Thermal generation investment analysis using decision tools

Conference Paper · July 2011

DOI: 10.1109/PES.2011.6039473

3 authors:


Anderson Rodrigo De Queiroz
North Carolina Central University
38 PUBLICATIONS **145** CITATIONS
SEE PROFILE


Luana Medeiros Marangon Lima
Universidade Federal de Itajubá (UNIFEI)
15 PUBLICATIONS **43** CITATIONS
SEE PROFILE


Jose Wanderley Marangon Lima
Universidade Federal de Itajubá (UNIFEI)
86 PUBLICATIONS **1,185** CITATIONS
SEE PROFILE

Thermal Generation Investment Analysis Using Decision Tools

A. R. Queiroz, IEEE *Student Member*, L.M.M. Lima, IEEE *Student Member,* and J.W.M. Lima, *IEEE Senior Member*

Abstract— **In this paper we present an investment problem where a decision maker from a company has to decide on the best among four possible alternatives of power supply. Two of these alternatives are related to investment in a thermal generator to produce electricity for the company own use. In this framework there are many uncertainties that have strong influence on the net present values of each alternative. Some of these uncertainties are identified and modeled for the purposes of this work. It is important to mention that electricity is an important input to the production process and represents considerable costs for the company. In order to avoid unnecessary expenses a solid analysis is necessary. This work combines decision analysis tools, as the influence diagram and decision tree, with investment analysis to help the decision maker to select the best supply alternative for the company.**

Index Terms— **Electricity Markets, Electricity Generation, Investment Decision Analysis, Uncertainty Analysis**

I. INTRODUCTION

THE figure of electricity market has emerged in the last few decades. The deregulation process in the electricity power market proportioned the opportunity for many market participants to produce their own energy for consumption or/and also to sell it. The access of these new producers to the transmission and distribution grid represents new offers in the market. In Brazil, as in many other countries around the world, the consumers with high demand started to have the opportunity to select its energy provider among different market agents as: distribution companies, generators and traders. The prices and the quantities of the contracts started to be directly negotiated between the consumer and the selected agent without the intermediation of the local utility.

Since the occurrence of the deregulation in the electricity market the private agents started to evaluate investment opportunities in the system. Therefore, for companies that have electricity as important factor on the production process it is necessary to compare the investment on its own generator with the alternative of maintaining the energy contracts with the local utility. Not differently from other markets it is important to develop cash flows of the investments alternatives incorporating all the market variables that affect the project value. In our analysis, the future electricity and gas prices and also the electricity distribution tariffs will be incorporated to analyze the investment problem.

In general, for the Brazilian and South American particular cases, the energy deficit risk has bothered companies and governments due to the depletion of the energy resources and demand growth. Thus, there exists an environment favorable to companies which are interested in investment opportunities in energy generation for their own consumption as much as an opportunity for them to sell this energy directly in the market. This work consists in evaluating an investment analysis of a 300 [MW] thermal generator to be installed in the Brazilian South East region. The time horizon of the investment problem is 15 years. The idea is to use decision analysis techniques to help the decision maker to select the best possible alternative for the company.

Usually, in this type of problem decision makers use a deterministic approach to analyze the investment opportunity. Sometimes it is performed types of sensitivity or scenario analysis to identify the most important uncertainties that have large impact in the cash flows and then evaluate the investment analysis. According to [1], among the many uncertainty variables that exists in the power market, three variables have the biggest influence in most the cash flow evaluations for a power generator, they are: fuel prices, electricity spot prices, and the system demand growth. Particularly in Brazil, the major portion of the installed capacity and energy generation is provided by hydro-generators (around 80%) with large reservoirs, so the inflows at the reservoirs have a direct effect on the electricity prices. Moreover, because of substantial dimensions of the country, the distribution tariffs play an important role in the economic analysis for a company to confront the present situation with the investment possibility in a power generator.

Facing these uncertainties, in this problem the investor has to decide between four alternatives presented further. According to the company preferences probabilities for each alternative the investor will choose the project that has the greatest certainty equivalent. A certainty equivalent is the amount of money that is equivalent in your mind to a given situation that involves uncertainty [4]. In this approach decision analysis techniques are used in order to help the decision maker of a risk neutral company to select the best

---

This work was supported by CAPES.

Thermal Generation Investment Analysis Using Decision Tools.

A.R. Queiroz is a PhD. student at the Department of Mechanical Engineering, University of Texas at Austin, Austin, TX 78759 USA (e-mail: ar_queiroz@mail.utexas.edu).

L.M.M. Lima is a PhD. student at the Department of Mechanical Engineering, University of Texas at Austin, Austin, TX 78759 USA (e-mail: luana_marangon@yahoo.com.br).

J.W.M. Lima is with the Department of Electrical Engineering, Federal University of Itajubá, Itajubá, MG 37500-000 Brazil (e-mail: marangon@unifei.edu.br).

alternative. It is important to say that the company prefers more money to less and that it follows the delta property, that is, if the value of each possible outcome were increased by the same amount delta, then the value of the uncertainty (its certainty equivalent) would be increased by the same amount delta. Section II presents the modeling of the investment decision problem. Section III addresses the uncertainties that were used in this work. Section IV contains a summary of the costs related to the alternatives of the problem. Section V presents the results obtained for the investment decision analysis with the decision tree. Section VI concludes the paper.

II. MODELING THE INVESTMENT DECISION PROBLEM

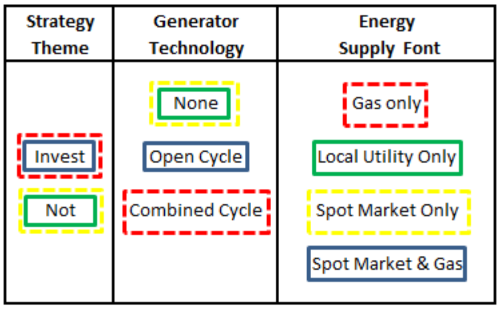
According to [5] one of the first steps of decision analysis (DA) is to list all the viable options for: gathering information, experimentation, and actions. The next step is to generate the list of events that might occur, and then sort this list into chronological order. The following step is to identify consequences for each possible state as well as each event probability. The most critical components are to include all costs, benefits and risks. We start the modeling part by identifying the possible electricity supply alternatives for the company and then we use decision analysis tools on the problem.

A. *Possible Alternatives*

The set of alternatives is described below:

- **Alternative 1:** The company stays as regular consumer buying electricity from the local utility;
- **Alternative 2:** The company starts to buy electricity in the spot market and uses the distribution system of the local utility;
- **Alternative 3:** The company invests in a 300 MW gas thermal plant with combined cycle that will operate full time;
- **Alternative 4:** The company invests in a 300 MW gas thermal plant with open cycle that will operate only when the spot price is higher than the operational cost of the plant.

With the set of alternatives described it is possible to draw a strategic table of the process. Figure 1 presents the strategic table for the problem, which helps in the visualization of the decisions that the investor is facing. So, for example, if the decision analyst decides to invest in a combined cycle generator the red squares are the ones that represent this alternative.



Strategy Theme	Generator Technology	Energy Supply Font
	None	Gas only
Invest	Open Cycle	Local Utility Only
Not	Combined Cycle	Spot Market Only
		Spot Market & Gas

Figure 1 - Strategic Table for the Process

B. *Influence Diagram*

The influence diagram is at once both a formal description of the problem and degrees of technical proficiency. An influence diagram is a way to describe the existent dependencies among uncertainties and decisions [6]. An influence diagram can be used to visualize the probabilistic dependencies in a decision analysis and to specify the states of information for which independencies can be assumed to exist.

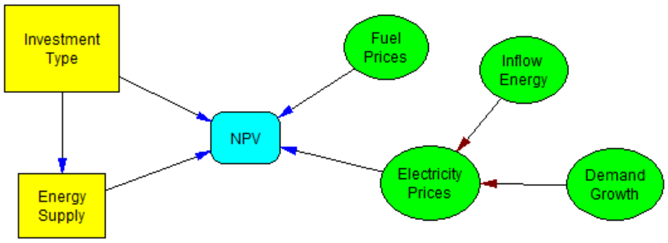


Figure 2 – Influence Diagram for the Decision Problem

The influence diagram presented in Figure 2 represents the relationships between the decisions, uncertainties and values in this problem. It is possible to notice that the electricity prices depend on the realizations of the system demand growth and the natural inflow energy. The decision about the energy supply depends only on the investment type that the decision maker selects. The value node is represented by the Net Present Value – NPV. It depends on the two decisions, and also on the gas prices and on the electricity prices.

C. *Decision Tree*

Using the influence diagram and the strategic table specified before it is possible to draw the decision tree related to the problem. Figure 3 presents a compact version of the decision tree. It is possible to notice for instance that for the alternative where the company makes the investment in a combined cycle thermal generator just the uncertainty related to gas prices is part of that branch of the tree.

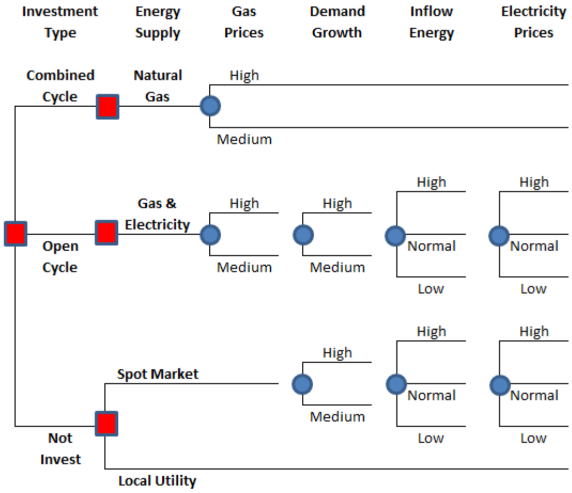


Figure 3 – Decision Tree for the Problem

III. UNCERTAINTY ANALYSIS

Uncertainty is a main component of many decisions that people usually have to deal with. One of the main basics of decision analysis is that it is possible to represent uncertainty of any kind through the appropriate use of probability. The form of the model that will be created has influence of the uncertainties faced, and the analysis required depends on the exigencies of the decision situations [4]. One of the primary concerns associated with the use of decision analysis deals with accuracy of costs, benefits and probabilities, these features are all needed for a good decision to be made [5]. The more accurate are the estimates, the better is the resulting decision.

In this work, the data that we use to model the uncertainties are based on the studies developed by the Brazilian institutions ONS (Independent System Operator), EPE (Energy Research Institution) and ANEEL (Electricity Regulatory Agency). These entities are responsible for the operating, the planning and the regulating processes of the Brazilian power system. We use the Brazilian optimal hydrothermal generation dispatch software to simulate the created scenarios, in order to obtain the electricity prices (besides the optimal dispatches this software also provides the operational marginal costs, used in Brazil as basis for the electricity spot prices).

A. Demand Growth

The electricity demand growth of the power system is an important variable to be considered in an investment analysis of a power generator. The demand growth does not affect directly the NPV of the power generator alternative but it is responsible for changes in the market electricity prices. For prices, a higher demand would require more generation in the system in order to balance supply and demand. In this case, if there is lack of cheap generation it is necessary to dispatch expensive thermal to supply the load what would increase the electricity prices.

The demand forecasts adopted for this work are based in the information of the Brazilian energy expansion plan for the period of 2007-2016. This expansion plan provides two different possible scenarios for the demand grow. For the first demand scenario it is considered an average annual grow of 4.7%. This percentage was used as the normal demand growth scenario. The other demand scenario represents an average annual grow of 5.5%. This percentage was used as the high demand scenario. Table 1 and Table 2 present the demand forecast for the period of 2008 – 2012, for each country region, for normal and high demand respectively.

Table 1 - Demand Forecast - period of 2008-2012 (Normal)

Region	**2008**	**2009**	**2010**	**2011**	**2012**
Southwest	33245	35176	36913	38525	40078
South	8612	9028	9456	9868	10277
Northeast	7681	8057	8439	8851	9264
North	3712	3935	4156	4390	4546
Total [MW]	**53251**	**56196**	**58964**	**61634**	**64165**

In order to represent the uncertainty with different probabilities of occurrence it was used the historical demand data from [10]. Figure 4 shows the average electricity demand growth for each year from 1988 to 2007. There are more data available (since 1952) but it was not considered because in the past the demand growth could reach more than 12% per year. The characteristics of the system in the past are not the same anymore, so demand growth of more than 10% is not likely to happen anymore.

Table 2 - Forecast - period of 2008-2012 (High)

Region	**2008**	**2009**	**2010**	**2011**	**2012**
Southwest	33979	35918	37662	39564	41495
South	8789	9298	9814	10302	10776
Northeast	7726	8112	8787	9138	9652
North	3794	3980	4132	4432	5875
Total [MW]	54288	57307	60395	63436	67798

In order to assign the high demand growth probability, at a particular year, it was calculated the number of years where the demand growth was greater than 5.1% (average between 4.7% and 5.5%). For the medium demand growth it was computed the number of years where the demand growth was less than or equal to 5.1%. There were 7 years for high demand growth and the other 13 years represent medium growths. To compute the probability of each demand growth we just divide each particular number by 20, that is the total number of years.

$$p_d^h = 7/20 \cong 0.35 \quad and \quad p_d^m = 13/20 \cong 0.65$$

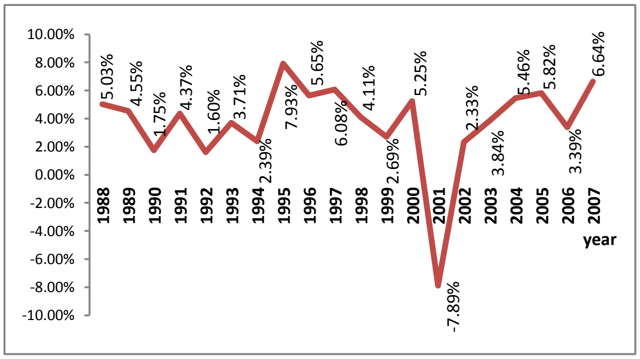


Figure 4 - Historical Energy Demand Growth

It is important to notice that there is a probability of 0.65 that the demand growth will be 5.5% and 0.35 that the demand growth will be 4.7%. Other alternative would be to create a cumulative distribution function for the demand growth and discretize it in intervals to consider different assumptions.

B. Fuel Prices

In order to consider the fuel prices uncertainty it was collected the future natural gas prices (Henry Hub) data from New York Mercantile Exchange (NYMEX) [8] for two different periods. The first series data was gathered from May of 2008 to December of 2020 (In May of 2008, because of a big turbulence in the market, the oil prices were high and so were the natural gas prices). The second series data was gathered from May of 2009 to December of 2021. The two series were considered as high and normal future trend fuel prices respectively. Figure 5 shows the different fuel prices trends for natural gas.

It was calculated the average gas prices for each series. The gas prices are considered in this analysis as a constant with value equal to the average price for each trend for the whole investment period. The probability that gas prices will have a high trend was assumed to be equal to the probability that the prices will have a medium trend.

$$p_F^h = 0.50 \quad and \quad p_F^m = 0.50$$

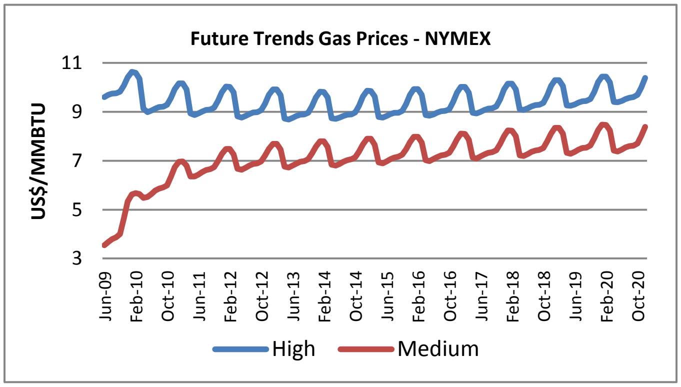


Figure 5 – Fuel Prices Future Trend for Natural Gas

The gas prices for the company interested on investing in thermal generation are about 11% (information provided by the company) higher than the Henry Hub prices. The average values for each trend and also the average gas prices for the company are presented in Table 3.

Table 3 – Average Gas Prices [$/MMBTU]

	High	Medium
Henry Hub	9.57	7.15
Company	10.59	7.91

Modeling gas prices is very important for the analysis because if the company decides to build the thermal generator the major part of the operational costs of this generator will depend on the gas prices. Thus this uncertainty will have direct impact on the project cash flows.

C. *Natural Inflow Energy*

The decision to utilize the “stock” of energy, which can be represented as the water stored in the reservoirs of the system, is an important decision. This decision problem is attached to the uncertainty of the future inflows. In a system where the major part of electricity is provided by cascade hydro generators, it is very important to model the future inflow at the reservoirs. Also it is important to notice that the natural inflows energy in the Brazilian interconnected system have direct influence on the electricity prices.

In the one hand, if during some period the real amount of water (from rain) is much less than the value that was expected, it is possible that the Independent System Operator will have to use expensive thermal generation in order to satisfy demand. On the other hand, if the amount of water is higher than the amount expected, there is a possibility that no thermal generation is needed. In both cases there is a variation on the electricity prices, in the first one, because of the expensive thermal generation, the prices in the market would be higher and in the second case the prices would be lower.

In order to compose the uncertainty on the natural inflow energy at the reservoirs it was considered the historical data from the Brazilian Independent System Operator [7]. The data is available for the period of 1931 to 2008. Using the natural inflow energy for each year it was generated 69 natural inflow energy series of 10 years each. For example the period of 1931 to 1940 represents the first 10 years natural inflow energy series, the period of 1932 to 1941 represents the second 10 years natural inflow energy series and so on, until the period of 1999 to 2008 that represents the last series.

Table 4 – Natural Inflow Energy – 10 year series

	P10	P50	P90
Region	**Low**	**Normal**	**High**
Southwest	3,367,406	3,868,015	4,509,100
South	800,442	1,030,449	1,001,253
Northeast	914,977	740,664	1,073,304
North	663,360	699,133	754,360
Total	**5,746,185**	**6,338,261**	**7,338,017**

The 10 year inflow energy series was approximated by a normal distribution. It was calculated the mean and the standard deviation for the data. It was used the approximation to weight the 10th, 50th and 90th percentiles of the data distribution to get the natural inflow energy values. Table 4 presents the natural inflow energy in [MW average] for a 10 years period for each region of the Brazilian electricity market.

D. *Electricity Prices*

With the deregulation of the electricity sector, the electricity prices became a very important parameter for the market participants. The prices give signals about possible investment opportunities in the power sector. In many countries the process to obtain the electricity prices is based on the supply and demand curve. In some markets as ERCOT (Electric Reliability Council of Texas), NYISO (New York Independent System Operator) and PJM (Pennsylvania - New Jersey - Maryland Interconnection) the prices are defined in real time within 5 to 15 minutes period. In most of the cases, the largest amount of power generation is provided by thermal plants what does not happen in Brazil. The Brazilian system has distinct types of thermal plants that use different fuels (natural gas, diesel, nuclear, oil and coal), but the highest energy amount is provided by hydro plants that operates in cascade reservoirs schemes.

In Brazil, the electricity prices at the free market are defined weekly. These prices are named PLD (clearing prices of the differences), they are set by calculating the operational marginal cost (OMC) of the energy derived from a hydrothermal dispatch optimization software. The optimization software provides the monthly OMC as the Lagrange coefficient of the load balance constraint. The objective is to minimize the production costs considering the operation of the hydro plant reservoirs and thermal generators. The main input variables of this software are: system demand, fuel prices, natural inflow energy, power generator availabilities, hydro reservoir storage and generation expansion plans. For the purpose of this work we consider only the demand growth and natural inflow energy as uncertainties that will define the electricity prices trends. The other inputs of this software are considered with their own values established by EPE. We analyze the historical data available for the monthly electricity prices since 2003 from [12] in order to define average prices for electricity.

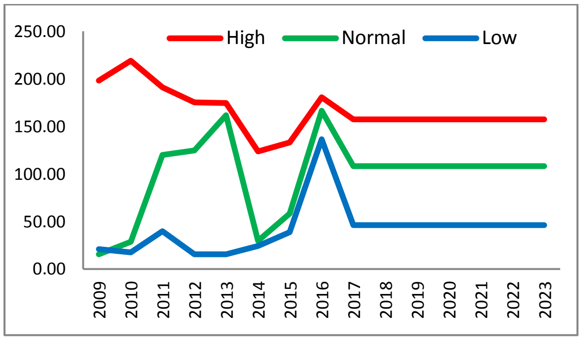


Figure 6 – Simulated Electricity Prices for the Investment Analysis

It was constructed tree possible cases, using the data available from the Brazilian studies for system expansion, to determine three 10 years ahead future scenarios for the electricity prices (high, normal and low). These cases were simulated using the hydrothermal dispatch optimization software to obtain the monthly OMC for electricity for a 10 years horizon. Because the investment period considered in this work is 15 years, for the last five years the prices were set to be equal the average of the previous 5 years.

Table 5– Historical Average Electricity Prices Since 2003

	Prob.	Price [R$/MWh]
High	0.25	102.79
Normal	0.50	52.08
Low	0.25	18.75

E. Electricity Distribution Tariffs

The distribution system usage tariffs (TUSD) are used to collect the revenue defined by the Brazilian electricity regulatory agency ANEEL. The TUSD aims to provide the appropriate economic signal for the rational utilization of the distribution system of any distribution company in the Brazilian interconnected system. Among the several TUSD applications, it is important to mention that this tariff is responsible for charging the captive consumers of the company, and also the free consumers that buy electricity directly from the market and just use the distribution network to receive at their connection point. The tariffs have different values for each customer type (depending on the voltage level that the customer is connected) and also are not the same for captive and free consumers (in Brazil, consumers with installed load higher than 3 [MW] have the option to become a free consumer, the free consumer can buy its energy from any provider of the interconnected system.). For the captive consumer TUSD has two main components one relative to the system use and the other relative to the energy that the company provides (every year in order to satisfy its load the distribution company has to buy energy on the electricity auctions or in the spot market to supply its demand, so the energy tariffs are computed by the mix of all the energy that the company bought weighted by their respective prices). For the free consumer, because they buy their own electricity, the TUSD has the first component and one additional term that represents others charges of the interconnected power system.

In this work, the customer that is planning the investment in thermal generation is a captive consumer connected at 138 [kV] with 300 [MW] of demand. It is also possible that, instead of investing in generation or staying as a regular customer, the company chooses to become a free consumer starting to buy its electricity in the spot market. The TUSD has immediate effect on the investment cash flows of these alternatives.

Table 6 presents the different TUSD values for each customer type during the 2005 - 2008 period. It is important to notice that there are different types of tariffs, for example the captive consumer at peak hours is charged a different demand tariff for peak and off-peak hours. For the energy tariffs besides peak and off-peak it is also differentiated by year season, represented by wet and dry seasons.

Because of the many different types of tariffs and the small number of years of data for tariffs, we consider the distribution tariffs with an average growth with probability of occurrence equal to one.

Table 6 – Electricity Distribution Tariffs for the Captive and Free Consumers in 138 [kV]

TUSD		Captive Consumers	2005	2006	2007	2008	05 - 06	06 - 07	07 - 08	average
Demand (R$/kW)		**Peak**	19.41	20.73	19.52	20.72	0.07	-0.06	0.06	0.02
		Off Peak	3.32	3.25	2.87	3.15	-0.02	-0.12	0.10	-0.01
Energy (R$/MWh)	**Peak**	**Season - Dry**	181.27	236.07	212.27	212.84	0.30	-0.10	0.00	0.07
		Season - Wet	163.54	213.92	191.99	192.92	0.31	-0.10	0.00	0.07
	Off Peak	**Season - Dry**	110.26	148.51	132.37	134.39	0.35	-0.11	0.02	0.08
		Season - Wet	99.19	135.42	120.6	122.83	0.37	-0.11	0.02	0.09

TUSD (R$/kW)	Free Consumers	2005	2006	2007	2008	05 - 06	06 - 07	07 - 08	average
Demand	**Peak**	18.75	18.33	17.73	19.05	-0.02	-0.03	0.07	0.01
	Off Peak	2.52	2.75	2.61	3.02	0.09	-0.05	0.16	0.07
Interconnected System Charges	**Peak**	19.93	29.3	19.93	21.41	0.47	-0.32	0.07	0.07
	Off Peak	19.93	29.3	19.93	21.41	0.47	-0.32	0.07	0.07

The tariff growth is also different for each consumer type. Table 6 presents also the tariffs growth rate for each period, and the average values that used as the tariff growths for each component. During the last five years of the investment period TUSD is kept constant at the same value of the 10th year. This assumption was considered to keep consistency with the previous adopted assumption for the future electricity prices.

F. *Modeling Uncertainty Relevance*

System demand growth and natural inflow energy at the reservoirs are mutually irrelevant uncertainties but the electricity prices depend on both of them. Because of the lack of data for the annual electricity prices, in the dependence analysis it is considered monthly data from May of 2003 to January of 2009. There are a total of 71 months, in order to calculate the conditional probabilities it was considered the prices, the demand growth and the natural inflow energy distributed according to a normal distribution with mean and standard deviation calculated from the monthly data. To compute, for example, $\{E^H|D^H I^H\&\}$ that is the probability that the prices will be high given that the demand was high and the natural inflow energy was high and the state of information, it is calculated the number of months where the natural inflow energy is high given that the demand was high too, and then it is calculated the number of months where the electricity prices are high given demand and natural inflow energy high. Then:

$$\{E^H|D^H I^H\&\} = \frac{\#months(price\ high/demand\ and\ inflow\ high)}{\#months(demand\ high\ and\ inflow\ high)}$$

The same idea is used in order to calculate the other conditional probabilities. Table 7 presents the conditional probabilities for the electricity prices given the demand and natural inflow energy.

Table 7 – Conditional Probabilities based on Monthly Data

		Electricity Prices		
Demand	**Inflow**	**High**	**Med**	**Low**
High	**High**	0,14	0,36	0,50
	Normal	0,13	0,50	0,38
	Low	0,40	0,30	0,30
Med	**High**	0,00	0,80	0,20
	Normal	0,18	0,68	0,14
	Low	0,25	0,42	0,33

Table 8 – Adjusted Conditional Probabilities

		Electricity Prices		
Demand	**Inflow**	**High**	**Med**	**Low**
High	**Wet**	0,10	0,35	0,55
	Normal	0,15	0,55	0,30
	Dry	0,60	0,35	0,05
Med	**Wet**	0,05	0,30	0,65
	Normal	0,12	0,50	0,38
	Dry	0,40	0,40	0,20

Although the monthly probabilities give some insight about the relationship among prices, demand and natural inflow energy they do not represent accurately what will happen for the whole investment period. It is possible to check in Table 7 that $\{E^H|D^M I^H\&\} = 0$ what is not true. There is some possibility for the electricity prices to be high even when the demand growth is medium and there are high inflows. So the probabilities will be adjusted a little to better represent the reality for the 15 years period. Table 8 presents the new values for the conditional probabilities.

IV. INVESTMENT DECISION ANALYSIS

The investment decision in new generation or change in the electricity supplier is often driven by price signals from the market. There are financial risks related to such decisions that complicate the problem. In this section it is presented a summary of the costs related to the alternatives of the problem.

A. *Company Stays as Captive Consumer*

In this alternative the company continues to buy electricity from the local distribution company. The investor does not have to allocate money to construct anything because the company already has connection to the distribution network. Money will be necessary to pay for:

- Use of the distribution system (load installed);
- Electricity consumed (contract with the local distribution company);
- Taxes (25% ICMS and 6.25% PIS/COFINS).

The demand, as mentioned before, is 300 [MW]. In order to compute the costs it is necessary to use the distribution tariffs of Table 6 (the portion related to captive consumer).

For example the amount that this company will have to pay monthly for demand is:

$$300 * 1000 * [20.72 + 3.15] \cong R\$\ 7{,}161{,}875.00$$

B. *Free Consumer Buying Electricity at the Spot Market*

In this alternative the company changes its consumer class to free consumer and starts to buy electricity directly from the spot market. In this assumption the free consumer still have to pay for the use of the distribution system to the local distribution company. Again, the investor does not have to allocate money to construct anything because the company already has connection to the distribution network. Money will be necessary to pay for:

- Use of the distribution system (load installed, note that the tariff values are different from the previous);
- Interconnected System Charges;
- Electricity consumed (purchases in the market);
- Taxes (25% ICMS and 6.25% PIS/COFINS).

For example, in order to compute the money required for the electricity purchases in one year it is necessary to know the number of hours that demand will be required during peak hours and off-peak hours. Assuming that this company operates full time at full capacity during the year, the number of peak hours is 792 (considering peak as a 3 hours period per day) and off peak hours 7968.

Using the average electricity market price of 2008 with value of 58.97 [R\$/MWh] the year cost for electricity purchases is:

$$300 * 8760 * 58.97 \cong R\$\ 154{,}184{,}760.00$$

C. Investment in a Combined Cycle Thermal Generator

In this alternative the company will no longer be supplied by the distribution company as before, it still has the connection but it will use electricity from the distribution company only when the generator is not operating because of a failure or maintenance. The idea is to invest in a thermal generator with combined cycle. For this alternative money is necessary to pay for:

- Use of the distribution system (load installed, note that the tariff values are the same as alternative where the company is a captive consumer from the distribution company);
- Electricity consumed (contract with the local distribution company, in this case the electricity that will be contracted is just the difference between the real demand and the electricity produced by the thermal generator);
- Investment Costs ($ 473,000,000.00);
- Fixed and Random Operational Costs.
- Taxes (25% ICMS and 6.25% PIS/COFINS).

D. Investment in an Open Cycle Thermal Generator

In this alternative the company will no longer be supplied by the distribution company. The company will only use the distribution network when it buys electricity from the market (when the electricity price is less than the electricity production cost of the generator). It is necessary to pay for:

- Use of the distribution system (load installed, TUSD demand referent to free consumers);
- Interconnected System Charges (when using the distribution system, if the generator is operating this cost does not exist);
- Electricity consumed (purchases in the market);
- Investment Costs ($ 234,400,000.00);
- Fixed Operational Costs (employee salaries);
- Random Operational Costs (refers to the use of gas to produce electricity)
- Taxes (25% ICMS and 6.25% PIS/COFINS).

V. RESULTS

It was performed the investment analysis for the different scenarios of electricity prices and gas prices for the 15 years horizon and it was calculated the net present value (NPV) for each alternative. The NPV results are presented in Table 9, the last column on the right presents the NPVs for each alternative in each scenario.

After calculating the NPVs the values were used in the decision tree illustrated before with a total number of branches equal to 57. Because of its size the tree will not be presented here, instead Figure 7 presents the certain equivalent for each alternative. It is possible to notice that the alternative that gives the company the best certain equivalent is the one where the investment is made in an open cycle thermal generator that will just operate during the months where the electricity prices are higher than the operational costs of the thermal generation ($ -2,393.75 millions).

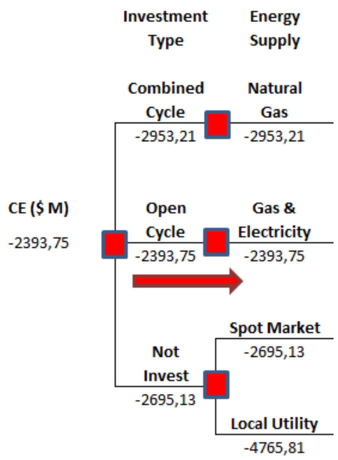


Figure 7 –Certain Equivalent for the Alternatives

Table 9 - NPV Values for Each Alternative Considering Uncertainties

	Gas	Electricity	Tariffs	NPV [$ Millions]
Local Utility			Average	-4,765.81
Spot Market		High		-4,118.32
		Normal		-2,758.56
		Low		-1,845.17
Combined Cycle	High			-3,122.80
	Medium			-2,783.62
Open Cycle	High	High		-3,015.72
		Normal		-2,638.61
		Low		-2,096.88
	Medium	High		-2,542.12
		Normal		-2,329.91
		Low		-2,057.03

Figure 8 presents a plot of the certain equivalent for the best alternative against the cumulative probability. In this graph it is possible to check the probability of the certain equivalent be less than or equal to certain NPV value. For example, there is a probability of 10% that the certain equivalent will be between -3,015.72 [$ Millions] and -2,638.61 [$ Millions]. Each step of the graph represents a different NPV for the Open Cycle alternative from Table 9.

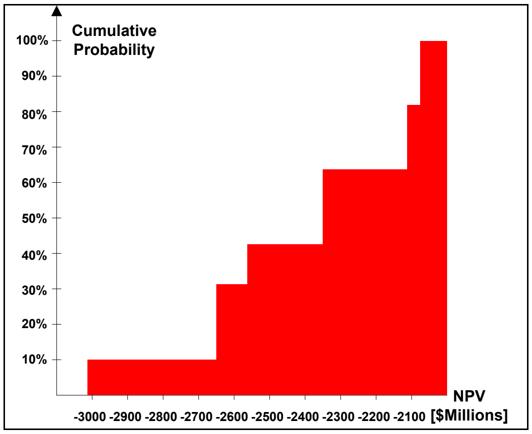


Figure 8 - Certain Equivalent X Cum. Probability for Best Alternative

VI. CONCLUSION

Real investment decisions are complex processes which are often complicated by the large amount of information together with the high level of risk involved. The analysis conducted in this paper presented some of the consequences of the use of logical and consistent techniques of decision analysis to help the decision maker to choose among possible alternatives of electricity supply. To improve the presented model more uncertainties can be modeled, as an example it is possible to mention: TUSD, reliability of the generators, other fuel costs (different costs of the other system thermal generators, imply in different electricity prices). It is also possible to add other alternatives to the problem which implies on changes in the decision tree.

VII. ACKNOWLEDGMENT

The authors would like to thank the support of CAPES.

VIII. REFERENCES

[1] Shams N. Siddiqi, “Project Valuation and Power Portfolio Management in a Competitive Market”, IEEE Transactions on Power Systems, Vol. 15, No. 01. February 2000.

[2] S.G. Jensen, P. Meibom, “Investments in liberalized power markets Gas turbine investment opportunities in the Nordic power system” Science Direct, Electrical Power & Energy Sys., June 2007.

[3] R. A. Howard, “Decision Analysis”, Manuscript in Progress, June 2005.

[4] R. T. Clemen, T. Reilly, “Making Hard Decisions” DUXBURY, December 2004.

[5] G. B. Sheblé, “Decision Analysis Tools for GENCO Dispatchers” IEEE Transactions on Power Systems, Vol. 14, No. 2, May 1999.

[6] R. A. Howard and J.E. Matheson, “Influence Diagrams”, Decision Analysis, Vol. 2, N. 3, pp. 127-143 September 2005.

[7] http://www.ons.org.br/ - Operational History (Histórico da Operação) > Inflow Energy (Energia Natural Afluente).

[8] http://www.nymex.com/ng_fut_psf.aspx. New York Mercantile Exchange.

[9] http://www.aneel.gov.br/. Brazilian Electricity Regulatory Agency.

[10] http://www.ipeadata.gov.br/ipeaweb.dll/ipeadata?Tick=105092125. Macroeconomic Indicators > Eletrobras > Energy Consumption.

[11] http://www.epe.gov.br/ Brazilian Energy Research Institution.

[12] http://www.ccee.org.br/ Brazilian Electric Power Commercialization Chamber.

IX. BIOGRAPHIES

Anderson R. de Queiroz received his B.Sc. and M.Sc. degrees in Electrical Engineering both from Federal University at Itajubá, Itajubá, Brazil, in 2005 and 2007, respectively. In July of 2007 he was awarded with a Capes/Fulbright Scholarship and he was accepted as a PhD student in Operations Research and Industrial Engineering at the Mechanical Engineering Department at the University of Texas at Austin. His areas of interest include electricity markets, including energy price, transmission and distribution regulation, and operations research where his focus is on simulation and optimization techniques as linear, integer, stochastic and large scale programming.

Luana M. M. Lima received her B.Sc. and M.Sc. degrees in Electrical Engineering both from Federal University at Itajubá, Itajubá, Brazil, in 2005 and 2007, respectively. In July of 2007 she was awarded with a Capes/Fulbright Scholarship and she was accepted as a PhD student in Operations Research and Industrial Engineering at the Mechanical Engineering Department at the University of Texas at Austin. Her areas of interest include electricity markets, including transmission and distribution tariffs and regulation, and operations research where her focus is on simulation and optimization techniques as linear, integer and stochastic.

José W. M. Lima received the B.Sc. degree from the Military Institute of Engineering, Rio de Janeiro, Brazil, in 1979, the M.Sc. degree from the Federal University at Itajubá, Brazil, in 1991, and the D.Sc. degrees from the Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, in 1994. He is now as a full professor at Federal University at Itajubá.