Electric Power Systems Research 97 (2013) 41–50

Contents lists available at SciVerse ScienceDirect

Electric Power Systems Research

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

A long term generation expansion planning model using system dynamics – Case study using data from the Portuguese/Spanish generation system

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ARTICLE INFO

Article history:
Received 20 June 2012
Received in revised form 12 October 2012
Accepted 4 December 2012
Available online 14 January 2013

Keywords:
Generation expansion planning
Long term analysis
System dynamics
Sensitivity analysis
Electricity markets

ABSTRACT

This paper describes a long term generation expansion model that uses system dynamics to capture the interrelations between different variables and parameters. Using this model, it is possible to estimate the long term evolution of the demand and of the electricity price that are then used by generation agents to prepare individual expansion plans. These plans are submitted to a coordination analysis to check some global indicators, as the reserve margin and the LOLE. The developed approach is illustrated using a realistic generation system based on the Portuguese/Spanish system with an installed capacity of nearly 120 GW and an yearly demand of 312 TWh in 2010. Large investments were directed in the last 20 years to the Iberian generation system both regarding traditional technologies and dispersed generation (namely wind parks and solar systems). Today, the excess of installed capacity together with the demand reduction poses a number of questions that should be addressed carefully namely to investigate the impact of several options. The planning exercise aims at identifying the most adequate expansion plans in view of the increased renewable generation (namely wind parks). For illustration purposes, we also conducted a sensitivity analysis to evaluate the impact of increasing the installed capacity in wind parks, of internalizing CO2 emission costs and of incorporating a capacity payment. These analyses are relevant in order to get more insight on the possible long term evolution of the system and to allow generation companies to take more sounded decisions.

1. Introduction

Power systems restructuring introduced new challenges both in operation and expansion planning activities. In particular, the generation expansion planning, GEP, problem was already a matter of concern for vertically integrated utilities and it was typically addressed in a combined way with transmission expansion planning. This was a complex problem given the discrete nature of possible investments, as well as their capital intensive nature and their one-step and irreversible characters, in the sense that once a decision was taken it could hardly be reversed. Finally, these were typically long pay back investments that required a long term analysis. However, before restructuring the risk of these investments was much more reduced than now given that the introduction of market mechanisms imposed a shorter term accent, the demand is now more uncertain and the increasing presence of renewables (namely using volatile resources as wind and solar radiation) originates new challenges not only for operation but also for long term activities. The restructuring lead to the introduction of competitive mechanisms in generation and retailing while usually keeping transmission and distribution wiring as regulated activities. In generation there are now several companies owning assets and competing to supply the demand so that the profit of a particular agent is affected by the demand and fuel prices evolution, by the incentives given to renewable stations and also by the decisions taken by other companies. As a result, the traditional multiyear mixed integer GEP problem is now much more than in the past influenced by uncertainties affecting several parameters that should be internalized in the decision process. Finally, there are interdependencies that should be adequately modeled to capture the real nature of the problem. In fact, investment decisions are driven by the expected profit along the horizon, which is influenced by the evolution of the demand and by the market prices. However, these two elements are interdependent to some extent and also depend on the evolution of fuel costs. This suggests the adoption of a systematic modeling tool to adequately represent all these interactions.

The objective of a GEP problem is to identify the most adequate investment schedule of generation plants together with their sitting and technology to supply the demand considering its possible

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0378-7796/$ – see front matter
http://dx.doi.org/10.1016/j.epsr.2012.12.001

evolution along the planning period while enforcing some reliability constraints. The GEP problem was usually addressed in an integrated way with transmission expansion planning [1,2]. Reference [1] details an approach using Stochastic Programming to model several uncertain parameters and [2] describes a mixed integer optimization problem that uses the DC model of the transmission system. References [2–4] use Benders decomposition and [5,6] describe multi-objective approaches considering investment, operation and transmission costs, environmental impacts and the risk of getting a plan very much exposed to uncertainties.

More recently, metaheuristics started to be used to solve the GEP problem, taking into account its combinatorial nature. In this scope, [7–10] report the use of genetic algorithms, simulated annealing, expert systems, ant colonies and particle swarm algorithms as well as combinations of these techniques [10]. These models minimize operation plus investment costs subjected to a number of constraints, for instance regarding the maximum amount of investment that can be accommodated in each planning period. Metaheuristics, both using a solution in each iteration or population based, characterize the investment plans using an evaluation function that combines the optimization function of the original problem plus penalties on the violated constraints.

The advent of restructuring created new concerns namely whether expansion plans prepared by individual generation agents are capable of ensuring the security of supply on the long term. In this scope, [11] describes a two step approach in which individual agents prepare expansion plans maximizing their profit that are then submitted to an upper level check to investigate the quality of the global schedule, namely computing LOLP and the reserve margin along the horizon. On the other hand, [12] compares centralized and liberalized GEP models formulating an optimization problem to maximize the profit of the investors. This problem is solved using dynamic stochastic programming together with discrete Markov Chains to model the demand uncertainty.

Finally, in recent years system dynamics started to be applied to the GEP problem. System dynamics [13] was created by Jay Forrester in the 60s and several applications to power systems are reported in [14]. Regarding the GEP problem, [15,16] report long term electricity market models and [17] describes the application of these concepts to the generation system of New Zealand.

Recognizing the complexity of the GEP problem, the authors developed an initial approach to the TEP problem in which the demand and the electricity price evolution were obtained using a Cournot model [18]. This approach was then enhanced in [19] in which the long term evolution of the electricity market was modeled using system dynamics. In [19] it is used a generation system that mirrored the main characteristics of the Portuguese generation system scaled by 50% to illustrate the approach.

Apart from describing the main characteristics and blocks of the long term dynamic model as well as the profit maximization problems to be solved by each generation agent to schedule new generation investments, we are now applying this approach to a larger system that incorporates the main features of the Portuguese/Spanish generation system having a total installed capacity of nearly 120 GW and an yearly demand of about 312 TWh in 2010. It is important to analyze both systems in a global way given the common electricity market established between the two countries and the increasing interconnection capacity that strongly contributed to reduce congestions in the transmission lines between them. The main motivation for using the Portuguese/Spanish generation system comes from the challenges that the Iberian countries face in the next years. In fact, in recent years a conjunction of factors occurred namely regarding the large amount of investments that were directed to new generation stations in the last 20 years, the rapid increase of dispersed generation (including renewable technologies as wind parks and solar systems, as well as non renewable cogeneration systems) and the recent decrease of the demand due to the on-going economic crisis. All these situations strongly suggested that the policies followed in the last 20 years should be looked closely using long term approaches to more adequately evaluate the possible evolution of the system. On the other hand, as a result of the massive introduction of dispersed generation, the liquid demand available to be supplied by traditional thermal technologies is now much more reduced. In this scope, it is not rare that in winter wet valley periods the generation from wind parks and hydro stations becomes enough to supply the demand in Portugal, so that the output of traditional thermal stations comes to zero as well as the market price. As a consequence, the number of yearly operation hours of several CCGT stations is much reduced and so generation companies are now complaining that their revenues are not enough to pay these stations. As a result, a capacity payment was awarded to some Portuguese stations in 2009 but it was recently much reduced by the current government. This corresponds to an important issue that also deserves attention at the Iberian level. In order to address this issue, the GEP model described in [19] now incorporates a capacity payment so that we can perform sensitivity studies in order to adequately calibrate the value of this payment, for instance as a way to guarantee a minimum return rate for some less used thermal stations.

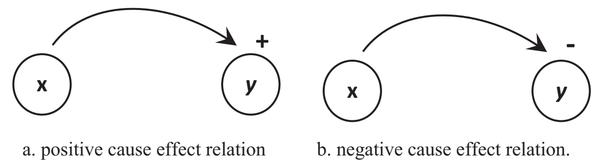

Fig. 1. Casual diagrams illustrating a positive relation in the left and a negative dependency in the right side.

Considering these ideas, Section 2 provides an overview on system dynamics and Section 3 describes the overall adopted solution approach. Section 4 details the investment planning problems incorporating the mentioned capacity payment and Section 5 describes the long term dynamic model of the electricity market. Section 6 illustrates this approach with a case study using data taken from the Portuguese/Spanish generation system in the scope of the common electricity market established by the two countries since 2007 and Section 7 draws the most relevant conclusions.

2. Overview on system dynamics

System dynamics is a modeling tool particularly suited to represent long term problems that involve a large number of variables and parameters as well as loops and inter dependencies. In brief, adopting system dynamics to model a problem implies developing an in-depth understanding of the system to identify its boundaries, the time horizon and the most relevant variables, parameters and inter dependencies. Then, it is developed an initial dynamic model using standard basic models that will be briefly detailed below. The developed model is then translated into a mathematical formulation, that typically includes differential equations. Finally, using this formulation, the model is validated after which more involving studies and simulations can be developed.

The relations and dependencies between variables are represented using a number of standard sub-models. Figs. 1 and 2

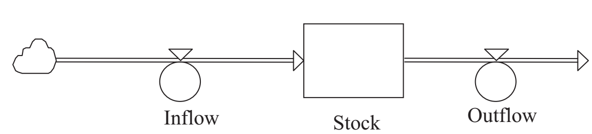

Fig. 2. Diagram of stocks and flows.