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Optimization modeling to support renewables integration in power systems

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ABSTRACT

This study focuses on the problem of generation expansion planning and the integration of an increasing share of renewable energy sources (RES) technologies in the power grid. A survey of papers addressing the use of optimization models for electricity generation planning is presented. From this, an electricity planning model able to integrate thermal and RES power plants was proposed. An analysis of different electricity scenarios for a mixed hydro–thermal–wind power system is presented using the proposed mixed integer optimization model. The results show the importance of these tools to support the strategic energy policy decision making under different regulatory or political scenarios. The expected impacts in terms of costs and CO_2 emissions are evaluated for a 10 year planning period, and a set of optimal scenarios is analyzed. The use of the model to obtain and characterize close to optimal scenarios is shown to be strategically useful. In particular the impact of different wind power scenarios is addressed, demonstrating the relevance of assessing other possible strategies that, despite not being original Pareto solutions, may be worth considering by the decision makers.

Contents

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1. Introduction

The decision making process for electricity power generation has gone through substantial changes across time. Several aspects previously not considered as important, are nowadays getting increasing attention from the decision makers. Therefore, tools that facilitate the increasingly difficult decision makers' task, play a fundamental role, particularly in addressing complex problems of electricity generation expansion planning. It is now commonly accepted that the underlying principles of the sustainable development concept must be recognized and included on power generation decisions in order to achieve satisfactory solutions from cost, environmental, and social points of view. However, achieving these solutions is not an easy task, and the integrated resource planning should seek to identify the mix of resources that best meets the future energy needs of consumers, economy, environment, and society. Optimization models are proved to be helpful tools that can be used to provide better information, and thus, contribute to the accuracy of the decision maker's policy. Several studies about energy planning models, where economic and environmental objectives are the predominant focus, are already available. A comprehensive review of energy modeling problems, addressing, among others, the energy planning models and the use of optimization tools, may be found in [1] or [2].

This paper's contribution is threefold. Firstly, a revision of the long term generation expansion planning is presented with the aim of providing some insight into the models used and their contribution to support energy decision making. Secondly, we present a useful tool for strategic energy decision makers, which is specially designed for the particular case of mixed hydro–thermal–wind power systems. The proposed model takes into account the seasonality of the hydro and wind regimes. Run of river, hydro storage, and pumping units are included aiming to tackle the problem of wind power variability. The optimization model entails the formulation of economic and environmental objective functions, subject to a set of constraints translating the legal, technical and demand requirements of the system. Thirdly the model projects possible optimal electricity scenarios into the future, establishing investment and generation plans and evaluating the cost, emissions and external dependency impact. The results are enriched with an analysis of alternative power solutions, that are not in the Pareto front but may be considered “close to optimal solutions”. This last step is particularly useful to assist decision making regarding the future of wind power.

This paper is organized as follows. Section 2 provides some recent and representative examples from the literature, addressing the usage of optimization models for electricity power planning and the analysis of renewable energy sources (RES) integration in power planning modeling. Section 3 describes the proposed model formulation and in Section 4 a realistic case study is presented, and the results are analyzed. Finally, conclusions are stated in Section 5.

2. Generation expansion planning

Until the 1970s the electricity planning problem consisted basically in determining the best size, timing, and type of power station, taking into account electricity demand [3]. Nowadays electricity planning is becoming more complex, with the growing share of (RES), some of them with variable output, contributing to this increasing complexity. Large sums of money are invested in the construction, operation and maintenance of new power stations and in the maintenance of existing ones. Optimization models may be greatly advantageous in the minimization of inherent costs, leading to a more efficient electricity system. Electric utilities became then one of the earliest users of optimization methods applied to electricity planning models [3].

Long-term horizon planning frequently addresses the generation expansion planning problem and envisages to support strategic decision making. In fact, generation expansion planning is often addressed in the literature, with its main concern being to find the least cost expansion plan, according to the characteristics of each electricity system [4]. However nowadays, CO_2 emission control and reduction is assuming an increasingly important role in energy decisions and support policies. Figueira et al. [5] recognized the importance of energy decisions based on the economic dimension but, according to the authors, power planning optimization requires not only total expansion cost minimization, but also environmental impacts minimization. Also, Cai et al. [6] underlined the importance of the environmental aspects for electricity decision making, along with other concerns such as fossil fuel increasing prices, reliability and security of supply, long seen as ongoing challenges faced by decision makers around the entire world.

2.1. Optimization models for power planning

According to Hobbs [3], optimization models are usually used for resource and equipment planning, with a time range between ten to forty years. The objective of these optimization models is to obtain the least cost mix generator addictions and decommissioning, taking into account electricity demand forecasts, investment costs and fuel prices. Optimization models for generation expansion planning are therefore seen as useful and powerful tools to many decision makers. The complexity of the optimization model results from the diversity of technologies available to systems expansion, the temporal and/or spatial evolution of parameters included in the model, and the environmental and social arguments that need to be integrated [7]. Generation expansion planning allows the identification of the most adequate technology and expansion size, taking into account economic criteria, and ensuring at the same time that the installed capacity follows the expected demand growth [8]. In line with this, Meza et al. [9] stated that generation expansion planning aims to determine the best solution for future generation utilities, recognizing that wrong decisions might result in considerable financial losses. To meet the increasing demand, new generation utilities will be needed. This incurs hefty operating costs and requires large investment. Generation expansion planning models aim to minimize the social costs of electricity, including environmental and financial costs.

Different approaches to solve the problem of generation expansion planning have been proposed in the literature. In conjunction with these different approaches different techniques were used, which encompassed multi-objective algorithms, bender's decomposition algorithms, stochastic programming, mixed integer programming (MIP), dynamic programming, genetic algorithms, linear programming and particle swarm optimization.

In a previous study, Linares and Romero [10], proposed and applied an electricity power planning model for Spain including multiple economic and environmental objectives. Although a large set of general optimization models have been proposed to tackle the generation expansion problem, it is evident that each model has to be adapted to the particular characteristics of the system under analysis taking into account technical, geographical, political, legal, and environmental restrictions. This led authors to develop and apply particular models that easily describe the underlying problem and conduct the intended simulations. See, for example, Meza et al. [9], presenting a single-period multi-objective mixed-integer nonlinear generation expansion planning designed for the case of the Mexican power system or Tekiner et al. [11] describing also a multi-objective generation expansion planning over a multi-period planning horizon of 15 years. Other studies considering multi-objective programming were