Valuation of Investments in Flexible Power Plants:

A Case Study in the Brazilian Power Market

Alexandre Vasconcelos Aronne
Faculdade Pedro Leopoldo
alexandre.aronne@gmail.com
Via Piave, 37 – Bologna. 40133. Italy
+39 3471922771

Haroldo Guimarães Brasil
Faculdade Pedro Leopoldo
strategor@uai.com.br
Rua Alvarenga Peixoto 435 apto 502 – Belo Horizonte. 30180-120. Brazil
+55 31 9791 9436

Ivan Dionysio Aronne
Centro de Desenvolvimento da Tecnologia Nuclear – CDTN/CNEN
ivanaronne@gmail.com
Rua Exp. Jose A. Anjos, 390 – Belo Horizonte. 31310-050. Brazil
+55 31 3427 1595

Abstract

In this paper, we discuss the real options valuation of investments in flexible power plants. After the Brazilian energy supply crisis in 2001, new investments in gas-fired power plants were made to increase electricity generation in the short term, due to the reduced maturity time of these investments. More recently, the nationalization of the Bolivian natural gas reserves raised uncertainties over prices and supply of this commodity. Initially we analyze an operating power plant that can switch fuels among natural gas and oil and afterwards we study the option to temporarily shut down the plant. Finally, we assess the interaction between these two options and determine the optimal operating policy of the plant. The valuation method used involves the use of two quadrinomial trees, supporting correlated GBM for the fuel prices.

1- Introduction

The Brazilian Power sector started its liberalization process in the beginning of the 90´s, in order to insert competition and attract private capital to investments in this sector. However, the results of the deregulation were not as successful as planned and in 2001 the country suffered an energy supply crisis. Investment in new gas-fired power plants was the main alternative found in order to increase electricity generation in the short term, due to the reduced maturity time of these investments. However, in 2006, the Bolivian natural gas reserves, from where most of the gas consumed in Brazil is extracted, were nationalized raising uncertainties over gas prices and supply.

The uncertainty and irreversibility of investments in this sector makes their analysis a more difficult task, since traditional analysis methods, such as the net present value (NPV), are not the most appropriate tools for the valuation of investments under these conditions. These methods don't take into account the managerial flexibility embedded in a project, and therefore, assume that investments are managed passively, and managers will not review their decisions.

However, under the conditions of uncertainty and irreversibility, managerial flexibility may be highly valuable and should be taken into account in a project valuation. The valuation of flexibility calls for more sophisticated techniques, such as the Real Options.

Recently, the literature on Real Options has grown a lot and these techniques have been applied in a wide range of industry sectors using many different approaches. Nevertheless, the real options technique has been applied in the energy sector mainly for the evaluation of Oil Investments.

During the last fifteen years, however, the application of real options analysis to power generation investments has increased significantly, mainly due to the liberalization process of electricity markets in many countries.

The aim of this article is to present the valuation of a flexible power plant, which can operate burning either natural gas or oil. Initially we calculate the value of the option to switch among these fuels. Later, we valuate the operational flexibility of the plant, that is, the option to temporarily shut down. Finally, we analyze the interaction between these two options.

A review of some important contributions to the literature focused on thermal power plants is shown below.

2 – Real Options Valuation applied to Thermal Power Plants

Apparently, the first application of real options analysis to a thermal power plant was shown by Kulatilaka (1993). The author assessed the fuel switch option of a dual-fired boiler, which could alternate fuel from natural gas to oil and vice-versa. Dynamic programming was used to value the managerial flexibility, which turned out to be more valuable than the extra cost of the flexible technology.

Deng *et al* (1998) used an analytical model to valuate thermal power plants that operate only when the spark spread is positive. Comparing the results of the real options approach to the “naive" NPV, the authors concluded that the first method provides values much closer to the market price of the assets than the traditional DCF method.

Brekke and Schieldrop (2000) analyzed the fuel switch option and the optimal timing of investing in a plant that can burn natural gas or oil. Analytically, they proved that the flexibility acquired with the flexible (dual-fired) technology reduced the value of the option of delaying the investment.

Using Monte Carlo simulation and dynamic programming, Tseng and Barz (2002) assessed a power plant capable of switching between two modes: on and off. For the first time in the literature, the operational restrictions of the plant, such as the time necessary to turn it on and off were taken into account.

Fleten and Nasakkala (2003) analyzed a license to build a power plant, held by an investor. Analytically, they evaluated the optimal timing and the option to abandon the investment taking into account stochastic CO_2 emission costs. They concluded that it was not optimal to build the plant, even if there were no emission costs.

Abadie and Chamorro (2006) used a quadrinomial lattice to valuate the investment in an Integrated Gasification Combined Cycle - IGCC, which can generate power burning either coal or natural gas. After analyzing the optimal time to invest, they showed that there was a small region in the price space in which it was optimal to wait instead of to invest.

Although the international literature contemplates many types of flexibility and a large variety of models, that is not the case in Brazil. The main contributions to the national literature are shown below.

Castro (2000) assessed the operational flexibility (option to shut down) of a gas-fired power plant. The spot price of the electricity was obtained using NEWAVE, a simulation software developed by CEPEL to determine the optimal operation strategy of the Brazilian Power System. Using simulation and dynamic programming, the author calculated the value of the flexibility acquired by declaring the plant flexible.

Silva *et al* (2001) also valuated the operational flexibility of a plant, using an approach analogous to that used by Castro (2000). However, instead of using NEWAVE, the authors developed an empirical forecasting model for the electricity prices, based on the experience of professionals related to the Brazilian power market and on a time series of spot prices. The results obtained are very close those obtained by Castro (2000).

Using Monte Carlo simulation, Rocha *et al* (2002) evaluated the effects of the "energy deficit cost" and the "normative value", two parameters regulated by the Electric Power Regulatory Agency, on the attractiveness of the investments in gas-fired power plants. They concluded that a regulation based only on an increase in the energy deficit cost is not effective to attract the required investments in power plants. Therefore, the normative value should match the critical price required to invest immediately, in order to induce new investments.

Gomes (2002) assessed the optimal time to invest in flexible power plants. He used NEWAVE and Monte Carlo Simulation to determine the value of the plants, and a binomial lattice to determine the best time to invest. Later, he has developed an option game model to determine the optimal time to invest under duopoly assumptions.

Most of the real options models used in Brazil have the energy spot price as the only source of uncertainty, and the fuel cost is usually taken as a constant. However, due to a significant rise of fuel prices in association to the uncertainties of prices and supply of the natural gas imported from Bolivia, this should be a key component in the valuation model.

3 – Valuation of the powerplant

We valuate an operating dual-fired thermal power plant that can burn either oil or natural gas.

3.1 – The Base Case

The parameters adopted in the base case are show on TABLE 1.

TABLE 1 – Basic Technical and Economical Parameters

Parameters	Gas Mode	Oil Mode
Plant Size (Mw) – P	300	300
Production Factor (% P) - PF	85	85
Efficiency (%) – E	50	30
Useful life (years) - T	25	25
Investment cost (US$/Kw) - I	495	495
Operation Cost (US$/MWh) - ($C_{O\&M}$)	7.0	7.0
Initial Fuel Prices (US$/MBtu)	4.2	7.0
Volatility (%)	19.88	23.66
Risk-neutral growth rate of fuels (%)	0,015	0,01
Correlation between fuels	0.74	0.74
Risk free interest rate (%) – r	6.0	6.0
Cambial rate (R$/US$)	1.85	1.85
Initial Energy Price (R$/MWh) - P_e	85.00	85.00

Source: Produced by the authors

Energy prices follow a deterministic path, growing at the risk-free interest rate. Initially, the switch cost from gas mode to oil mode - C(g→o) – and the switch cost from oil mode to gas mode - C(o→g) – are considered nil.

The fuel prices are modeled as correlated Geometric Brownian Motion (GBM). Pindyck (1999, pg 24) suggests that the mean reverting rate of these commodities is slow, and the GBM assumption will be appropriate if the volatility is relatively constant. Pindyck (2004, pg 18) argues that the fluctuations in volatilities of oil and natural gas are short-lived and should not have any significant impact on most real options and investment decisions related to the price of these commodities.

Even though these commodities are traded in US Dollar-US$ in Brazil, electricity prices and contracts are traded in Brazilian Real-R$. Therefore, a cambial rate was used to convert all the prices and costs from US$ to R$. This rate is taken as constant during the plant useful life.

3.2 –Valuation Models

3.2.1 – Model for the power plant with option to switch fuels

We make use of the quadrinomial model presented in Copeland and Antikarov (2001, pg 279-286) to assess the value of the power plant taking into consideration the imperfect correlation between oil and natural gas. The risk-neutral quadrinomial probabilities are obtained according to the following equations:

$$Puu = (u_1u_2 + u_2g_1 + u_1g_2 + \rho_{12}\sigma_1\sigma_2\Delta t) / 4u_1u_2 \quad \textbf{(1)}$$

$$Pud = (u_1u_2 + u_2g_1 + d_1g_2 - \rho_{12}\sigma_1\sigma_2\Delta t) / 4u_1u_2 \quad \textbf{(2)}$$

$$Pdu = (u_1u_2 + d_2g_1 + u_1g_2 - \rho_{12}\sigma_1\sigma_2\Delta t) / 4u_1u_2 \quad \textbf{(3)}$$

$$Pdd = (u_1u_2 + d_2g_1 + d_1g_2 + \rho_{12}\sigma_1\sigma_2\Delta t) / 4u_1u_2 \quad \textbf{(4)}$$

Where:

$u_1 = \sigma_1\sqrt{\Delta t}$ → up move of natural gas **(5)**

$d_1 = -u_1$ → down move of natural gas **(6)**

$u_2 = \sigma_2\sqrt{\Delta t}$ → up move of oil **(7)**

$d_2 = -u_2$ → down move of oil **(8)**

g_1 and g_2 → expected risk-neutral growth rate of the prices of natural gas and oil

ρ_{12} → correlation between variations of the prices of natural gas and oil

In order to compute the value of the operating power plant, we use two quadrinomial lattices with 100 steps[1]. In this way, we illustrate the adjustments of natural gas prices, made once every three months in Brazil. The first lattice corresponds to initial operation in natural gas mode and the second one corresponds to initial operation in oil mode. Independently of the operating mode, the value of the plant at the last operating moment is nil, i.e.:

Vg=0 if the end of the plant's life is reached in gas mode,

Vo=0 if the end of the plant's life is reached in oil mode,

where Vg represents the value of the natural gas lattice nodes and Vo represents the value of the oil lattice nodes. For anterior nodes, the best of two options is chosen[2], i.e.:

---

[1] Consequently, Δt=0.25.

[2] A similar approach using 2 binomial lattices can be found in Trigeorgis (1996, pg 177-184). Abadie e Chamorro (2006, pg 24-28) also present a similar approach using 2 quadrinomial lattices.

- continue: receive the cash flow of the current operating mode plus the present value of the corresponding lattice

- switch: receive the cash flow of the current non operating mode plus the present value of the non operating mode lattice, minus the corresponding fuel switch cost.

The natural gas lattice values are obtained as follows:

$$Vg = MAX\ (\ (CF_g + e^{-r\Delta t}\ (Puu \cdot Vg_{uu} + Pud \cdot Vg_{ud} + Pdu \cdot Vg_{du} + Pdd \cdot Vg_{dd}))\ ;$$
$$(CF_o - C(g \rightarrow o) + e^{-r\Delta t}\ (Puu \cdot Vo_{uu} + Pud \cdot Vo_{ud} + Pdu \cdot Vo_{du} + Pdd \cdot Vo_{dd})))\quad \textbf{(9)}$$

The oil lattice takes on the following values:

$$Vo = MAX\ (\ (CF_o + e^{-r\Delta t}\ (Puu \cdot Vo_{uu} + Pud \cdot Vo_{ud} + Pdu \cdot Vo_{du} + Pdd \cdot Vo_{dd}))\ ;$$
$$(CF_g - C(o \rightarrow g) + e^{-r\Delta t}\ (Puu \cdot Vg_{uu} + Pud \cdot Vg_{ud} + Pdu \cdot Vg_{du} + Pdd \cdot Vg_{dd})))\quad \textbf{(10)}$$

Cash flows for natural gas operating mode are given by:

$$CF_g = A \cdot P_e \cdot \Delta t - B_g \cdot P_g \cdot \Delta t - A \cdot C_{O\&M} \cdot 2{,}15 \cdot \Delta t \quad \textbf{(11)}$$

Cash flows for oil operating mode are given by:

$$CF_o = A \cdot P_e \cdot \Delta t - B_o \cdot P_o \cdot \Delta t - A \cdot C_{O\&M} \cdot 2{,}15 \cdot \Delta t \quad \textbf{(12)}$$

Where:

$A = P \cdot 365 \cdot 24 \cdot PF \rightarrow$ Annual production in MWh

$P_e \rightarrow$ Current energy price

$B_g = (P \cdot 365 \cdot 24 \cdot PF \cdot 3{,}412) / E_g \rightarrow$ Natural gas energy needed per year (MBtu/year)

$B_o = (P \cdot 365 \cdot 24 \cdot PF \cdot 3{,}412) / E_o \rightarrow$ Oil energy needed per year (MBtu/year)

$P_g \rightarrow$ natural gas price at current node (R$/MBtu)

$P_o \rightarrow$ oil price at current node (R$/MBtu)

3.2.2 – Model for the power plant with option to shut down temporarily

The model shown above can be easily adapted to allow the valuation of the option to temporarily shut down the power plant. In this way, the operation of the plant can be seen as an option and not an obligation, and the plant operates only when cash flows are positive[3]. In order to do that, we simply substitute equations 11 and 12 by 13 and 14, respectively:

$$CF_g = MAX((A \cdot P_e \cdot \Delta t - B_g \cdot P_g \cdot \Delta t - A \cdot C_{O\&M} \cdot 2{,}15 \cdot \Delta t); 0) \quad \textbf{(13)}$$

$$CF_o = MAX((A \cdot P_e \cdot \Delta t - B_o \cdot P_o \cdot \Delta t - A \cdot C_{O\&M} \cdot 2{,}15 \cdot \Delta t); 0) \quad \textbf{(14)}$$

4 – Results

4.1 – Value of an operating power plant

The value obtained for the power plant characterized in the base case was R$203,286,000. Subtracting the initial investment of R$275,000,000 made to build the power plant, we find a negative NPV of R$ 71,714,000.

4.2 – Value of the fuel switch option

The value of the fuel switch option is obtained based on Table 2, where the value of the plant is show, as a function of switching costs.

TABLE 2 – Value of an Operating Power Plant

Fuel Switch Costs (R$) C(g→o) = C(o→g)	Plant's Value (R$)
0	203,286,000
10,000	203,013,000
30,000	202,566,000
50,000	202,149,000
100,000	201,254,000
1.000,000	192,832,000
Infinite	169,175,000

Source: Produced by the authors

As fuel switch costs go up, flexibility loses its value. Therefore, when switch costs are infinite, flexibility has no value. The difference between the value of the plant with zero switching costs and the value of the plant with infinite switching costs corresponds to the value of the flexibility. Therefore, the fuel switch option value is R$34,111,000.

[3] A similar approach is shown in Trigeorgis (1996, pg 193).

4.3 – Value of the option to shut down temporarily

Truncating the cash flows and considering infinite fuel switching costs, we obtain a value of R$534,129,000 for the power plant. From this value, we subtract the value of the plant without option to temporarily shut down, as shown at the last line of TABLE 2. Therefore, the value of the option to shut down temporarily obtained is R$364,954,000.

4.4 – Interaction between the fuel switch option and the option to shut down temporarily

Valuating the plant with the fuel switch option and the option to shut down temporarily, we obtained the value of R$545,189,000, which corresponds to a NPV of R$270,189,000.

Subtracting the value of the inflexible plant from the value of the plant with two flexibilities, we obtain the value of R$364,954,000 for the combination of both flexibilities.

Adding up the value of each single option, we obtain R$376,014,000. The sum of the isolated option values is therefore 3.03% greater than the real value of the two options.

5 – Concluding remarks

In this paper, we have analyzed the valuation of flexible power plants in Brazil as real options. In order to consider the uncertainty and correlation of the fuel prices, we have used quadrinomial lattices. This model was chosen due to its simplicity, flexibility and adequacy to determine the optimal operating policy of the plant.

Although the switch option value was low, due to higher prices and lower efficiency associated to oil, we should highlight that this flexibility may avoid the stopping of the plant in case of shortage of supply of natural gas imported from Bolivia.

The value obtained for the option to temporarily shut down the plant is very high. Moreover, the investment NPV was positive only when this flexibility was taken into account.

In line with the real options literature, we have shown the interaction of the two options, which, however, was demonstrated to be very low.

REFERÊNCIAS

ABADIE, L., CHAMORRO, J. Valuation of Energy Investments as Real Options: The case of an Integrated Gasification Combined Cycle Power Plant. The 10th Annual Real Options Conference, 2006.

BREKKE, K.; SCHIELDROP B. Investment in Flexible Technologies under Uncertainty. In: BRENNAN M.; TRIGEORGIS, L. Project Flexibility, Agency and Competition: New Developments in the Theory of Real Options. Oxford University Press, 2000. pgs 34-49

CASTRO, A. L. Avaliação de Investimento de capital em projetos de geração termoelétrica no setor elétrico brasileiro usando teoria das opções reais. PUC Rio, Rio de Janeiro, 2000. (Dissertação de Mestrado em Engenharia de Produção)

COPELAND, T.; ANTIKAROV, A. Opções Reais: Um novo paradigma para reinventar a avaliação de investimentos. Rio de Janeiro: Campus, 2001.

DAMODARAN, A. Avaliação de investimentos: ferramentas e técnicas para a determinação do valor de qualquer ativo. Rio de Janeiro: Qualitymark 1997.

DENG S.; JOHNSON B.; SOGOMONIAN A. Exotic Electricity Options and the Valuation of Electricity Generation and Transmission, Proceedings of the Chicago Risk Management Conference, 1998.

DIXIT, A. K., PINDICK, R. S. Investiment under Uncertainty. Princeton: Princeton University Press, 1994.

FLETEN S.; NASAKKALA, E. Gas Fired Power Plants: Investment Timing, Operating Flexibility and Abandonment. The 7th Annual Real Options Conference, 2003.

GOMES, L. Avaliação de termelétricas no Brasil estudando o melhor momento de investimento por modelos opções reais. PUC Rio: Rio de Janeiro, 2002. (Tese de Doutorado)

KULATILAKA, N. The value of flexibility: The case of a dual-fuel industrial steam boiler. Financial Management, 1993. Disponível em: http://search.ebscohost.com/ Acessado em: 21/08/2006.

PINDYCK, R. The Long-run Evolution of Energy Prices. In: The Energy Journal, Vol 20, No. 2, 1999. Disponível em: web.mit.edu/rpindyck/www/. Acesso em: 16/12/2006.

PINDYCK, R. Volatility in Natural Gas and Oil Markets. In: The Journal of Energy and Development, Vol 30, No. 1, 2004. Disponível em: web.mit.edu/rpindyck/www/. Acesso em: 16/12/2006.

ROCHA, K.; MOREIRA, A.; DAVID, P. Investments in Thermopower Generation: A Real Options Approach for the New Brazilian Electrical Power Regulation. The 6th Annual Real

SILVA, B.N.; TEIXEIRA, J. P. & GOMES, L.L. Previsão de Preços Spot e Avaliação Econômica de Projetos de geração Termelétrica. IX Seminário de Planejamento Econômico-Financeiro do Setor Elétrico (SEPEF), Recife-PE, Out. 2001.

TRIGEORGIS, L. Real Options: Managerial Flexibility and Strategy in Resource Allocation. Cambridge, MA: The MIT Press, 1996.

TSENG, C.; BARZ, G. Short-term generation asset valuation: a real options approach. Operations Research, Vol 50, No 2, 2002. Disponível em: http://search.ebscohost.com/ Acesso em: 02/09/2006.