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What is the value of the option to defer an investment in Transmission Expansion Planning? An estimation using Real Options

A. Henao [a], E. Sauma [b,*], T. Reyes [b], A. Gonzalez [a]

[a] Department of Industrial Engineering, Universidad del Norte, kilometro 5, Barranquilla, Colombia
[b] Department of Industrial and Systems Engineering, UC Energy Research Center, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile

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ABSTRACT

In deregulated markets, Transmission Expansion Planning (TEP) is usually performed by a central network planner seeking to maximize social welfare. In doing that, the network planner commonly follows a traditional project valuation, considering a discounted cash flow (DCF) methodology, although incorporating uncertainty and reliability considerations. Accordingly, once the optimal transmission expansion plan is determined, the network planner frequently auctions the needed investments, obligating the investor to execute the expansion in the fixed (inflexible) terms defined in the bidding process. A key problem is that DCF does not take into account the responses of the planner when uncertainties are resolved because DCF evaluates the project with the information available today. In TEP, managerial flexibility may be valuable because optimal decisions may change over time with the release of new information. Transmission investors may want to defer or expand according to such information. The aim of this article is to estimate the value of adding some flexibility in TEP through real options. In particular, by means of using a real-option approach with binomial trees, we study the benefits for a social network planner of having the option to defer some transmission investments. Our results suggest that incorporating flexibility in TEP may increase social welfare.

1. Introduction

The economic growth of a country is closely linked to their electricity consumption (Apergis and Payne, 2010a, 2010b; Yoo and Lee, 2010) and therefore to the strength of its electrical infrastructure. Transmission networks are key components of power systems because they allow transporting electricity from generators to end users. Accordingly, Transmission Expansion Planning (TEP) is of interest to any government. A centerpiece in TEP is the identification of social-welfare improving transmission lines to ensure reliability, interconnect new generators and support future demand growth.

Most countries around the world have deregulated their electric power sector, splitting generation, transmission, distribution and even marketing by imposing restrictions to vertically integrated utilities. Their objective has been to promote competitiveness and thus efficiency, but with the disadvantage of increasing uncertainties and conflicts of interests in the decision making processes. Under deregulated environments, TEP is mutually interrelated with other processes such as generation planning, demand side management, power system operation, and the evaluation of transmission line alternatives from a financial and economic perspective (Xu et al., 2006).

A TEP process is complex and subject to several uncertainties in restructured markets, so mechanisms providing flexibility to cope with uncertainties are required. Some elements of TEP presenting uncertainty are: 1) availability of lands; 2) duration of the process to obtain all necessary environmental authorizations; 3) investment costs; 4) demand growth rate; 5) the entry and exit of new generators, their occurrence in time, location, and characteristics; 6) the development of alternatives for transmission systems such as distributed generation and FACTS; and 7) the exploitation of renewable energy sources that are frequently distant from load centers; among others. These uncertainties motivate exploring the introduction of flexibility in TEP. Moreover, some of these uncertainties have gained importance over the last years because of global and local governmental goals in terms of replacing carbon-intensive sources of energy and the growing importance of environmental conservation. However, there is relatively scarce literature about flexibility applications on TEP (Andrews, 1995; Latorre et al., 2003; Maboke and Kachienga, 2008).

* Corresponding author.
E-mail address: esauma@ing.puc.cl (E. Sauma).

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Given the complexity of the TEP process, it has been analyzed from diverse perspectives (Hemmati et al., 2013; Latorre et al., 2003). TEP has been modeled using linear programming (Villasana et al., 1985), mixed integer linear programming (Alguacil et al., 2003; Romero and Monticelli, 1994), Benders decomposition (Binato et al., 2001), and game theory (Pozo et al., 2013; Sauma and Oren, 2006, 2007, 2009), among others.

From an economic perspective, the traditional project valuation method of discounted cash flows (DCF) is usually used to determine the Net Present Value (NPV) of the social welfare created by the transmission investment project and whether the project should be executed or not. In other words, if a transmission investment project has a positive social-welfare NPV (and it improves system reliability), the planner auctions the project and the winning bidder commits to execute it under the predetermined fixed terms.

The DCF approach assumes that the manager takes a passive attitude once committed to execute the project. In many real-world decision processes, managers have the flexibility to alter their strategy to appropriately react to different realizations of initially forecasted variables. Under TEP, managerial flexibility may also be valuable because optimal decisions may change over time with the release of new information. Accordingly, the purposes of this paper are: (i) to evaluate the economic impact of introducing some flexibility in TEP and (ii) to estimate its monetary value. In this context, flexibility is incorporated as the option to defer a transmission expansion.

We estimate the value of adding this flexibility in TEP by means of a real options approach. We assume that the network planner designs the long-term network expansion plan seeking for the maximization of the social welfare, while considering an oligopolistic behavior of generation firms. In this framework, in order to shelter investments against risk, we assume that the planner has the possibility of making a flexible (deferrable) transmission expansion.

Roughly speaking, introducing flexibility in investment decisions makes sense when: (i) the investment implies high costs and benefits, (ii) the investment is partially irreversible, and (iii) the benefits coming from the investment are subject to high uncertainty. TEP has these three features, so introducing flexibility in TEP is an interesting research topic. Nonetheless, literature about flexibility applications on TEP is scarce.

Some few authors have included flexibility in TEP to cope with uncertainties, using different approaches such as multi-stage stochastic programming, adapting cost, and real options (Blanco et al., 2011a, 2011b; Boyle et al., 2006; Hedman et al., 2005; Konstantelos and Strbac, 2015; Lopez et al., 2013; Munoz et al., 2014, 2015; Ramanathan and Varadan, 2006; Zhao et al., 2009). Multi-stage stochastic programming is used to identify investments that can be delayed until new information arrives (Munoz et al., 2014) or until it is unavoidable (Konstantelos and Strbac, 2015). In this approach, a solution is identified based on the consideration of previously defined scenarios, but generally ignoring the possibility that the investor may react or perform any adaptation as uncertainty evolves. The adapting cost approach is similar to a robust-optimization scheme in the sense that both analyze the performance of alternative plans under several scenarios and select the most flexible plan based on the least adapting cost in the worst-case scenario (Qiu et al., 2015; Zhao et al., 2009). Real options (RO) have been widely used to incorporate flexibility in investment projects (Mun, 2006; Trigeorgis and Schwartz, 2001). RO theory evolved from proposed models by Cohen, Black and Scholes (Cohen et al., 1972) and Merton (Merton, 1973). In general, there are two approaches to value RO: the first one uses a continuous-time random walk model for the underlying asset price evolution (Cohen et al., 1972; Dixit and Pindyck, 1994; Merton, 1973) and the second one is based on a discrete-time model for the evolution of the price (Cox et al., 1979; Mun, 2006; Trigeorgis and Schwartz, 2001). Discrete-time binomial models are widely used to capture the value of flexibility (Trigeorgis and Schwartz, 2001) by allowing the agent to react explicitly to different realizations of initially forecasted variables.

The RO approach has been applied to power systems using binomial trees and Monte Carlo simulation (Blanco et al., 2011a; Ramanathan and Varadan, 2006). Some authors use RO to build cash flow streams (Hedman et al., 2005) or to incorporate options – such as sequential expansion, abandonment, defer, etc. – in order to introduce flexibility in transmission investments (Boyle et al., 2006). Others use a mix of dynamic programming and game theory (Lopez et al., 2013). But all these authors use RO to estimate the private value of the flexibility added. That is, in all these works, the value of flexibility is captured in terms of the investor's profit (Ramanathan and Varadan, 2006; Vasquez and Olsina, 2007; Vasquez et al., 2008) and the total cost savings (Blanco et al., 2011b; Lopez et al., 2013).

In this paper, we use RO in order to estimate the value of adding flexibility to defer a TEP expansion project from the perspective of a social network planner. In our model, we estimate the value of the added flexibility using a binomial RO pricing model (Cox et al., 1979). This discrete-time binomial tree model allows us to explicitly compute the value of the investment-defer flexibility over time. In doing that, we consider the improvement in social welfare as the underlying asset.

The rest of the paper is organized as follows. Section 2 defines our methodology, which integrates TEP modeling with RO. Section 3 illustrates the proposed methodology through a case study. Section 3 contains the results and sensitivity analysis of the case-study simulations. Section 4 concludes the paper.

2. Methodology

The proposed methodology makes the following general assumptions:

- The power network presents congestion at some time within the time horizon analyzed.
- Initial conditions such as power generation capacity at each electrical node, loads, and power flow capacity of transmission lines are known.
- New transmission assets are available for operation the period after the expansion decision is made.
- A single transmission investment project is analyzed to study the effects introducing flexibility.
- The capacity of the flexible transmission investment is known in advance.
- The underlying asset, the improvement in social welfare in our case, follows a path described by a binomial tree.

The diagram in Fig. 1 roughly describes our methodology. Initially, the conditions (i.e., topology, parameters, and assumptions) of the power network are defined. Then, we specify the base case as an inflexible (rigid) transmission expansion project. This expansion allows the system to be better prepared to handle forecasted future scenarios of, for example, higher demand. We evaluate the benefits of investing in this inflexible expansion by computing the incremental present value of the expected total surplus (*EITSPV*) associated to it, where total surplus refers to the social welfare of the entire system.[1] Expected incremental total surplus values are computed, at each year, as the difference between the forecasted total surplus when doing the proposed expansion and the forecasted total surplus in the case without the expansion. Therefore, *EITSPV* represents the present value of the expected total surplus due to the realization of the expansion now, but ignoring investment costs. This is the underlying asset value at period 0, S_0, considered as the starting node in our binomial tree model, as we will explain later on this section. If investment costs are subtracted from S_0, we would obtain the value of the expansion project without having the flexibility to defer, *PVWF*.

Now, we analyze the introduction of flexibility in TEP as an option to defer the previously described transmission expansion. Next, we

[1] We adopted the usual definition of social welfare in power networks as the sum of consumers' surplus, producers' surplus and congestion rents.