is proposed to solve the GEP problem. There are two levels of decision variables; which are variables responding to the uncertainty (dispatching decisions) and variables responding to the distribution of uncertainty (investment decisions). Investment decisions are considered as binary variables. Therefore, the problem is a multi-objective, multi-period, mixed integer programming problem.

Kagiannas et al. [1], Zhu and Chow [2], and Hobbs [3] provide a survey of modeling techniques developed for GEP. These authors provide detailed lists of previous research using dynamic programming approaches, decomposition techniques, stochastic optimization, genetic algorithm (GA), fuzzy set theory, artificial neural networks, network flows, simulated annealing, etc. Nara [4] presents a systematic survey for applied simulated annealing, genetic and evolutionary algorithms, and tabu search applied to power systems planning problems.

Malcolm and Zenios [5] propose an optimization model to produce robust power system capacity expansion under uncertain

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doi:10.1016/j.epsr.2010.05.007