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Delays in electricity market models

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ABSTRACT

From several types of material delays that can be found in literature, most System Dynamics (SD) modelers select, apparently for simplicity, first-order delays (FODs) to represent the construction and decommissioning of power plants in electricity market models, even though pipeline delays, or transport delays (PLDs) model better the entry and exit of power plants. Although both types of delays can be used for representing material delays, each one offers different results with pros and cons that need to be well considered. Therefore, this paper seeks to implement FODs and PLDs in a generic electricity market model in order to assess their effectiveness and adequacy in the closest representation of the reality. As a result, SD modelers shall see through this investigation the importance and implications of material delays in their models, but also they will be able to choose the appropriate material delays for their applications. In fact, the simulation results comparing both models markedly show that PLDs are a better approximation to model the delays of construction of new plants as well as the retirement of old plants. Accordingly, if FODs are solely used, the electricity market models not only always provide less electricity in one or various years, they also produce inaccurate values that can lead to a dangerous energy planning, mainly because they modify the dynamics of the entire system.

1. Introduction

SD has become a powerful modeling technique since its foundation in the mid-1950s by Professor Jay Forrester of the Massachusetts Institute of Technology [1]. This approach can be a useful mathematical modeling technique for understanding and discussing complex issues and problems in several areas [2].

SD modeling has been extensively used to study electricity markets and has also been considered one of the most appropriate modeling techniques when it is desired to analyze complex systems [2–5]. Therefore, analysis in security of supply [6–8], energy efficiency [9–12], market reforms [13–15], greenhouse gases [16–18] among others [4,19,20], are contributions that not only reflect the importance of modeling electricity markets, but also the necessity of developing models with an increasingly higher degree of realism. For this reason, the purpose of the present study is to assess an important characteristic of the electricity markets: the delays. An adequate model of delays guarantees that the dynamic of the systems reflect better the reality.

In this context, when talking about electricity markets it is clear that there will be plants to construct when a producer of energy decides to invest, or there will be retirement of old plants, which are turned off, when their lifetime ends; however, the construction of new plants or the retirement of old ones always takes time. Depending on different conditions, the construction of new plants might take between 5 and 7 years while the retirement of old ones might take between 20 and 35 years, if the generation source is a hydro-base system. In other words, there is a delay between the investment decisions and the finished plants, and there is a delay between the finished plants and their decommissioning. The present facts suggest that these delays are *material delays* with constant delay time (as the example of mailing letters mentioned by J. Sterman in Ref. [1]). The output distribution of these kind of material delays is depicted in Fig. 1. As can be seen, after the decision of constructing a plant is made, put it into operation takes some years, but also, after a long period of time it becomes useless and must be decommissioned, i.e., retired from the installed capacity.

Modeling and using delays have become a determining in the electricity market behavior, especially when their output distributions are very different. According to Ref. [1], PLDs and FODs (which

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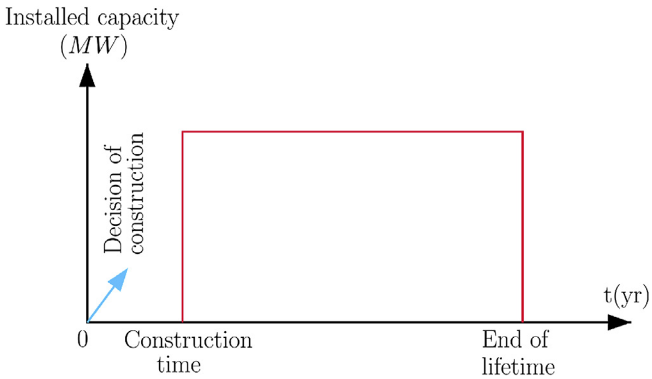


Fig. 1. The plant construction and its respective retirement always involve a delay.

are considered the first approximation of PLDs) have a stock and flow structure and an output distribution as shown in Fig. 2.

Mathematical differences can also be observed from the stock and flow diagram of Fig. 2(a), which are defined as follows:

1.1. PLD

$$o(t) = i(t-\tau) \quad (1)$$

1.2. FOD

$$o(t) = S_2/\tau \quad (2)$$

where $o(t)$ is the outflow, $i(t)$ is the inflow (defined as a unit pulse [1]), τ is the constant delay time and S_2 is a stock.

Notice that mathematically and graphically speaking the models of PLDs and FODs are completely different; nevertheless, though both are material delays, it constantly becomes confusing about what should be used in the variety of existing electricity markets. On one hand, some authors use FODs for simplicity or because they are considered a good and valid approximation to PLDs, see for example [14,21,22]. On the other hand, both types are usually applied, PLDs for modeling the construction of new plants, but also FODs for the case of retiring old plants [23–25]. Unfortunately, in other cases the authors do not even mention what type of material delays were implemented [7,26–28], which might raise doubts about the overall results or conclusions of their research.

In this manner, the pressing open problem not only remains on choosing the appropriate material delay for achieving more accurate models, it is also necessary to raise SD community awareness about the importance and implications of using determined delays. Therefore, the aim of this paper is to assess the electricity market behavior when two different types of material delays (PLDs and FODs) are used, so that SD modelers recognize their differences and understand the importance of mentioning the type of delay they are using in their models. For doing so, in this work PLDs and FODs are applied in a generic electricity market model as an example. In particular, a simplified scenario based on the Colombian electricity sector is considered in order to avoid unreal examples. However, this study only focuses on comparing the implications of using these material delays, we are not evaluating the Colombian electricity market or policy/decision issues.

The paper is organized as follows: Section 2 explains in detail the models to be analyzed. Specifically, Section 2.1 formulates the dynamic hypothesis of the generic electricity market model, followed by Sections 2.2 and 2.3, where is proposed and described stocks and flows diagrams with PLDs and FODs giving a detailed specification of each variable involved. Then, Section 3 exposes the differences of the models with PLDs and FODs by using simulations. After all, Section 4 explains the final discussion and conclusions of this paper.

2. Detailed SD model

After a brief introduction of the main problem to be address in this paper, here we start defining the dynamic hypothesis of a generic electricity market model, which will be used to implement both types of delays.

2.1. Dynamic hypothesis

Similarly to Ref. [29], Fig. 3 shows the hypothesis of a generic

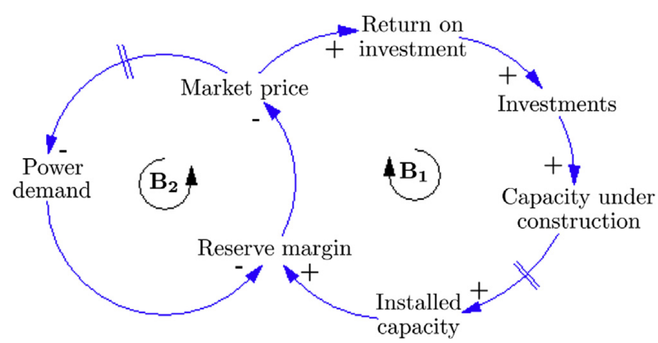
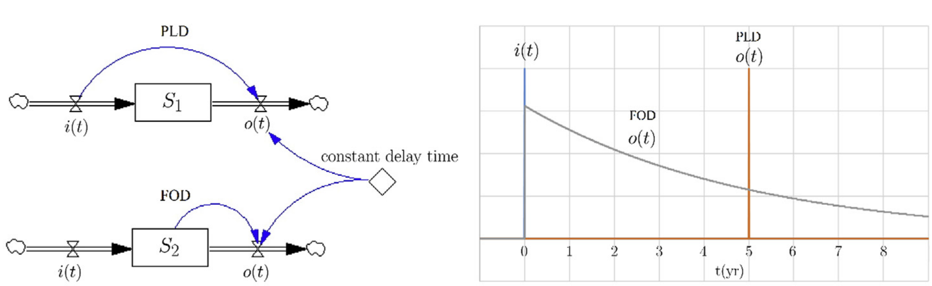


Fig. 3. Causal loop diagram of a generic electricity market model.



(a) (b)

Fig. 2. PLD and FOD comparison. (a) Stock and flow structure of a PLD and a FOD and (b) their output distributions. The constant delay time is 5 years.