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Transmission assets investment timing using net present value curves

Reinaldo C. Garcia [a], Javier Contreras [b,*], Pedro F. Correia [c], José I. Muñoz [b]

[a] Faculdade de Tecnologia, Universidade de Brasilia – Asa Norte, 70910-900 Brasilia, DF, Brazil
[b] E.T.S. de Ingenieros Industriales, University of Castilla – La Mancha, 13071 Ciudad Real, Spain
[c] Instituto Superior Técnico, Technical University of Lisbon, 1049-001 Lisbon, Portugal

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ABSTRACT

Improvement and expansion of the transmission grid is still an unresolved issue in the new competitive environment. In current electricity markets, transmission lines have become assets that need financial instruments for investors who wish to ensure steady long-term returns and to withstand short-term market volatility. The timing and the combination of new transmission investments is key to analyze their long-term effects. This paper presents the concept of net present value (NPV) curve to estimate the best investment time for the investor, where the curve is constructed by calculating the NPVs resulting from the investment in successive years. A specific contract model based on financial transmission rights (FTR) is used for the NPV evaluation of transmission assets, and the stochastic properties of all variables related to the investment market structure are considered. The model is applied to the IEEE 24-bus Reliability Test System (RTS) showing the approach capabilities as a decision-aid tool for transmission investors.

1. Introduction

New energy markets undergoing deregulation, with increasing competition and volatility of energy prices, expose participants to risk. Deregulation impacts both consumers and producers, thus the need of risk management and the use of financial derivative instruments to control exposure to volatile energy prices. New financial instruments are especially needed in the case of new transmission investments placed to overcome grid congestion.

The problem of network expansion is a very complex multi-period and multi-objective optimization problem (Rosellón, 2003). Its inherent uncertainty of future developments and nonlinear nature constitute major complications being difficult to solve even in the earlier centralized environments. In the vertically integrated electricity market structure, the construction of new transmission facilities was associated with the addition of new generating resources and their integration into the existing network.

The deregulation of the energy sector resulted in a new economic environment, due to the daily operations of the electric markets, and this new environment needs to be considered with the economics of investment in new facilities (Kirschen and Strbac, 2004). The multiplicity of players, including existing owners, investors, regulators, and the broad variety of customers, represent a key complication issue. The long-term horizon with the sequence of appropriate decisions adds to the complexity of the problem. Besides all these factors there is the wide range of uncertainty in the actions of market players and transmission investments, whose combined effects make this problem a stochastic one. Thus, a future investor in transmission assets must have a tool to decide when and where to invest in new assets. In order to analyze transmission expansion in a competitive environment all the uncertain variables of the system, including locational marginal prices (LMP), fuel costs and bidding schemes, must be properly quantified considering a wide variety of long-term scenarios.

The outline of the paper is as follows: Section 2 presents the literature review. Section 3 states the main objectives and contributions of our work. Section 4 describes contracts for transmission investment from different FTR models showing various degrees of hedging. Section 5 shows how the stochastic LMP values are obtained and used in transmission investment to calculate the stream of cash flows and the net present value (NPV) obtained from the FTR contracts. Section 6 describes a general pool-based electricity market, including the electrical transmission network that generates the LMPs. In Section 7 the FTR contract for line investment and the generated NPV curve (a curve whose points are made of different NPVs obtained when investing in successive years) are evaluated and applied to a realistic multi-year case study, the IEEE 24-bus RTS (Grigg et al., 1999). The paper ends in Section 8 presenting relevant conclusions and future work.

* Corresponding author: Tel.: +34 926 295464; fax: +34 926 295361.
E-mail addresses: rcgar@yahoo.com (R.C. Garcia), Javier.Contreras@uclm.es (J. Contreras), pfcorreia@ist.utl.pt (P.F. Correia), JoseIgnacio.Munoz@uclm.es (J.I. Muñoz).

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2. Literature review

Current literature shows how transmission property rights can express the revenue stream accrued by a transmission line owner. The proposals for transmission rights considered rely on the concept of financial transmission rights (FTR) in congested electricity networks (Gribik et al., 2005). The FTR are financial instruments issued by the transmission network operator, and they entitle the holder to be reimbursed for the congestion charges paid when energy is sent (if it is a producer) from one location to another (Hogan, 1992). When a line is congested, the values of the LMP are not identical in the network because, if they were equal, all the lines could withstand the transactions taking place simultaneously. Therefore, when a thermal limit is reached in one or more lines, the LMP are the signals indicating a state of congestion. In a bilateral transaction, if a generator sends energy from node A to B, it pays a congestion charge equal to the amount of energy flowing between A and B times the LMP difference between them. To hedge against this stochastic payment, the generator can purchase an FTR guaranteeing a revenue equal to the LMP difference times an agreed-in-advance contract flow.

Proposals have been made to attract investors to transmission network investment using the FTR auctions.

As mentioned in Hogan (1992), the motivation of developing FTRs is the need for long-term rights that are compatible with the short-term market. The way to assign FTR in auctions is described as a "merchant" mechanism to attract investment to transmission networks. The starting point is a bid-based security-constrained economic dispatch whose optimal solution has associated shadow prices that can be used either for obligation or option contracts of the "point-to-point" or "flowgate" types (these contracts are discussed in more detail in Section 4). Hogan (2002) states that financial transmission rights are in use in several electricity markets to hedge against the volatility of LMP differences when there are transmission constraints. Such rights are either allocated to pre-existing transmission rights holders, or sold through a centralized auction or sequence of auctions, or both. Hogan (2003) argues the use of transmission investment based on FTR auctions discussing that, with the right choice, merchant transmission investment could play a significant but not exclusive role in efficient transmission expansion.

Chao and Peck (1996) and Chao et al. (2000) postulate a different system consisting of flow-based transmission rights or "flowgate" rights, where they match the scheduled transactions with power flows as closely as possible. The trading rule adopted by them uses the power transfer distribution factor (PTDF) to translate the physical effects of each transaction into transmission right requirements. In this way, line power flow, and not nodal power injection, as it happens with FTRs, is fundamental for defining transmission rights. Therefore, flowgate rights are more related to transmission assets, providing incentives to possible investors.

Bushnell and Stoft (1996, 1997) show that FTR has non-negative effects on welfare only if there is a previous match between dispatch and FTR awards, being uncertain the effects on welfare if there is no match. They formalize a feasibility rule to award property rights to investors so that detrimental investments are avoided. Detrimental investments are not encouraged by linking the contracts to the actual dispatch: as long as the set of contracts represents a feasible dispatch, the revenues of the contract collected by the holders do not exceed the merchandising surplus.

Joskow and Tirole (2005) show the inconveniences and negative externalities of FTR under market failures including lumpiness, loop flows, information asymmetry, market power and stochastic changes in supply and demand conditions that imply uncertain nodal prices. They assume the existence of two different entities, the system operator (SO), who takes care of the matching of the bids in the day-ahead market, and the transmission owners (TO), who own the transmission assets and receive compensation to their investments by means of FTR. Perverse behavior can be expected by incumbent investors who, in order to collect more congestion rents to recover their investments via FTR, avoid the construction of new assets that are beneficial to the system in terms of social welfare because their profits diminish by reducing the nodal price differences. Moreover, generators can exert their market power by artificially increasing the nodal prices in certain areas leading to either under- or over-investment in transmission, depending on the location of the generators and their effect on congestion rents and nodal prices. Finally, it is mentioned that the inherent lumpiness of investments produces under-investment similarly to the case of incumbent investors, and the lack of coordination of different investors is prone to lead to wars of attrition between them.

Kristiansen and Rosellón (2006) present a transmission investment mechanism for meshed based on FTR "proxy" awards discussing its effects on welfare. They assume a stylized model in which investments are not lumpy and agents do not have market power. In their model, the system operator awards incremental FTRs to maximize the investor's preferences and preserves certain unallocated FTRs (proxy awards) defined according to the best use of the current network along the same direction of the incremental expansion, always maintaining the feasibility rule (all FTRs are simultaneously possible).

Baldick (2007) proposes a property rights model for electric transmission called "border flow" rights that support financial hedging of transmission risk and merchant transmission expansion through associated financial rights known as "contracts for differences of differences". He postulates that the owner of a transmission line joining two nodes should be remunerated by two terms, each of them corresponding to the product of the nodal price at the node times the power flow from the line into that node. In this way, the line's owner is paid at the nodal price for energy delivered to the system and pays at the nodal price for energy received from the system.

3. Objectives

Our approach to value transmission assets is related to the financial models based on FTRs. In particular, the concept of flow-based-like transmission rights is used to pay an investor willing to fund a merchant transmission investment (Chao et al., 2000). For every transaction period, the investor can collect the LMP difference between the connected nodes with its new transmission line times a fixed (or, in our case, variable) amount of power flow agreed upon with the transmission network operator. Thus, the stochastic variables of the system, including the LMP and flows, must be modelled for several years to simulate the system evolution with time. We apply then a particular FTR model, as shown in Section 4, and obtain the NPV curves of transmission assets considering the stochastic properties of all the variables related to the investment and market structure.

The main contributions of this paper are as follows:

- Stochastic investment approach where all the variables: fuel costs, prices, demands, etc. are carefully modelled in the FTR calculation.
- Use of the stochastic FTR contract model to estimate the net present value (NPV) of the investor as a function of the investment timing. In order to do that, the investor constructs the NPV curve whose points are made of different NPVs