Integrated Gas-Electricity Adequacy Planning in Brazil: technical and economical aspects

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***Abstract*--this paper discusses how the integration between the natural gas and electricity markets has been occurring in Brazil, analyzing the challenges and describing the solutions that are being implemented to the insertion of gas-fired generation in a country almost entirely based on hydropower.**

***Index Terms*-- Natural gas industry, Hydroelectric-thermal power generation.**

I. INTRODUCTION

BRAZIL is the largest energy market in South America, accounting for 40% of the continent's energy consumption [1]. On the generation side, the country is hydro-dominated, where 85% of the installed capacity and more than 90% of the energy production comes from hydropower.

The country has a modest natural gas production, most of which is associated with oil extract. Since 1999, imported gas has been flowing into the country through pipelines from Bolivia and Argentina and in 2003 a discovery of a large offshore natural gas field (Santos field) capable of more than doubling the country's reserves, has been announced.

Despite its gas reserves and imports, Brazil has a relatively undeveloped gas market. Historically, natural gas has contributed very little to Brazil's energy mix. The country has little or no need for space heating; hence there is little market potential for gas in the residential and commercial sectors, and local distribution networks are not very developed. As a result, gas consumption in the country is concentrated in energy-intensive industries (chemical and petrochemical) that are replacing oil derivatives and electricity use by natural gas. Although the natural gas demand for industrial/vehicle use has been growing at relative high rates – because of the increase in oil prices and government incentives – this demand growth solely is unlikely to justify large investments in gas production and transportation.

This means that, at the moment, the power sector is the largest potential market for natural gas, which can provide the necessary anchor demand to spur production and infrastructure investments on the natural gas side.

However, this immediate dependence on the gas consumption from power generation creates special challenges for the country:

(a) since the Brazilian power sector is hydro-based, the insertion of gas-fired generation is not straightforward due to the direct competition between hydro and thermal resources;

(b) the hydro predominance in the country creates volatility on the dispatch of the gas-fired plants, which ends up creating an undesirable (from the gas-sector point of view) volatility in the natural gas consumption. Since the gas-market is still incipient, gas contracts are typically of long-term with high "take or pay" and "ship or pay" clauses to ensure financing of the production-transportation infrastructure. From the power sector point of view, these clauses are undesirable: due to the uncertainty of dispatch gas-based generators want to negotiate a higher flexibility (but always having the "guarantee" of the gas availability whenever the dispatch is needed). This "dilemma", demands the development of more flexible supply-demand options;

(c) the power system operation planning is independent from the operation planning of the gas sector: only the electricity network is represented in the current models used for hydro-scheduling, i.e., the gas production and transportation constraints are not represented. This approach assumes no constraints in the gas sector, which is not true for a country whose gas transportation infrastructure is still developing and where heavy gas network constraints exist in areas where gas-fired thermal plants are located. Thus, an integrated operations planning of the electricity and gas sector in the country is needed and the gas sector constraints must be incorporated in the traditional production-costing models used to schedule the power system;

(d) finally the ongoing developments (and government incentives) on the gas sector and new large discoveries of natural gas fields (Santos basin) poses natural gas as a real supply expansion option for the power sector. This introduces new challenges for power system planning, since supply options now comprise decisions on building hydro plants (with heavy investments, including connection to the transmission network, but having lower operating costs) and thermal plants (less investment, higher operating costs) and now with investment decisions on gas infrastructure. Since some parameters for decision (such as gas prices) depend on the results of decisions on

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both sectors, there is now demand for an integrated operation planning and adequacy planning of the electrical and natural gas resources.

The objective of this presentation is to discuss and assess the above issues in Brazil, under a technical and economical point of view.

The remainder of this extended summary discusses with a little more detail the above issues (that are still under development in the country) and is organized as follows: section II presents an overview of the power and the gas sector in the country and sections III – VI details the main challenges described above. Section VII draws some conclusions.

II. Overview of the Brazilian Power and Gas Sectors

A. Power Sector

The Brazilian interconnected system[1] had, in 2004, a total installed capacity of about 88 GW. The system is hydro-dominated[2], with 110 hydro plants larger than 30 MW distributed in 12 main river systems. Some plants have large reservoirs, capable of multi-year regulation. Thermal generation (28 plants) includes nuclear, natural gas, coal and diesel plants.

The area supplied by the system is served by 75 thousand km of meshed EHV transmission network, called Basic Grid, with voltages ranging from 230 kV to 765 kV AC, plus two 600 kV DC links connecting the binational Itaipu power plant to the Basic grid. The main direct international interconnections are the back-to-back links with Argentina, with a maximum flow of 2,200 MW. Fig. 1 presents an overview of the Brazilian transmission system [2].

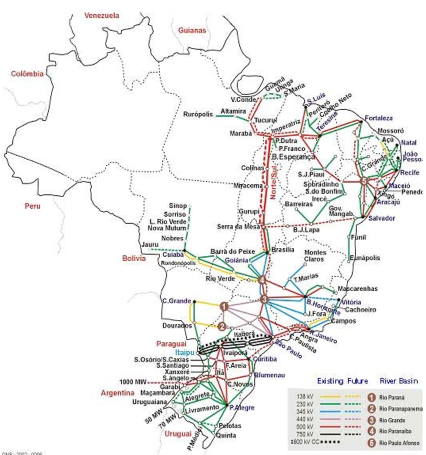


Fig 1. Brazilian Transmission System [3]

1) G, T and D sectors

In December 2003 there were 64 distribution utilities (Discos). Sector reform brought about the privatization of most distribution companies and of transmission expansion, so that private Discos now serve 85% of total captive load. Political opposition interrupted the privatization of generation companies (Gencos); as a result, only 15% of total generation capacity is controlled by private investors. The transmission sector is composed of 26 transmission companies (Transcos), 13 of which were created after the reform.

2) Power Sector Reform

A power sector reform with emphasis on privatization and competition was initiated in Brazil in 1996. The reform process was disrupted in mid-implementation by a severe energy rationing that took place between June 2001 and February 2002 [4]. After some regulatory changes that occurred after the rationing, a new government took power in the country in 2003 and launched, in 2004, a new model for the power sector. The main features were: (a) every load must be 100% covered by bilateral financial contracts at all times. All contracts must be "backed" by firm energy certificates; (b) Discos must contract their energy through public PPA auctions, with standardized rules and contracts.

B. The Natural Gas Sector

1) Resources

Brazil has modest proven gas reserves (estimated as 220 billion cubic meters (bcm)), accounting for 3% of South America's total proven reserves [1]. Despite this low level of reserves, Brazil is thought to have substantial potential for new gas discoveries. In particular, a discovery of a large offshore natural gas field (Santos basin) has just been announced. Even though this field requires very deep sea drilling, its reserves are estimated at 420 bcm, which can more than double current reserve levels.

National gross production levels in 2003 were in the range of 42 MMm3/day. Production in the recent discovered Santos field are expected to increase this figure in about 20-25 MMm3/day when it starts operating (current forecasts points for 2010).

Because many of the natural gas reserves are associated with oil in offshore fields, a large portion of natural gas production has traditionally been reinjected (22% of gross production) or flared (19% of gross production).

2) Natural Gas Imports

Since 1999 Brazil has been importing gas from Bolivia through the "Gasbol" pipeline. It is the largest capacity pipeline in Latin America, with 30 MMm3/day, built by private investors. Imports in 2004 are in the range of 21 MMm3/day. Since 2000, Brazil has also been importing gas from Argentina to supply a 600 MW thermal plant on the Brazilian side of the border between the countries.

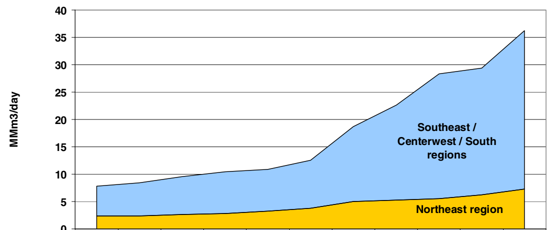
3) Natural Gas Demand (non-power use)

Without considering the gas for power use, the natural gas consumption levels in 2003 were in the range of 30 MMm3/day. Most of the gas is used in the industrial sector. Because there is virtually no need for space heating in Brazil, gas use for the residential and commercial sectors remain limited to cooking and water heating, making it harder to develop urban gas distribution networks. The use of gas for transport has been increasing, mostly encouraged by the competitive price of the compressed natural gas (about half

[1] The interconnected system accounts for 98% of total demand
[2] Hydro generation accounts for 85% of the installed capacity.

the price of gasoline when driving the same distance).

As one can see by Fig.2, there was a strong growth outlook over the last years, where industrial and transportation sectors have been the main growth areas (motivated by government policy and increase in oil prices).



	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004 until Aug
SE/CW/S	5.4	6.0	6.9	7.6	7.6	8.8	13.7	17.4	22.8	23.1	29.0
NE	2.4	2.4	2.6	2.8	3.2	3.8	5.0	5.3	5.6	6.2	7.3
Total	7.8	8.4	9.6	10.4	10.8	12.6	18.7	22.7	28.3	29.4	36.3
yearly growth		7.8%	14.1%	9.2%	3.8%	16.1%	48.6%	21.2%	24.9%	3.8%	23.4%

Fig 2. Historical consumption of natural gas (non-power use)

4) Natural Gas Demand in power generation

Since 1990's Brazil has been calling for a larger share of thermal capacity, fueled mainly by natural gas, in order to reduce dependence on hydroelectricity and to boost natural gas demand. However, little happened until 1999-2000, where under the imminence of the energy supply crisis, a program for incentive for thermal generation was launched in the country. This program resulted in the construction of about 5000 MW of gas-fired plants, that *could*[3] correspond to maximum gas consumption in the range of 29 MMm3/day in 2003.

5) Natural Gas Transportation Network

Because Brazil is a country the size of a continent, several distinct gas markets can be expected to develop, each characterized by its own supply sources, demand centres and transportation networks. Today one can distinguish three natural gas markets in Brazil: the largest and most developed system by far comprises the South, Southeast and Center-West regions. Coastal cities from the Northeast form the country's second natural gas system. The third system, with abundant reserves still to be developed, is the Amazon region, located North in the country.

The pipeline network is not as developed as the electricity network and thus these three markets are still physically separated. There is a planned integration between the Northeast and the Southeast. Figure 3 shows the main (cross-regions) natural gas transportation network. Comparing Fig. 1 and 3, one can see that the gas network is still developing its infrastructure when compared to the existing electricity network.

[3] This is because, as it will be seen later, these plants are not base-loaded.

Fig 3. Main Natural Gas Transportation network

6) Natural Gas Regulation

Brazil does not yet have a clear policy or guidelines concerning the gas sector. The law that liberalized the petroleum sector in 1997 treats gas as sub-product of oil. It fails to adequately address the particularities of the gas industry. The Brazilian government is currently (2004) starting to work on a new law for the gas sector, that will address, among others, the role of the private sector;the role of public companies; the structure and market rules for the electricity and gas sector; the role of gas in electricity generation, etc.

III. Hydro x Thermal Generation: Competition or Complementarity?

The absolute predominance of hydropower in Brazil and the fact that Brazil still has hydropower as a supply expansion option, introduces a direct *competition* between thermal and hydropower generation, which naturally creates difficulties and for the development of gas-fired generation.

Hydropower costs have "higher" fixed investment costs (negligible direct operation expenses) and thermal costs comprise "lower" fixed costs (investment) plus "higher" operating expenses (fuel). Currently, the final energy price of a hydro project (~36 US$/MWh) is more competitive than the price of a thermal project (~42 US$/MWh) and a simplistic analysis could say that hydropower is always the most economic supply option.

However, as it will be seen in this presentation, the answer is not straightforward because the reliability of supply is different for both sources. In order to know the real final cost to the consumer, it is necessary to add to the hydro-costs the expected value of the "interruption cost", which is the cost assumed by the society when the hydro project fails to meet the load, due to an adverse hydrological situation.

As it will be seen in this presentation, these energy resources *are not competitors,* but *complementary* and their complementarity should be taken into account in an integrated electricity-gas adequacy planning.

IV. The Challenge of The Flexibility

A. The volatility of the Natural Gas Consumption

In hydro-dominated systems thermal generation is generally useful as back-up for periods of low rainfall. This means that the existing thermal plants may be idle in periods of high (or average) precipitation, which happens most of time. This pattern is illustrated in Fig. 4, which shows the observed short-run marginal costs (proxies for market prices) in the Brazilian South-Southeast system from January 1993 to August 1997.

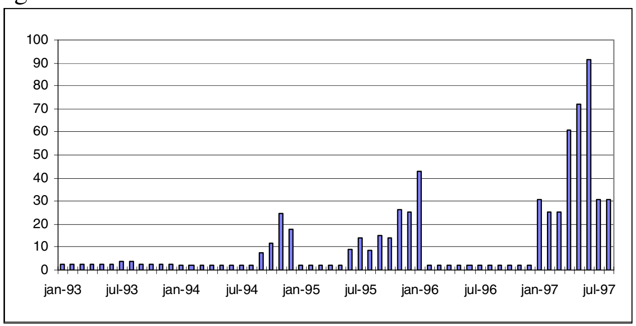


Fig. 4 - Historical Monthly Short-Run Marginal Costs (US$/MWh)

We see in the figure that the system marginal cost was close to zero in 36 out of the 56 months. We also see that the longest low-price period lasted for almost two years (21 months). Consequently, there was no thermal dispatch during these periods.

The reason for this behavior is that predominantly hydro systems are designed to ensure load supply under adverse hydrological conditions, which occur very infrequently. Hence, most of the time there are temporary energy surpluses, which result in very low marginal costs and in no need of thermal dispatch. In turn, if a very dry period occurs, spot prices may increase sharply, and even reach the system rationing cost. An occurrence of a dry period usually calls for the dispatch of all thermal plants "at the same time", which in turn calls for a robust pipeline network capable of meeting this "volatile" gas demand.

This situation holds true even when the probability of rationing is high. Fig. 5 shows the evolution of marginal cost and stored energy for the largest sub-market in Brazil before, during and after the 2001-2002 crisis. After the rationing was over (Feb.2002), prices immediately dropped to values close to 6 US$/MWh and have been very low ever since, keeping almost all thermal plants shut down.

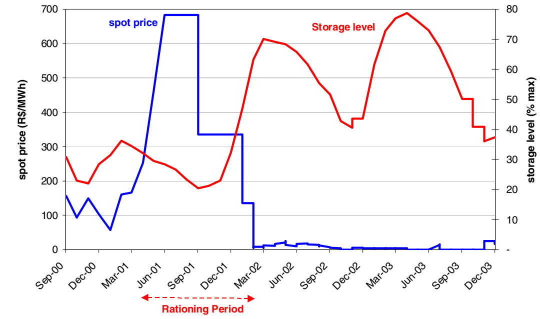


Fig.5 – Recent short-run marginal costs (R$/MWh) and storage levels

Finally, Fig. 6 illustrates the spot price behavior from a different angle: it shows a typical spot price distribution for the Brazilian system[4].

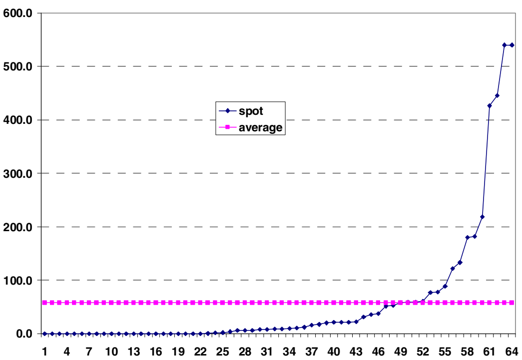


Fig.6 – Spot Price Distribution (US$/MWh) – January 2005

We see in the figure that the spot price distribution is very skewed: fifty-one out of the 66 simulated hydro scenarios have prices lower than the average, which imply in low thermal dispatch. Of these, 26 scenarios have zero spot price, neglecting any dispatch from thermal plants. In contrast, there are a few scenarios where the spot price exceeds US$300/MWh, where all thermal plants must be dispatched altogether.

One of the consequences of this "feast or famine" price characteristic is that it creates a very "volatile" gas demand from power generation. Since it is not economical to build production and transportation infrastructure to be idle most of time, this "irregular" consumption pattern from power generation makes it difficult for the gas-sector to build the necessary infrastructure without mandatory "take or pay" and "ship or pay" clauses on the gas contracts between gas producers and thermal plant owners.

The "take or pay" contracts are then used to stable, from the gas producer point of view, the irregular cash flow that would arise from the market operation of the power plants. For example, these agreements form the basis of the economic feasibility of the Bolivia-Brazil pipeline. On the other hand, these clauses decrease the competitiveness of the thermal projects, since thermal owners are paying fixed for a gas volume independently of its use.

In overall, the relatively young stage of development of the

[4] The figure presents the spot prices for the 66 hydrological scenarios ranked from lowest to highest spot price; which gives an idea of the dispersion around the average.

gas industry in Brazil implies less flexible gas supply contracts to power generators and also means that there is no or little opportunity for power plants to sell their contracted gas on the secondary market[5], because the other markets for gas are not very developed.[6]

The discovery of the large natural gas field at Santos and the management of the existing reserves poses new challenges to the country, since a "market" for these reserves must be found in order to make feasible their development. This rationale also applies for any effort to expand gas imports from Bolivia and Argentina. Since it is not economical to build a pipeline infrastructure underused most of the time, it becomes necessary to develop flexible supply and demand options, such as: (i) secondary gas market; (ii) flexible gas/electricity consumption; (iii) flexible production (e.g. LNG exports) and (iv) storage options, such as depleted oil/gas fields and/or hydro reservoir capacity (gas stored as water in hydro plants reservoirs).

V. Integrated Electricity-Gas Operations Planning

In Brazil the system dispatch is carried out in a centralized way by the system operator, who acts as if all plants belonged to the same owner. Hydro plants are dispatched based on their expected opportunity costs ("water values"), which are computed by a multi-stage stochastic optimization hydrothermal scheduling model that takes into account a detailed representation of hydro plant operation and inflow uncertainties (see [5,6]).

Traditional hydro scheduling models used for system dispatch take into account a detailed representation of the power system (including electricity network), but do not take into account the representation of the constraints of the infrastructure (production and transportation) of the natural gas sector. In other words, there is a decoupling between the modeling details of the electrical sector and the gas sector in traditional hydro-scheduling models.

This decoupling may imply in dispatch results for the power sector that can be dangerously "optimistic", since the model may consider thermal dispatches that will turn to be "infeasible" due to gas production or transportation constraints. For example, in January 2004 a shortage of hydropower in the Northeast of Brazil implied in a decision by the System Operator to dispatch the existing gas-fired resources in the region. However, only a third of the gas-fired capacity installed in that region was able to generate due to gas production and transportation constraints, which were not "seen" by the scheduling model.

The consideration of the gas sector (production and transportation constraints) in the operations of the power sector is of great importance and has been focus of recent research by many authors [7]. However, most of these works are focused on thermal systems and little has been done for hydro systems.

Therefore, the objective of this section of the presentation will be to introduce explicitly the availability and transportation constraints from the gas sector in the hydrothermal operations planning model.

VI. Integrated Electricity-Gas Expansion Planning

A. Power system expansion planning

Expansion planning methods and tools have historically been used for decisions regarding the power sector, that is, decisions on the construction of generation and transmission assets. In Brazil, for example, hydro power and combined cycle natural gas are competitive technologies. On the one hand, hydro plants have comparatively higher investment cost and transmission charges; on the other hand, they have very low operation costs. Conversely, combined cycle plants have lower investment and transmission costs, but higher operation costs. In order for a system planner (or a private investor) to evaluate whether a given plant – e.g. a combined cycle – can bring the desired rate of return, it is necessary to carry out a system expansion study, where the least-cost expansion is used as a proxy for the result of competition. Uncertainty on study parameters such as hydrology, investment and operation costs are used in the planning study to represent important factors such as reliability-related costs[7] and hedges against currency and fuel.

When the range of investment options includes international interconnections – Brazil, for example, has 2 privately-constructed DC links with Argentina, 1100 MW each – the planning study becomes more complex, as it has to include the modeling of the neighboring country's expansion. The problem becomes even more complex when international power exchanges involve several countries. In this case, it is necessary to take into account not only the tradeoff between generation and transmission investments, but different regulations in each country concerning supply security and market organization.

Traditional planning tools so far have been modeling the aforementioned issues with greater details. For example, Ref. [8] presents an application of a methodology for multi-regional system expansion planning of generation and interconnections under uncertainty.

B. Integrated Electricity – Gas expansion planning

In the majority of the power-sector planning models, the natural gas sector is modeled as an "exogenous" variable: gas prices are assumed as given (not the result of decisions on the construction of gas infrastructure) and the gas infrastructure itself is not explicitly modeled as "decision variables".

With the development of the natural gas sector and its

[5] Gas-based generators wish to negotiate higher flexibility due to high uncertainty of dispatch in the hydro-dominated system.

[6] Depending on the region, the gas consumption from thermal generation exceeds the gas consumption of the whole region. Furthermore, besides the absence of a secondary market, the current gas contractual conditions for power generation do not allow the use of this gas for other clients.

[7] In contrast with thermal plants, hydro plants are vulnerable to severe droughts and may thus incur heavy penalties if they fail to meet the supply contract conditions.

strong interconnection with the power sector, these planning tools should be adapted to consider, among others:

a) decisions to build new gas pipelines;
b) compute natural gas prices as a result of the overall cost of the gas sector (result of decisions made);
c) feedback of the resulting gas prices of step (b) to the planning decisions of the power sector.

Therefore, the final part of this presentation will present the ongoing developments to integrate the electricity planning tools with the gas sector, aiming at providing an integrate resource adequacy planning among these resources in Brazil.

VII. Conclusions

The development of the natural gas sector in Brazil is heavily linked with the power sector, since power generation tends to be the main anchor for the creation of the needed natural gas consumption. However, the reliance on the power sector poses complex challenges for the integration between both sectors, such as : (i) competition (or complementarity?) between hydro and gas-fired generation resources; (ii) the creation of flexible supply-demand options to avoid heavy take or pay constraints, (iii) the integration of electricity and natural gas sectors both in terms of operations and adequacy planning.

VIII. Acknowledgment

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X. Biographies

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