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“Valuación de Inversiones en Infraestructura Eléctrica y Comportamiento Estratégico”

ANEXO 05
PGT 2.1 – Formulación matemática de modelos de Opciones Reales – Informe

Coordination of flexible generation and transmission investments under uncertainty

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Abstract— **The liberalization of power markets has led to a paradigm shift in the scope of the generation and transmission expansion planning. The assessment of this issue is complex because of the uncertainties that usually determine the long-term evolution of the market. Moreover, and from the point of view of regulators and policy makers, an optimal assessment is of great interest because the lack of coordination between two types of investments can jeopardize competition and efficiency in the whole sector. In this regard, the literature suggests the use of holistic approaches, which are a suitable to address risks associated to the coordination of investments in the power market. This allows regulators to identify an efficient investment alternative, even in scenarios in which the uncertain variables evolve unfavorably. In that context, this paper proposes an improved method to assess the joint Transmission and Generation Expansion Planning segments, considering the inherent flexibility of generation investments, using the Real Options Valuation approach, calculated with the Least Squares Monte Carlo.**

Index Terms-- **Flexibility, Least Square Monte Carlo, Real Options Valuation, Regulation, Uncertainty.**

I. INTRODUCTION

The electric sector evolution towards a competitive environment has increased the requirement for proficient planning of the system expansion to enhance the degree of market competition. Therefore, regulatory frameworks and proper assessment for inducing efficient and well-timed investments in power markets are currently issues of considerable interest for researchers, policymakers and energy investors.

The regulation refers to a set of practices and rules by which the government changes or guides the conduct or structure of an industry or public or private facility with the purpose of: a) minimizing transaction costs associated with institutional factors, and b) improving the efficiency and equity of market in accordance with social interests.

In this sense, the regulation must establish the access conditions to the existing system capacity; the expansion mechanisms; as well as, technical operation requirements related to proper levels of competition, quality and reliability.

Thus, despite continued efforts to improve the regulatory aspects related to the coordination of TEP and GEP, they have not reached a point of balance yet, so that the study of these issues remains a major topic of discussion and analysis.

Typically, the indicative GEP problem can be formulated as a large-scale stochastic, nonlinear, mixed-integer optimization problem. A large number of algorithms and approaches have been proposed for solving this complex problem. Notwithstanding, the current theory and tools for assessing the coordination of TEP and GEP are still below the practical requirements of the new power markets. This limitation is particularly emphasized in aspects such as the flexibility assessment.

This flexibility refers to the actions at different stages of the investment horizon, such as the options to defer, expand, or even abandon the project. In this context, flexibility has a substantial value, and must be taken into consideration within the decision-making process.

Strategic flexibility is a risk management technique that is increasingly gaining research attention, as it allows properly managing major related to the player uncertainties. However, represent the value of flexibility in economic terms is not a trivial task and requires sophisticated valuing tools [1]. Any attempt at valuing flexibility almost naturally leads to the notion of Real Options (ROV) [1].

The ROV technique provides a well-founded framework –based on the financial option theory- to assess strategic investments under uncertainty [1].

In this context, in [2] has been proposed an approach for solving interacting financial options, calculated with Monte Carlo simulations. Then, in [3] has been reported an extension of ROV for valuing capital investment problems with embedded options taking into consideration the interaction and interdependence between them.

In this sense, grid reinforcements are usually focused on investments in new Transmission Lines (TL). This type of investments has a significant level of irreversibility, which leads to a high risk exposure to long-term uncertainties. An alternative of dealing with these shortcomings is the installation of local flexible generators, in order to satisfying the demand growth allowing operating without depending of the network [4]. Hence, it would be possible to defer the investment of new lines [5].

This paper extends the approach proposed in [3] and proposes an integrated system approach that quantify the value of the option of deferring expansion investments in TL while the option of investing in flexible generators units, which can be expanded, relocated or even abandon according to the arrival of new information that clarifies the power market uncertainties.

This section addresses the problem of valuation of flexible power system investment portfolios on the basis of the social welfare of the electricity market. It proposes a methodology based on real options approach for valuing the flexibility of strategic investments in the power generation and transport network and finding the optimal timing of the execution of the investment alternatives including the flexibility value [6]. In this sense, as it was mentioned before, flexible generators seem to be an appropriate

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alternative for increasing the flexibility of the TI portfolios (TIP).

II. VALUING COORDINATION ON FLEXIBLE INVESTMENTS IN POWER MARKETS

As mentioned in [3], the investments in the transmission typically exhibit intrinsic characteristics that have an effect on their performance and should be considered along their evaluation. Some of these features are [7]:

- Economies of scale, i.e., lower unit cost as long as the size of the expansion increases.
- A significant fraction of the required capital must be paid out prior to the commissioning of the new TL, while the depreciation takes many years, even decades.
- Investment projects in the transmission system are exposed to unforeseen scenarios along the investment horizon.
- In general, opportunities to invest in the transmission system are not the now-or-never type, i.e., have the investment can be deferred.

Thus, an approach for valuing power system investments has to incorporate these features in a quantitative manner, which can be incorporated into three fundamental features: irreversibility, long-run uncertainties and flexibility.

Furthermore, it has been showed that the classic method of Net Present Value (NPV) is not proper for assessing irreversible investments [6]. In this context, the ROV method has been proposed as an evaluation technique for assessing the flexibility of projects under uncertainty, which applies methods based on finance options theory for the valuation of derivate assets.

In this context, to evaluate the gained overall flexibility in power expansion plans by investing in flexible generation projects while deferring conventional transmission projects is a key issue that still remains uninvestigated.

As it was presented in [8], the main flexibility options provided by the generation are analyzed in the following.

A. *Abandon option*

The abandon option highlights the importance of recognizing and quantifying the value added to the project by the chance to partially recuperate the capital expenditures, in case the project should be abandoned for scrap value [9]. The execution of this option will take place only when the uncertainties unfold severely. Within this paper, the scrap value of the generation devices is considered equal to 40% of the total investment cost of these equipments.

B. *Expand option*

It allows expanding installed capacity, if the market conditions that occur after one has performed some initial investment, are more favorable than expected. Within this paper, the generation is considered modular and it is possible to increase the number of modules under favorable circumstances.

In order to illustrate, three expansion strategies have been considered, which are:

I1: Generation (first-mover), TL (second-mover)
I2: TL (first-mover), Generation (second-mover)
I3: TL and Generation (simultaneously-mover)

The map of Generation (first mover), TL (second move) is shown in Fig. 1. The diagram shows the options that become available once the generator has moved (installed). It should be noted that defer the option is available at each stage of decision, and execution means defer all other options available in this period to the next.

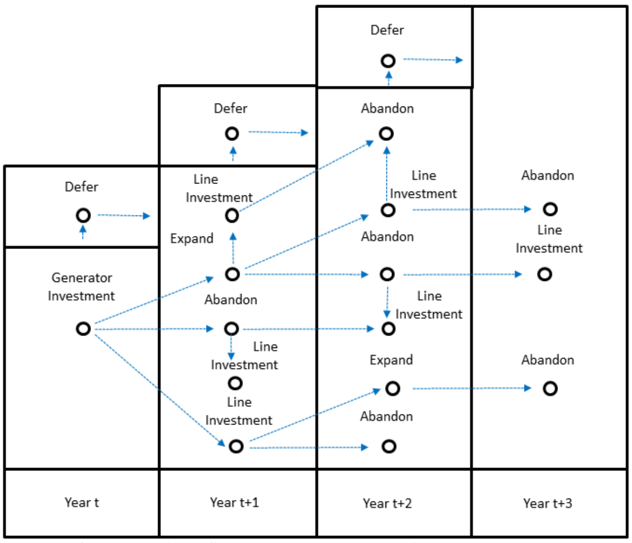

Fig.1. Map of “Generation (first-mover), TL (second-mover)”

Similarly, Fig. 2 and Fig. 3 represent the map of options strategies remaining investment: TL (first mover), Generation (second move) and TL and Generation (simultaneously move), respectively. In all cases, the option expiration is three years.

It should be noted that the flexibility added by generators appears only once run investment and strategic flexibility is available after investment spending has been committed. The generators allow making investments in stages, flexibility for managing uncertainty remains throughout the planning horizon.

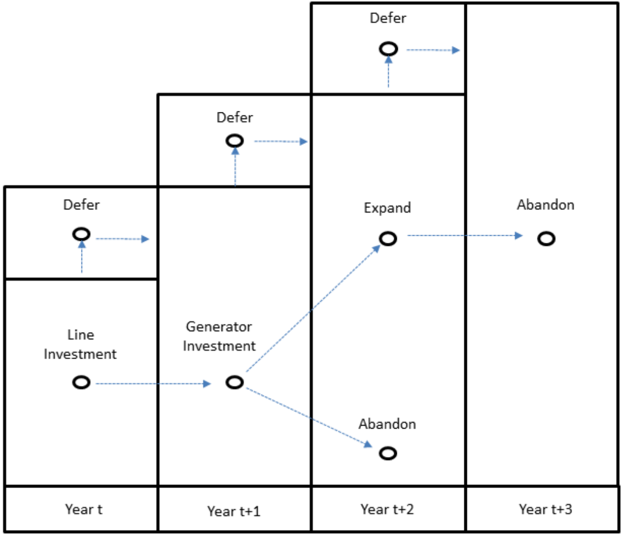

Fig.2. Map of “TL (first-mover), Generation (second-mover)”

By contrast, the value of the option for line expansion alternative, which these options are not available (only the option of deferring available) is considerable due to the enormous uncertainties about return on investment and the fact that flexibility is lost at the time of execution of the investment. This suggests that planners should "wait-and-see" until a substantial portion of the uncertainty is solved in the long-term.

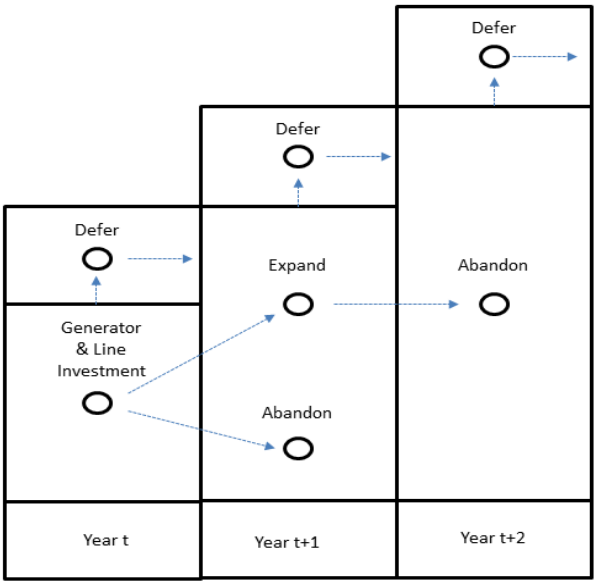

Fig.3. Map of “TL and Generation (simultaneously-mover)”

Bellman equations [10] for evaluating the options are given below:

Option of Generation (first-mover), TL (second-mover):

$$F_G(t_n, X_{t_n}) = \max\left\{\begin{array}{l} \Pi_G\left(t_n, X_{t_n}\right) + \cdots \\ \max\left(\begin{array}{l} F_E\left(t_{n+1}, X_{t_{n+1}}\right) \\ \cdots ; F_A\left(t_{n+1}, X_{t_{n+1}}\right) \\ \cdots ; F_{TL}^G\left(t_{n+1}, X_{t_{n+1}}\right) \end{array}\right) \cdot df \\ \cdots ; \mathbb{E}_{t_n}^*\left[F_G\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{1}$$

Option of TL (first-mover), Generation (second-mover):

$$F_{TL}(t_n, X_{t_n}) = \max\left\{\begin{array}{l} \Pi_{TL}\left(t_n, X_{t_n}\right) + \cdots \\ F_G^{TL}(t_{n+1}, X_{t_{n+1}}) \cdot df ; \cdots \\ \mathbb{E}_{t_n}^*\left[F_{TL}\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{2}$$

Option of TL and Generation (simultaneously-mover):

$$F_{TL\&G}(t_n, X_{t_n}) = \max\left\{\begin{array}{l} \Pi_{TL\&G}\left(t_n, X_{t_n}\right) + \cdots \\ \max\left(\begin{array}{l} F_E^{TL\&G}(t_{n+1}, X_{t_{n+1}}); \\ \cdots F_A^{TL\&G}(t_{n+1}, X_{t_{n+1}}) \end{array}\right) \cdot df \\ \cdots ; \mathbb{E}_{t_n}^*\left[F_{TL\&G}\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{3}$$

where is the valuation of the option and the gain of the option, for the *m* option (G: Generator, TL: Transmission Line, E: Generator Expansion, A: Generator Abandon) and the state *n* (G: Generator investment done, TL: line investment done, Ab: Generator Abandon done). Expanding (1) yields:

$$F_E(t_n, X_{t_n}) = \max\left\{\begin{array}{l} \Pi_E\left(t_n, X_{t_n}\right) + \cdots \\ \max\left(\begin{array}{l} F_{TL}^E(t_n, X_{t_n}); \cdots \\ F_A(t_{n+1}, X_{t_{n+1}}) \cdot df \end{array}\right); \cdots \\ \mathbb{E}_{t_n}^*\left[F_E\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{4}$$

$$F_A(t_n, X_{t_n}) = \max\left\{\begin{array}{l} \Pi_A\left(t_n, X_{t_n}\right) + F_{TL}^A(t_n, X_{t_n}); \cdots \\ \mathbb{E}_{t_n}^*\left[F_A\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{5}$$

$$F_{TL}^G\left(t_n, X_{t_n}\right) = \max\left\{\begin{array}{l} \Pi_{TL}^G\left(t_n, X_{t_n}\right) + \cdots \\ \max\left(\begin{array}{l} F_E^{TL\&G}(t_{n+1}, X_{t_{n+1}}); \\ \cdots F_{Ab}^{TL\&G}(t_{n+1}, X_{t_{n+1}}) \end{array}\right) \cdot df \\ \cdots ; \mathbb{E}_{t_n}^*\left[F_{TL}^G\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{6}$$

Similarly expanding the equations (2) and (3)

$$F_G^{TL}(t_n, X_{t_n}) = \max\left\{\begin{array}{l} \Pi_G^{TL}\left(t_n, X_{t_n}\right) + \cdots \\ \max\left(\begin{array}{l} F_E^{TL\&G}\left(t_{n+1}, X_{t_{n+1}}\right); \cdots \\ F_{Ab}^{TL\&G}\left(t_{n+1}, X_{t_{n+1}}\right) \end{array}\right) \cdot df; \\ \cdots \mathbb{E}_{t_n}^*\left[F_G^{TL}\left(t_n, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{7}$$

$$F_E^{TL\&G}(t_n, X_{t_n}) = \max\left\{\begin{array}{l} \Pi_E^{TL\&G}\left(t_n, X_{t_n}\right) + \cdots \\ F_{Ab}^{TL\&G,A}\left(t_{n+1}, X_{t_{n+1}}\right) \cdot df; \cdots \\ \mathbb{E}_{t_n}^*\left[F_E^{TL\&G}\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{8}$$

$$F_A^{TL\&G}(t_n, X_{t_{n+1}}) = \max\left\{\begin{array}{l} \Pi_A^{TL\&G}\left(t_n, X_{t_n}\right); \cdots \\ \mathbb{E}_{t_n}^*\left[F_A^{TL\&G}\left(t_{n+1}, X_{t_{n+1}}\right)\right] \cdot df \end{array}\right\} \tag{9}$$

III. STUDY CASE

Following, a detailed numerical is presented. The importance of considering the value of flexibility within the proposed investment framework is tested. An investment in an interconnection TL of 1,000 MW between two isolated systems is considered (Fig. 4).

Load growth of the region 2 and fuel cost evolution are taken into account in the evaluation as uncertain variables.

The demand growth rate is assumed to follow a Brownian motion, which the expected growth rate is 5% for the peak load period with a standard deviation of 0.4% and 2% for the low load period with a standard deviation of 0.3%.

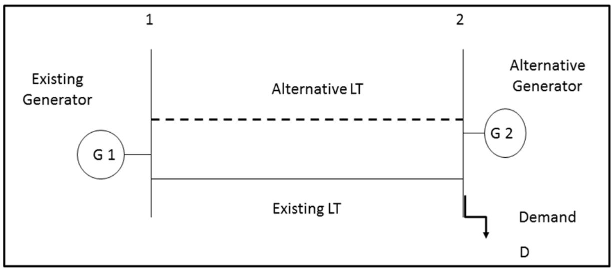

Figure 4 – Study case

The generator 1, by the TL, supplies the demand at the beginning, according to the uncertain evolution of the load; the capacity of this TL may be overloaded. In order to warranty the supply the demand, an expansion investment is needed. Investment alternatives are:

1. A new TL interconnecting both buses and it is parallel to the existing line, with the option to postpone the investment for three years.
2. A generator 2 in bus 2, with the option to postpone the investment for three years and once the investment is executed, are available.

The different scenarios for the analysis of the differences of investment costs with respect to the initial case are the following:

The first case is the installation of the generator in bus 2; the second case a new TL that interconnects both buses; the third case is the combination of the generator installation in bus 2 and the new TL that interconnects both buses; the fourth case is to expand the capacity of the generator already installed in the bus 2 and the fifth case the combination of expanding the capacity of the local generator already installed in the bus 2 and the new TL that interconnects both buses.

The obtained values from the different case studies are used for the calculation of the valuation of the three investment options both through the traditional NPV method and using the flexibility of ROV.

As a result of this analysis, it is determined that I1 is the best decision considering the ROV criteria, unlike the decision suggested by NPV criteria shows that the I2 is the best option (see Table I).

TABLE I. VALUATION RANKING OF THE INVESTMENT AND FLEXIBILITY VALUE OF THE OPTIONS

Strategy	**Options Portfolio Value (ROV) [MUSD]**	**Net Present Value (VPN) [MUSD]**	**Flexibility [MUSD]**
I1	89,891(1st)	16,211(2nd)	73,681
I2	76,997(3rd)	59,945(3st)	17,052
I3	77,320(2nd)	-27,454(3rd)	351,586

IV. CONCLUSION

This paper shows a methodology that addresses the characteristics of investments in the field of TEP and GEP together, considering the flexibility of the expansion strategies: Generation (first-mover), TL (second-mover); TL (first-mover), Generation (second-mover); TL and Generation (simultaneously-move), under uncertain conditions. The large uncertainties inherent in power markets have been successfully modeled in order to understand manage the investment risk profiles, also the stochastic method such as Brownian motion and mean-reverting stochastic process have been incorporated. These expansion strategies induce the execution of investments in stages rather than just the postponement of large transmission line projects.

By a numerical validation, the case study has shown that traditional investment assessment methods may be inappropriate in the evaluation of transmission investments, since the presence of uncertainty drastically increases the risk involved in large-scale irreversible decisions. The flexibility to postpone, expand or abandon an investment project provides valuable information in such an uncertain environment.

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