IEEE POWER ENGINEERING SOCIETY
ENERGY DEVELOPMENT AND POWER GENERATION COMMITTEE

PANEL SESSION: INTEGRATED NATURAL GAS-ELECTRICITY RESOURCE ADEQUACY PLANNING IN LATIN AMERICA

IEEE 2005 General Meeting, San Francisco, 12-16 June 2005

Chairs: Luiz Augusto Barroso, Mercados de Energia/PSRI, Rio de Janeiro, Brazil,
E-mail: luiz@mercados.com.br
Tom Hammons, University of Glasgow, Scotland, UK.
E-mail:T.Hammons@ieee.org
Hugh Rudnick, Pontificia Universidad Catolica de Chile, Santiago, Chile,
E-mail: h.rudnick@ieee.org

Track 2: Securing New Sources of Energy

INTRODUCTION

Latin America has emerged in the recent years as one of the most dynamic regions for natural gas and electricity. The continent boasts abundant natural gas reserves and high-growth energy markets. The need to diversify away from heavy investment hydro power and expensive oil is driving many countries to promote natural gas use, especially for power generation. The economic reforms, that have opened to private investments a number of sector previously reserved to the state, led the region to develop an infrastructure of electricity and natural gas pipelines, both in each country separately as well as cross-border energetic interconnections. These interconnections consist of basically cross-border electricity transmission links, power projects at the border (mainly hydro plants jointly owned by different countries) and cross-border natural gas pipelines.

The countries of the region have a great diversity in size, installed capacity, power demand and transmission/natural gas network characteristics (level of meshing and geographical extension). Because the regional infrastructure is still developing, heavy investments in both generation and transmission investments are required. In those countries where hydropower is an expansion option, it is also necessary to determine the most economic tradeoff between cheaper distant hydro, with higher electricity transmission costs, and more expensive "local" gas-fired thermal generation, with lower electricity network costs plus the cost of the correspondent gas pipeline.

Another important issue in Latin America is the multi-country electricity-gas markets, which are a natural evolution to the existing "official" cross-border interconnections, which were originally established by the countries' governments for sharing reserves and carrying out limited economic interchanges. The energy and gas links were originally built as private initiatives and mainly carried out under a local (not regional) framework and without an integrated planning, thus decoupled from each other.

The recent episodes in the electricity and gas sectors in the Southern Cone, both in terms of crisis (for example, natural gas supply difficulties in Argentina, that directly affected the Chilean, Brazilian and Uruguayan markets) and in terms of new opportunities (such as new natural gas sites and new gas pipelines) have brought up and restored the opportunity to work towards a robust energetic regional integration, introducing natural gas as one important component of the expansion options and calling for an integrated electricity-gas resource planning for the region .

The Panel will address the natural gas-electricity resource adequacy planning in Latin America, with emphasis on the institutional and operational arrangements adopted in each country, the competition between electricity transmission and natural gas pipelines and the success/difficulties observed in handling the recent conflicts in the region that arose from natural gas supply difficulties. The strategic value of electricity-gas integration in the region will also be discussed, focusing on alternatives

that provide energetic back-up for each country, assure a better use of system resources, share of investments and maximize economic benefits for all. Finally, the possibility of using carbon emission credits (to be provided by the related countries) in benefits of reducing financing costs will be also discussed. This issue is particularly important in this region, which has "green and clean" energy and interconnections displacing oil and fossil fuel generation in some of its countries.

PANEL SESSION PRESENTATIONS

1. Power and Natural Gas Integration in the Southern Cone – Past, Present and Future (Paper 05GM0310)
Luis V. Sbértoli, Sigla – Argentina.

2. Growing Interactions between Mexican Gas Markets and Electricity System Planning (Paper 05GM0312)
Gonzalo Arroyo, CFE – Mexico; Marcelino Madrigal, Secretaria de Energía – Mexico

3. Electricity generation and transmission expansion under uncertainty in natural gas supply (Paper: 05GM094)
Hugh Rudnick, PUC-Chile

4. Integrated Gas-Electricity Adequacy Planning in Brazil: technical and economical aspects (Paper 05GM0160)
Luiz Augusto Barroso, Mercados de Energia/PSR, Bruno Flach, Mercados de Energia/PSR, Rafael Kelman, Mercados de Energia/PSR, Silvio Binato, Mercados de Energia/PSR, José M. Bressane, Mercados de Energia/PSR and Mario Pereira, Mercados de Energia/PSR.

5. Natural gas and electricity market issues in Colombia (Paper 05GM0311)
José Manuel Mejía, Estudios Energéticos – Colombia; Alberto Brugman, Estudios Energéticos – Colombia.

6. The Role of Natural Gas as an Instrument for the Energy Integration in Latin America (Paper 05GM0313)
Marco Tavares, Repsol/YPF – Brazil

Power and Natural Gas Integration in the Southern Cone – Past, Present and Future

Luis V. Sbértoli , *SIGLA S.A., Energy Consultants*

Abstract—Power and natural gas integration in the southern cone has begun sveral years ago, and took a very important part in the development of hydro and fuel resources. Regional integration is not just one more option; it is an obligation that must be undertaken in order to reduce social and environmental costs in the region. For this purpose, commitments at the highest level and stable national and international policies are required, in order to promote investment and efficient operation by adequately distributing the roles between the public and private sectors. In this paper a revision is done of key technical, commercial and regulatory issues needed to improve regional markets development in the southern cone of America.

Index Terms—Energy Markets. Energy Resources. Interconnected Power Systems. International Trade. Natural Gas Industry. Planning. Power Industry. Regulation. System Operation.

I.INTRODUCTION

Regional power integration in the Southern Cone of America had its inception before any political and economic partnership projects, and exhibits a wealthy history of shared undertakings and a variety of physical links and exchanges.

In its early stages, a characteristic of the way regional power integration evolved in this region was the development of bi-national undertakings by State agencies: Salto Grande, Itaipú, Yacyretá. This development gave rise to a parallel integration of the very high voltage networks existing in the region and to the implementation of a large exchange capacity, which has not always been properly utilized.

At the same time, a series of smaller interconnections were also implemented. These interconnections provided for border exchanges: Argentina-Uruguay (Río de la Plata Treaty),

Clorinda-Asunción, Uruguaiana-Paso de los Libres, Rivera-Santana, and were often located in areas not connected to the main networks of the respective countries involved.

In the 90's, as a consequence of the growing trend toward the development of a regional block, Power and Natural Gas Integration Protocols were signed within Mercosur, in parallel with market reform measures. At this point, the challenge was to interrelate a supra-national regulatory framework structuring and promoting the development of mainly private investment projects with the prospective integration and liberalization of gas and power trade .

In this context, high capacity works were implemented in the power sector as private undertakings, such as the 2000 MW Itá-Garabí connection. Natural gas connections were also implemented among Argentina, Bolivia, Brazil and Chile. In addition, integrated projects involving gas exports and power generation were also developed (Termoandes/Interandes, CT Uruguaiana).

The regional integration process was ultimately adapted to the primary resource matrix available in each country, with increasing expectations as regards the satisfaction of local demand with foreign supplies. A noteworthy case was that of Chile, which undertook a program involving the change of its power supply on the basis of gas imported from Argentina. A similar situation, but to a lesser extent, arose in Brazil with Bolivian gas.

This scheme was geared toward the full utilization of the existing network capacities and the generation of new links. The coexistence of firm exchanges (based on long-term contracts) and spot exchanges was not conflictive, as the market operated on the basis of capacity surplus..

The full utilization of the internal power and gas network capacities led the systems to a border situation where the interaction between natural gas and power, a characteristic feature of this new stage, took on a dominant role in the rationale of system development.

Towards 2002, when the whole system suffered the shock of the Argentine crisis, the regional system, without exhibiting the features of an open market, already showed the following traits:

- Long term gas operations: exports from Argentina to Chile and Brazil; exports from Bolivia to Brazil.
- Long term power operations: capacity and energy exports from Argentina to Brazil, Termoandes, exports from bi-national entities from Paraguay to

Argentina and Brazil.

- Spot operations: exchanges at bi-national power stations, exports from Brazil to Argentina and Uruguay.

The integration scenario has shown some signs of stagnation in the last couple of years, especially in view of the relative isolation of individual plans and a stronger emphasis on self-sufficiency at the national level.

II. REGULATORY AND COMMERCIAL SITUATION

During the last few years, the pace of reforms has slowed down at international level, and market organization at national level is undergoing active reviews. Without having fully retreated from the systems implemented in the 90's, transition periods are under way both in Argentina and Brazil, with a higher degree of participation by the State in sector management.

This review includes the destination of "free" supplies (freely contracted supplies), which imposes some limits on the deregulation process envisaged in the early stages.

Perhaps the interpretation of the supply crises which occurred in different places and with varying characteristics (Brazil, California) has been especially important in this sense. Such crises, which were contemporary to the reform process, gave rise to doubts as to the true roots of the problems.

However, bearing in mind that these are complex phenomena, there is a linking thread which brings together the various difficulties experienced, which is the role of investment and the capacity, or lack thereof, of the current systems to guarantee the replacement and expansion of the facilities with sufficient anticipation. This aspect, which is a general truth for any utility, was worsened by the relative decline of external investment flows in the Region in the late 90's.

The other area affected by the changes and restrictions appearing in the first years of the century was the integration of the markets at regional level: the regulatory frameworks governing interconnections have proven to be inadequate, despite the many protocols and agreements in force. In a context of strong national debates, protectionist or isolationist schemes imposing restrictions on the compliance with contractual conditions have been retaken. It is as if the contracts freely entered into by private parties lacked a smooth relationship with the guarantee of supply in each country.

An aspect contributing to the integration is the progress made as regards operating regimes and the coordination of load dispatches and network usage, all of which was facilitated by the long working experience with interconnected systems. It is true that competition has taken place with respect to the firm and uninterruptible access to the networks.

The role distribution between the public and private sectors is on hold. Although the high rate of privatizations that characterized the 90's has slowed down, no significant re-nationalizations have taken place. In Argentina, Chile and Brazil this has resulted in a mixed system sporting a wholesale market with significant private participation.

Reviews have focused mainly on the search for more effective regualation and control and on the adjustment of the pricing systems both at the wholesale and retail levels in order to ensure efficient, low-cost procedures which, in turn, make the financing of any required investments feasible..

In this sense, a review is being made of the role of the capacity and energy supply contracts with distributors, traders and large consumers and their relation with the spot pricing systems.

III. SOUTHRN CONE INTEGRATION ISSUES

Regional energy integration is key to development. As we have seen, it is a project dating back quite a few years and in full development. However, at present there is a need to guarantee stable rules of the game and dispute settlement mechanisms based on agreements made at the highest political level.

Today, there is a large number of outstanding issues related to integration:

Political, Institutional and Regulatory Issues

- The future of economic integration and regional policies. The complementary and alternative political and economic integration processes (Mercosur, FTAA, etc.) include and determine infrastructure and services integration projects. Within this supra-sectoral framework, some noteworthy aspects are homogeneous tax treatment and the stabilization of export and import authorization regulations.
- The development rate and implementation of effective and mutually agreed methods for the settlement of supra-sectoral disputes derived from the simultaneous partnership and competition conditions inherent to any project of this type.
- In particular, existing energy integration protocols should be reviewed and new ones implemented. The inadequacy of such instruments came to light only recently (crises of the power and gas contracts between Argentina, Chile, Brazil, Bolivia, etc.). There is a need for higher-hierarchy multinational agreements with a larger degree of flexibility in order

to adapt to particular situations that may affect performance. To align policies and regulations among the various countries is an important step that would encourage spot and long-term exchanges.

- The relevance and scope of potential Regional Regulatory Frameworks and the composition of the bodies to be acknowledged as regulatory authorities should also be discussed.
- In particular, in the operating sphere, progress should be made towards the establishment of operating and quality standards applicable to exchanges, with the aim of enhancing a harmonious interaction between national systems.
- The development regimes for shared undertakings should be reviewed and updated, including possible bi- and multinational construction and operation concessions.
- Another important aspect is to develop a shared vision of the environmental sphere to serve as a framework both for local and international projects and to integrate the region into this decisive worldwide issue.

Market Issues

- It is necessary to foster the stabilization of mechanisms aimed at establishing price benchmarks for exchanges and eliminating circumstantial distortions.
- The tendency to integrate open and competitive markets with long-term contracts and spot exchanges should be maintained, since such markets allow to minimize supply costs in the long-term.
- For this purpose, it is essential to develop effective non-discriminatory treatment mechanisms for demand and local and foreign supply, within the framework of liberalization and regional trade opening.
- At present, capital market conditions are not positive for the sector. This causes delays in expansion projects. An integrated activity could increase fund availability for the various types of works: hydro stations, thermal power stations, power and natural gas transport, etc.
- It is necessary to develop a joint prospective view, since integration requires evaluating project advantages in different contexts, and in the case of exchange projects, it is necessary to enhance the internal power and gas networks in order to maximize the use of interconnection structures. This implies developing projects conceived taken into account the whole region, and to eliminate the bottlenecks that actualy limit their use.
- The progressive deregulation of customers at the local and regional levels has begun and should continue to be an incentive toward competitive and transparent markets, improving end-users supply and the performance of the economic actors both in the local and the international trade.

SUMMARY

Regional integration should not only include but also advance beyond infrastructure connections and individual exchanges. Ideally, free, long-term and spot exchange markets should be created between regional producers and consumers, with due safeguards against crises or emergencies.

Regional integration is not just one more option; it is an obligation that must be undertaken in order to reduce social and environmental costs in the region. For this purpose, commitments at the highest level and stable national and international policies are required, in order to promote investment and efficient operation by adequately distributing the roles between the public and private sectors.

TABLE I
PRESENT POWER AND NATURAL GAS INTERCONNECTION CAPACITY

POWER INTERCONNECTIONS (MW)

TO / FROM	Argentina	Brasil	Chile	Paraguay	Uruguay
Argentina		2000	700	Yacyretá 500	Salto Gde 2750
Brasil	500 (2000)				Rivera 70
Chile	(700)				
Paraguay	Yacyretá 1840 76m (3200)	Itaipú 12600 (14000)			
Uruguay	Salto Gde 2750				

NATURAL GAS INTERCONNECTIONS
Number of links-Mm3/día present use
(Installed Capacity)

TO / FROM	Argentina	Bolivia	Brasil	Chile	Uruguay
Argentina		1 - 4	1 – 2 (10)	7 - 20 (35)	3 - 2 (10)
Bolivia	1 - 4		2 – 19 (33)		

TABLE II

MAIN INTEGRATION ALTERNATIVES

ELECTRIC POWER

Argentina-Chile: Comahue – VIIth Region interconnection
Argentina-Chile: Mendoza- Santiago interconnection
Argentina- Brazil: Yacyretá-Itaipú interconnection
Argentina- Brazil: Enhancement of the Garabí-Itá corridor, complemented by the NOA-NEA line in Argentina.
Argentina-Paraguay: Bi-national projects Añá Cua, Yacyretá level increase, Corpus.
Argentina-Brasil: Bi-national projects Alto Uruguay (Garabí. Roncador)
Uruguay-Brasil (Argentina): Salto Grande-Garabí interconnection

NATURAL GAS

Argentina-Brazil: NEA gas pipeline up to Porto Alegre.
Argentina-Brazil: Uruguaiana-Porto Alegre extension
Uruguay-Brazil: Cruz del Sur gas pipeline extension up to Porto Alegre.
Argentina- Paraguay: Connection of the city of Asunción to the NEA gas pipeline.
Argentina-Bolivia: Refurbishment and possible expansion of the Santa Cruz-Campo Durán gas pipeline.
Bolivia-Brazil: Expansion of the Santa Cruz de la Sierra-Sao Paulo corridor
Argentina-Chile: Expansion of gas pipelines running from Mendoza and Comahue.
Peru-South Cone: Possible gas injection from Camisea.

BIOGRAPHY

Luis V. Sbértoli (1949) Electrical Engineer (1974) School of Engineering University of Buenos Aires.
For over twenty years co directed and managed technical projects undertaken by SIGLA, an Argentine Consulting firm specialized in the energy sector, with particular stress in new business and project evaluation both in the public and private fields. Appointed for several public duties in Argentina, performing official functions in 1998-1999 as Under Secretary of Energy and in 1989 1991 period as National Director of Energy Sector Planning

Presently acts as Partner and CEO of SIGLA, monitoring foreign relations and contract matters on the firm's relations with clients and other joint venture partners.

Growing Interactions between Mexican Gas Markets and Electricity System Planning

Gonzalo Arroyo, *Member IEEE*, Marcelino Madrigal *Member IEEE*

***Abstract*— The Mexican electricity system is still highly planned and operated as a traditional vertically integrated company where resource adequacy in electricity is centrally planned with traditional minimum cost models. However, the growing interactions among competing solutions in the gas sector, which is open to competition, is increasingly influencing traditional expansion models in electricity. The paper will describe particular scenarios in whish gas-transport and electricity-transmission competing solutions need to be considered for the sting of new plants. The paper will also describe how the liquefied natural gas market in Mexico has had unforeseen impacts in traditional electricity expansion models which now need be considered some how by electricity planners. This growing interaction in between gas market and a mostly vertically integrated electricity system, call for integral tools in resource planning which represent a interesting opportunity for the research community.**

Index Terms—**Electric power system planning, gas markets, liquefied natural gas and integrated resource planning.**

I. Paper Summary

The Mexican gas and electricity sectors followed a non synchronized agenda of reforms. Some of the reforms in the Gas sector have been uncompleted and the more profound reforms in the electricity sector have remained idle or without consensus for the last five years. However, the interactions among the two systems, one –the gas sector– with a considerable degree of openness and the other, basically vertically integrated, have not avoided their growing interactions due to new technological and cost development in the gas markets that have direct impacts in electricity systems resource planning. The increasing interactions among the two systems arise important questions among them the need for new planning tools that represent important opportunities for the research community.

The paper will shortly describe the regulatory evolution of the Mexican gas and electricity sector and will give a picture of the current state of the two sectors. Then the paper will describe particular scenarios in which competing solutions of gas-transport and electricity transmission have had an effect on traditional electricity system expansion planning.

Of increasing importance for Mexican reliable and cost effective supply of gas to the electricity systems are the Liquefied Natural Gas Markets (LNG) which nowadays represent a clear alternative to continental gas supply to our electricity systems. The dynamics of LNG markets have also had and effect on traditional electricity system planning which call upon attention that more complex tolls for system planning may be required. The paper will describe how traditional electricity system expansion planning has been used to consider such fuel supply alternatives.

The paper concludes with some observations on the general regulatory framework of the Mexican gas and electricity systems which observer interesting opportunities due to the decoupled nature that resulted from uncompleted reform agenda. Also the presentation will describe some guidelines of desirable characteristics of new tools that can help planning a vertical electricity system with increased interactions with a more complex gas market such as the situation that we observe in Mexico.

II. Gas supply demand for electricity production

Electricity expansion planning in Mexico indicate that less-cost expansion planning of the system will continue to rely in combined cycle plants for the next ten years (Figure 1-2) as id has done in the lat ten (Figure 3) [3-4]. The share of gas as fuel for electricity supply will grow from 27% to 44 % of total electricity production from 2003 to 2013. The increasing extension of the national gas pipeline system and its connection to the US market and the growing world wile Liquefied Natural Gas Market (see figure 4) have resulted in interesting interaction among the traditional planning of an almost vertical integrated electricity utility and a more open and mature market for natural gas.

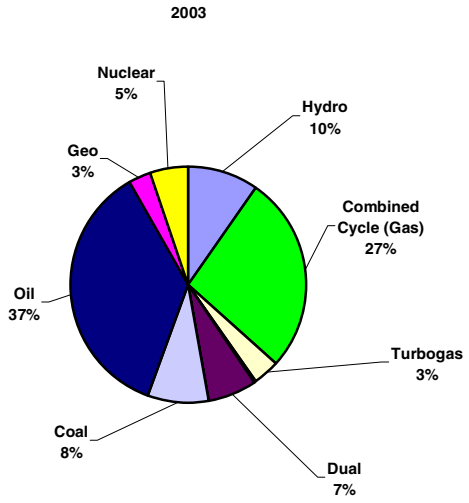


Figure 1. Electricity generation installed capacity shares by fuel type, actual e 2003

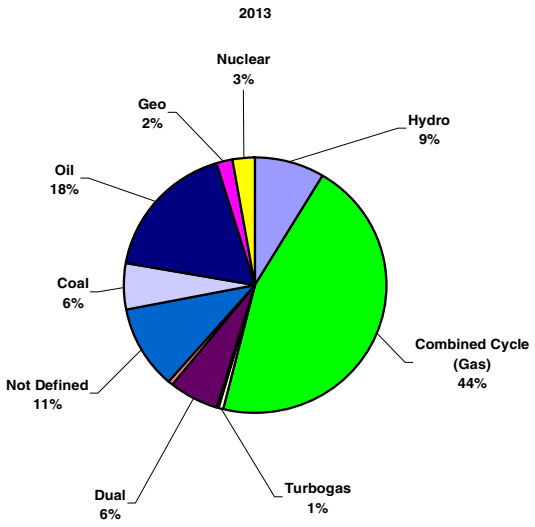


Figure 2. Electricity generation installed capacity shares by fuel type, planned 2013

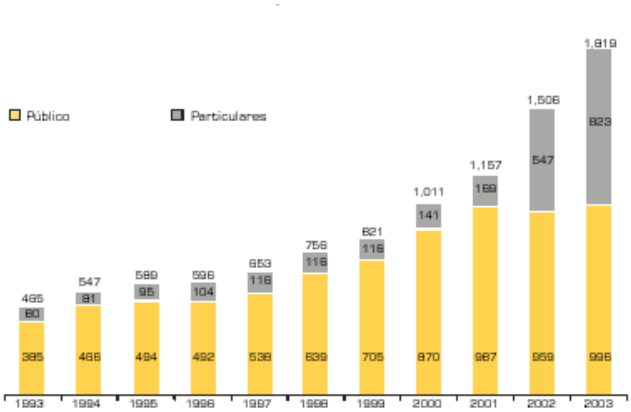


Figure 3. Historical gas consumption for electricity generation (in million cubic feet per day).

III. Gas/Electricity Network Interactions

An specific project for electricity generation called *Tamazunchale* consisting of a large combined cycle plant of around 1000 MW required to supply the central region of Mexico expected consumption was identified by the classic cost-minimization approach used in Mexican electricity system expansion planning [1-2]. Current models did not captured the fact the territorial sitting of the plant had different alternatives that would require each either: (i) the sitting of the plant beside an existing gas pipeline with the need of a new transmission line to connect the plan or (ii) the sitting of the plant beside and existing transmission line with the need of a new gas pipeline to transport gas supply to the plan. The decision of the sitting was left to the investors (*i.e to the market*) in a bidding process that asked for a 1046 MW combined cycled plant with two different sitting options. The panel presentation will describe how traditional vertical integrated planning interacted with a bidding (market) mechanism that asked for a long term contract of electricity supply with two alternated delivery points resolved the interaction between the Gas/Electricity transport choices for the proyect.

IV. LNG/Electricity Expansion Interactions

The increasing consumption of Gas in Mexico for electricity production along with the lesser than expected national growth of internal production in Gas, indicates that import of gas from the US (Texan or Californian) market trough the national pipeline system will still be an alternative to secure gas supply although not at competitive prices. However, the increasing maturation of the Liquefied Natural Gas Market (LNG) worldwide makes this alternative an even less-cost effective alternative supply of gas y certain considerations are made in the electricity generation expansion plans. This part of the paper will describe how the dynamics of LNG markets cannot easily or directly be incorporated in traditional expansion models and how multiple expansion scenarios are being used in the electricity system expansion models to consider LNG supply for the combined cycle plants. The results will show how possible shifts in electricity system expansion can aggregate demand for gas to a particular level that may make LNG and alternative less-cost alternative to supply gas to electricity plants rather than using pipeline gas from US markets trough the national system.

Figure 4. In construction and expected (circled in yellow) LNG installations in Mexico

V. References

[1]. M. Madriga, F. Aboytes, R. Flores, *"Transmission Management, Pricing and Expansion Planning in Mexico: Current Status*". In Proccedings of IEEE Power Engineering Society Annual Meeting, June 2004, Denver, Colorado USA. ISBN 0-7803-8466-0.

[2]. M. Madrigal, F. Rosenzweig, *"Present and Future Approaches to Ensure Supply Adquacy in th eMexican Electricity Industry,"* Procc. IEEE-PES General Meeting, Toronto Canada, July 2003.

[3]. Secretaria de Energía, Prospectiva del Sector Eléctrico 2004-2003 (In Spanish), México 2004.

[4]. Secretaria de Energía, Prospectiva del Mercado de Gas Natural 2004-2013 (In Spanish), México 2004.

VI. Biographies

Gonzalo Arroyo. Obtained a masters degree in electrical engineering from Instituto Tecnológico y de Estudios Superiores de Monterrey, México. Has been teach on the area of electric power systems at different academic institution in Mexico including Instituto Tecnológico de Morelia and I.P.N. Worked for several years at the Mexican Electricity Company (CFE) where he was general manager of the National Energy Control Center, later he joined the Economic Commission for Latina American an the Caribbean where he was chief of the energy unit. He spent also several years at the Inter American Development Bank as energy specialist dealing with different aspects of energy reforms and investment in the electricity sector in the Latin American Region. Today he is General Manager of the Planning department at CFE, whose responsibility is to perform the nation wide planning of the electricity system.

Marcelino Madrigal. Received a B. Sc, M. Sc and Ph. D from I.T. Morelia México, UANL México and the University of Waterloo, Canada, respectively.. Has been an Associate Professor at Morelia Institute of Technology since 1996 where he leads research on electricity markets design and analysis. He has served as a consultant and instructor in software development and training for the national electricity company in Mexico, where he has implemented the first training program on electricity markets since 2001 for the National Energy Control Center and several other areas of the to main public utilities in Mexico as well as different countries in Central America. He has been director and adjunct general director for research and regulatory development at the Energy Regulatory Commission in Mexico and now serves as General Advisors Coordinator to the Vice ministry of Electricity in Mexico.

Electricity generation and transmission expansion under uncertainty in natural gas supply

Hugh Rudnick, *Fellow, IEEE*

***Abstract*—Natural gas and combined cycle generation plants have become a clean and low cost alternative for electricity generation in Latin America. Abundant natural gas resources in Venezuela, Bolivia, Peru and Argentina have made it attractive for gas networks to develop region wise. Chile chose ten years ago a path of power sector evolution based on Argentinean gas and made heavy investments to achieve it. Transmission line developments withdrew, giving place to international natural gas pipelines that brought the fuel next to the load centers, with combined cycle plants being built and planned around major cities. The global economic Argentinean crisis brought this to a halt, uncertainty in gas supply becoming the every day reality, and insecurity in future generation technologies becoming the common situation in Chile. What fuels will be attractive for future thermal plans, how to plan for transmission expansion when a recent change of law introduced centralized planning, are open questions. The presentation will highlight the process and the challenges that arise.**

***Index Terms*— deregulation, gas supply, transmission planning, gas transport, generation costs.**

I. Introduction

The Chilean power sector, that started a deregulation process back in 1982, has experimented several crisis over its development that have tested the strengths, or weaknesses, of its market model [1,2]. The most recent crisis started when the Argentinean government started facing problems with its gas supply and in April 2004 decided to reduce gas exports to Chile.

Chile is a country with limited energy resources other than its hydro reserves in the Andes mountains. Its own oil only provides less than 10% of the country's needs, while its coal is of poor quality, so that imported coal has to be used for electric generation. Hydroelectric generation has developed using most of the low cost resources in the central part of the country, remaining significant reserves over two thousand kilometers south of the main load. Argentinean gas arose as an attractive abundant cheap alternative and an energy integration protocol was signed in 1995 with the neighboring country. Under that protocol, both governments agree to establish the necessary regulations to allow freedom of trade, export, import and transportation of natural gas. Private investors were strongly behind the process, and invested heavily in several pipelines that crossed the Andes and defined a path that would rely heavily on the efficient combined cycle generation plant technologies. The protocol worked very well and Chile fully relied on Argentina to provide the necessary energy required to sustain its important economic growth. Gas exports grew steadily through several pipelines (Figure 1). The petrochemical industry and the thermoelectric generation became the main users of natural gas (Figure 2). The arrival of this cheap fuel and the efficient generation technologies meant a significant reduction in the electricity prices in the main central interconnected system (Figure 3).

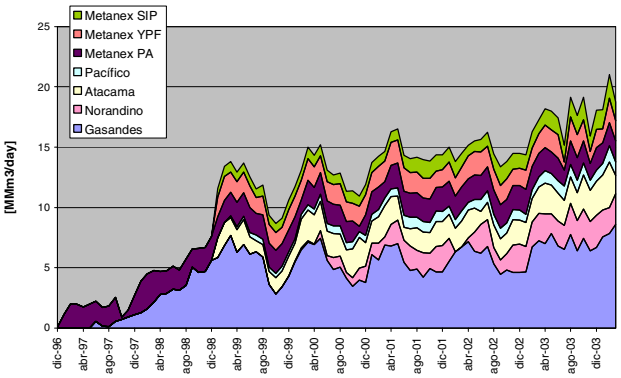


Figure 1.- Natural gas exports from Argentina to Chile [3]

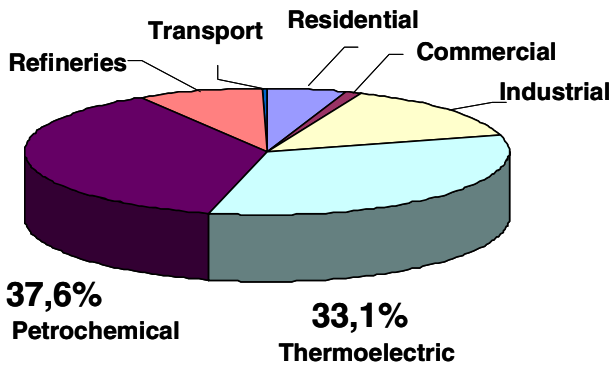


Figure 2.- Natural gas consumption in Chile, 2003 [3]

This work was supported by Fondecyt Project 1020801 and Catholic University of Chile

H. Rudnick is with Universidad Católica de Chile, Casilla 306, Correo 22, Santiago, Chile (e-mail: h.rudnick@ieee.org).

Argentina, among other acute problems in the global crisis it is going through, started facing an energy deficit. Natural gas prices were reduced to one third of their previous levels (due to a severe devaluation of the Argentinean peso) and this led to an escalating demand, not necessarily backed by investment in the exploration of new gas fields neither in new pipelines. Given these conditions, the Argentinean government did not comply with its international agreements and decided to favor national supply, to the detriment of the consumers of Chile and other neighboring countries.

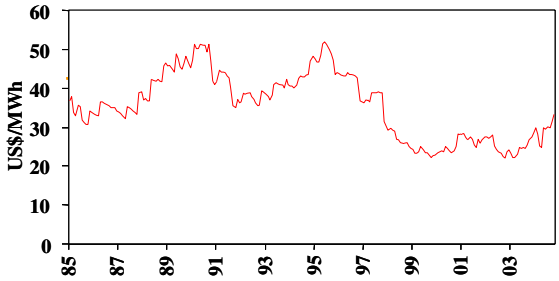


Figure 3. - Evolution of electricity prices in Chile

II. Electricity Sector Evolution

Chile was not prepared for the surfacing conditions. The National Energy Commission, in its indicative plan of April 2004, projected the building of seven combined cycle natural gas plants in the next ten years, all fed by pipelines from Argentina. Mainly expansions of existing electric transmission corridors were included in that plan. Major new hydro plants and interconnections with other systems were postponed until 2010 or later, gas continued to be the major driver of expansion in a market with demand growing around 7% year.

The October 2004 indicative plan introduced radical changes to the government view of energy supply expansion (Table 1). Only one combined cycle plant based on Argentinean gas was considered (Campanario in 2007). The government decided to bet on liquefied natural gas as the alternative and defined a project to build the necessary installations to import it from abroad (Indonesia, Australia and Algeria being supply alternatives).

But in the deregulated privatized Chilean power market, where private capital is the one making investment decisions, there is little space for the government to act, unless changes of laws are introduced. The electricity price scheme relies essentially on market competitive forces, with only part of it, prices for small consumers (under 500 kW), being regulated by the government.

At the end, it is the cost of different generation technologies that will drive development. And the comparison has to be centered on the particular geographic conditions and infrastructure development of the country. Hector Rojas [4] makes a comparison where liquefied natural gas combined cycle plants compete with circulating fluidized-bed boilers fueled by coal (Table 2).

However, the essential question for investors remains, what if gas supply from Argentina returns to normal? If a decision is made, for example, to contract liquefied natural gas, and cheaper natural gas starts re flowing without restrictions from Argentina, who will make the lost? High financial exposures may arise depending on decisions made.

Fecha de entrada Mes	Año	Obras Recomendadas	Potencia
Abril	2006	Hidroeléctrica Pasada :Rehabilitación Coya-Pangal	25 MW
Septiembre	2006	Ampliación Itahue-San Fernando 154 kV Subestación Nueva Temuco 220 kV Seccionamiento Nueva Temuco-Puerto Montt	198 MVA
Marzo	2007	Aumento de capacidad A.Jahuel-Polpaico 220 kV a 500 kV Línea Ancoa-Rodeo-Polpaico 500 kV Final:	390 MVA 1400 MVA
Abril	2007	Central Ciclo Combinado Campanario I	405 MW
Septiembre	2007	Aumento de Capacidad Chena-Alto Jahuel 220 kV	260 MVA
Octubre	2007	Nueva Línea Charrúa-Nueva Temuco 220 kV Central Hidroeléctrica Hornitos	2x500 MVA 55 MW
Enero	2008	Central Hidroeléctrica La Higuera Transformación 154-220 Sistema 154 Kv Itahue-Alto Jahuel	155 MW 2x400 MVA
Abril	2008	Central Ciclo Combinado GNL Quintero I Aumento de Capacidad C° Navia-Polpaico 220 kV Ampliación Línea Pan de Azúcar-Los Vilos-Quillota 220 kV	385 MW 300 MVA 166 MVA
Octubre	2008	Central Carbón Pan de Azúcar I	400 MW
Abril	2009	Central Ciclo Combinado GNL Concepción I Nueva Línea Cardones - Maitencillo 220 kV	385 MW 200 MVA
Enero	2010	Central Hidroeléctrica Confluencia Central Ciclo Abierto GNL Quintero I	145 MW 125 MW
Abril	2010	Central Geotérmica en Calabozo 220kV Etapa 1 Nueva Línea P. Azúcar – Los Vilos 220kV	100 MW 230 MVA
Mayo	2010	Central Ciclo Combinado GNL Quintero II	385 MW
Enero	2011	Ciclo Abierto GNL Hualpén I	125 MW
Abril	2011	Central Geotérmica en Calabozo 220kV Etapa 2	100 MW
Enero	2012	Ciclo Abierto GNL Quintero II	125 MW
Abril	2012	Central Geotérmica en Calabozo 220kV Etapa 3 Central Hidroeléctrica Neltume Nueva Línea P. Azúcar – Maitencillo 220kV	100 MW 403 MW 235 MVA
Mayo	2012	Central Carbón Maitencillo I	400 MW
Enero	2013	Ciclo Abierto GNL Hualpén II	125 MW
Julio	2013	Central Carbón Hualpén I	400 MW
Enero	2014	Ciclo Abierto GNL Quintero III	125 MW
Abril	2014	Central Carbón Valdivia	400 MW

Table 1. - October 2004 Indicative Plan

Tecnologies	Investment (US$/kW)	Average generation cost (US$/MWh)	Fuel cost (US$/mBTU)
Reservoirs (400 MW)	1100	25.5	0.0
Run of river hydro (400 MW)	1250	28.7	0.0
Combined cycle natural gas (394 MW)	530	31.6	2.8
Coal circulating fluidized bed (250 MW)	1270	44.5	1.8
Combined cycle liquefied natural gas (394 MW)	530	45.1	4.7
Combined cycle diesel (394 MW)	550	66.8	7.9
Gas turbine (120 MW)	430	103.5	7.9

Table 2. - Cost of different generation technologies, Chile, 2004 [4]

III. Transmission Expansion

In March of 2004 a change of law was introduced in Chile that modified the previous market based transmission expansion to a regulated centralized process [5], directed by a multiagent committee (with representatives from generators, transmitters, distributors, large consumers and the government). The first transmission expansion plan is to be developed from March 2005, with no signs that uncertainty in gas supply will clear before then. Sophisticated planning methodologies being proposed, even with techniques that minimize the maximum regret, will have to face basic questions and propose solutions that do not mean “do nothing”, as that avenue may have damaging impacts on the

country's economic growth.

The presentation will highlight the process until mid 2005, the challenges that have arisen and how they are being dealt with.

IV. References

[1] Rudnick, H., Zolezzi, J., "Electric sector deregulation and restructuring in Latin America: lessons to be learnt and possible ways forward", IEE Proceedings Generation, Transmission and Distribution, Vol 148, Nº2, March 2001, pp. 180-184.

[2] Rudnick, H., "Risk Responsibility for Supply in Deregulated Electricity Markets- The Chilean Case", IEEE PES 2003 General Meeting, Toronto, July 2003

[3] Cornejo, N., "The Argentinean gas crisis", Systep Engineering, 2004

[4] Rojas, H., "Thermal generation, costs and development alternatives, comparison among different sources", in Spanish, International Symposium on Liquefied Natural Gas, Catholic University of Chile, December 2004, Santiago, Chile

[5] Rudnick, H., "The challenges of transmission expansion in the Chilean power sector: market or central planning?", IEEE PES 2004 General Meeting, Denver, USA, June 2004

V. Biographies

Hugh Rudnick (F'00) was born in Santiago, Chile. He graduated as an electrical engineer from the University of Chile, Santiago, Chile. He received the M.Sc. and Ph.D. degrees from the Victoria University of Manchester, Manchester, U.K. Currently, he is Professor at Catholic University of Chile, Santiago, Chile, and a Director of Systep Engineering Consultants. His research activities focus on the economic operation, planning, and regulation of electric power systems.

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

L.A.Barroso, *Member, IEEE*, B.Flach, R.Kelman, B.Bezerra, S. Binato, J.M.Bressane and M.V. Pereira, *Member, IEEE*

***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

All authors are with Power Systems Research, Rio de Janeiro, Brazil (email: psr@psr-inc.com).

L.A.Barroso and R.Kelman are also with PESC/COPPE-UFRJ, Rio de Janeiro, Brazil.

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].

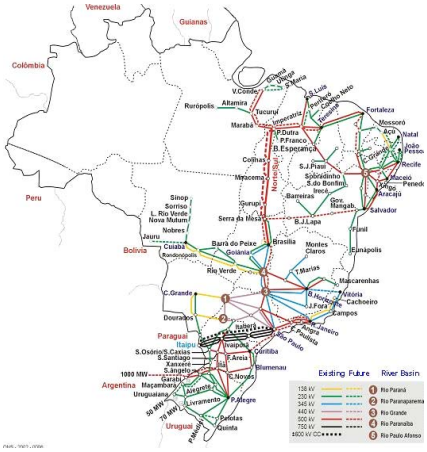


Fig 1. Brazilian Transmission System [3]

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)

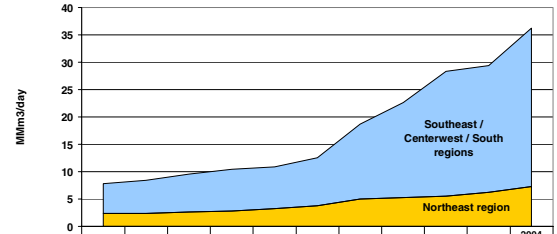
Without considering the gas for power use, the natural gas consumption levels in 2003 were in the range of 30 MMm3/day. Most of the gas is used in the industrial sector. Because there is virtually no need for space heating in Brazil, gas use for the residential and commercial sectors remain limited to 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.

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

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

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.

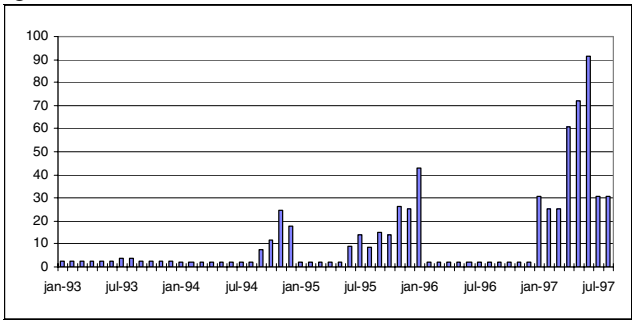


Fig. 4 - Historical Monthly Short-Run Marginal Costs (US$/MWh)

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.

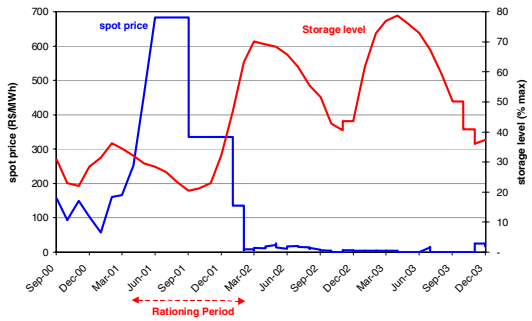


Fig.5 – Recent short-run marginal costs (R$/MWh) and storage levels

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

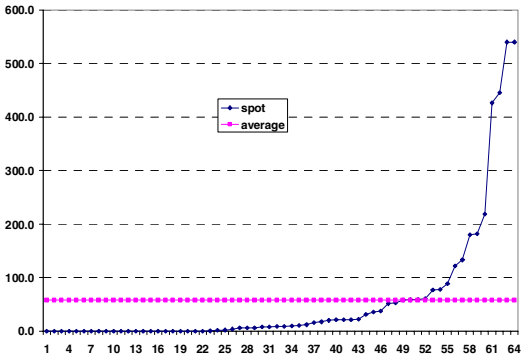


Fig.6 – Spot Price Distribution (US$/MWh) – January 2005

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

The authors gratefully acknowledge the contributions of M.Junqueira and J.Milanez from PSR/Mercados de Energia for their work on the original version of this document.

IX. References

[1] IEA – South American Gas – Daring to tap the bounty, IEA Press, 2003.
[2] L.A.Barroso, J.M.Bressane, L.M.Thomé, M.Junqueira, I. Camargo, G. Oliveira, S. Binato, M.V. Pereira, "Transmission Structure in Brazil: Organization, Evaluation and Trends" Proceedings of the IEEE General Meeting, Denver, 2004 – Available at http://www.psr-inc.com
[3] ONS website: http://www.ons.org.br
[4] M. Pereira, L. A. Barroso and J. Rosenblatt "Supply adequacy in the Brazilian power market" Proceedings of the IEEE General Meeting, Denver, 2004 – Available at http://www.psr-inc.com
[5] M.V.Pereira, N. Campodónico, and R. Kelman, "Long-term hydro scheduling based on stochastic models", Proceedings of EPSOM Conference, Zurich, 1998 – Available at http://www.psr-inc.com
[6] S. Granville, G. C. Oliveira, L. M. Thomé, N. Campodónico, M. L. Latorre, M. Pereira, L. A. Barroso, "Stochastic Optimization of Transmission Constrained and Large Scale Hydrothermal Systems in a Competitive Framework," Proceedings of the IEEE General Meeting, Toronto, 2003 – Available at http://www.psr-inc.com
[7] R.R.Mercado, "Natural Gas Pipeline Optimization", Handbook of Applied Optimization, Edited by P. M. Pardalos and M. G. C. Resende, Oxford University Press, 2002.
[8] N. Campodónico, S. Binato, R.Kelman, M. Pereira, M. Tinoco, F. Montoya, M. Zhang, F. Mayaki, "Expansion Planning of Generation and Interconnections Under Uncertainty", 3rd Balkans Power Conference, 2003– Available at http://www.psr-inc.com

X. Biographies

Luiz Augusto Barroso has a BSc in Mathematics and an MSc in optimization from UFRJ and is working towards a PhD in optimization at COPPE/UFRJ. He joined PSR in 1999, where he has been working in project economics evaluation, system planning studies and market power analysis in energy markets. He has been a speaker on power system planning and operations issues in Latin America, Europe and US/Canada.

Bruno Flach has a BSc in Electrical and Industrial Engineering and is currently working towards a MSc degree in Optimization, both from PUC-Rio. During his undergraduate studies he spent one year at the Electrical and Computer Engineering Department at the University of California, San Diego. He joined PSR in 2002 and has been working in various projects related to software development and technical support, demand forecasting and optimization models. Mr. Flach's research interests are now focused on stochastic optimization and strategic bidding.

Rafael Kelman has a B.Sc degree in Water Resources Engineering from the Federal University of Rio de Janeiro and a MSc degree in Operations Research (COPPE). He joined PSR in 1997, where he has worked in several projects related to economic evaluation of hydro and thermal projects, strategic bidding, water pricing and allocation and transmission pricing. He has been working in the development of a short term scheduling model with unit commitment. He has also been working in the development of computer models for the application of financial instruments to the energy sector, including risk management and physical / financial optimization. Mr. Kelman has been an instructor of several PSR courses in Europe, South America and the US. His research interests include water resources, stochastic optimization, planning under uncertainty and finance.

Bernardo Bezerra has a BSc in Electrical and Industrial Engineering and is currently working towards a MSc degree in Optimization, both from PUC-Rio. He joined PSR in 2004 and has been working in several projects related to demand forecasting, integration between gas and electricity, stochastic optimization models and synthetic streamflow generation.

Silvio Binato has BSc and MSc degrees in Electrical Engineering and a DSc degree in Systems Engineering and Computer Science. He has more than fifteen years' experience in the power sector, and is the responsible for the development of new methodologies and software for operational planning, expansion planning and integrated database design. He has also participated in expansion planning studies in Latin America and Europe. Previously, Dr. Binato worked at Cepel, where he managed R&D projects in areas of transmission network expansion planning, optimal power flow and meta heuristics for global optimization in power systems.

José M. Bressane has a MSc in Power Systems from WSU/Wa., USA. He is a consultant engineer for MdE/PSR and for ONS, the Brazilian ISO, and has been engaged in integrated G-T planning, design and operational studies, and regulatory studies.

Mario Veiga Pereira has a BSc degree in EE from PUC/Rio and PhD degree in Optimization from COPPE/UFRJ. He is the president of PSR and he is currently engaged in regulatory studies and the development of new methodologies and tools for risk management in competitive markets. Previously he was a project manager at EPRI's PSPO program and research coordinator at Cepel, where he developed methodologies and software for expansion planning, reliability evaluation and hydrothermal scheduling. He was one of the recipients of the Franz Edelman Award for Management Science Achievement, granted by ORSA/TIMS for his work on stochastic optimization applied to hydro scheduling.

Natural gas and electricity market issues in Colombia

J.M. Mejía and A. Brugman

Abstract-- **This panel presentation addresses the current state of power and natural gas markets in Colombia. These markets are characterized by a substantial volatility arising from the large hydroelectric composition of the power system. Key issues resulting mainly from the volatility are signaled.**

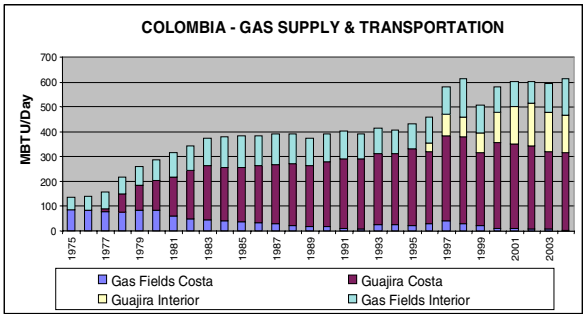
Index Terms—**Electricity, Natural Gas, Hydroelectricity, Volatility, Markets**

I. Background

Colombia has numerous primary energy resources: Oil and associated natural gas in the Interior region of the country, free natural gas in the Atlantic Coast region, hydroelectric resources mainly in the Andean Mountains and extensive coal deposits both in the Atlantic Coast and the Interior regions. Hydroelectricity is used to serve around 65% of the electricity market; the remaining 35% is served by coal and natural gas fired plants. Natural gas is also used in oil refining, industrial, residential, commercial and transportation uses. The development of the natural gas industry in an environment where its requirements are very volatile due to the randomness of river discharges is a key issue in Colombian energy sector.

II. Natural Gas Market

Natural gas in Colombia has been a non-internationally traded energy product, and therefore its development and use has been subject to the growth of the local gas market. Average supply of natural gas in Colombia during 2003 was 595 MBTU/Day [1], 478 MBTU/Day of it produced en the Atlantic Coast fields (Guajira and Others).

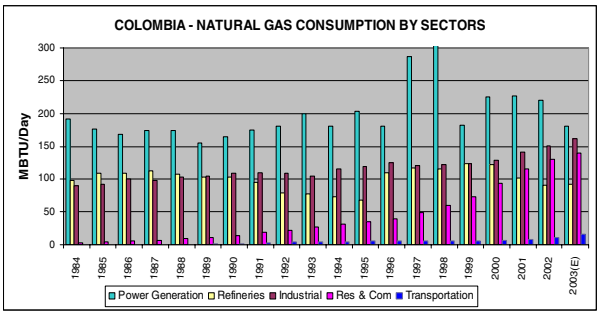


It is expected that in 2007 an interconnection gas pipeline with Venezuela will start operation and, therefore, should enable natural gas exports to such country during several years (150 MPCD) and, eventually, allowing future natural gas imports. This interconnection would enlarge the Colombian gas market, enabling international natural gas trades to develop the Colombian natural gas reserves (7,490 GPC of proven reserves remaining on Dec. 31, 2001[2]).

Development of the natural gas industry in Colombia is recent. Although there were local natural gas uses since the 1950's, its massive utilization started in the middle of the 1970's in the Atlantic Coast region with the utilization of free natural gas reserves located in such region. In the middle of the 1980's a Government plan named "Programa de Gas para el Cambio" accelerated natural gas service extension towards urban centers. Later on, in the 90's decade, the "Plan de Masificación de Gas Natural" was implemented; its main component was the gas transportation infrastructure, in operation today connecting the gas fields with main consumption centers.

The above actions have been complemented with an increase of natural gas reserves due to new findings of in the Interior of the country, the start of a new regulatory framework for the natural gas market, and by the dynamics of new natural gas demands. In particular, since the start of this Plan 3010 MW of new gas fired thermal plants have been installed which represent 22% of the total electricity generating capacity installed in the country.

Demand for natural gas in Colombia has been growing in an important manner, subject to volatility due to gas consumption for thermoelectricity which reached an annual average of 304 MBTU/Day for this use in 1998. Natural gas consumption in Colombia was 589 MBTU/Day in 2003, 181 MBTU/Day for electricity generation.



Authors are with Estudios Energéticos Ltda in Bogotá, Colombia (e-mails jmmejia@cable.net.co and abrugman@cable.net.co).

[1] Ecopetrol Statistics, 2003.

[2] "La Cadena del Gas Natural in Colombia". UPME. 2001-2002 Version

UPME, the government unit of energy planning, estimates that natural gas demand would reach around 750 MPCD by 2010, when the Colombian natural gas supply capacity should be increased to around 900 MPCD if the natural gas export program to Venezuela of 150 MPCD is accomplished.

The end of current decade would be reached with a reserves-to-production ratio of around 20 years. Such ratio is based on the current quantified proven and probable levels of natural gas reserves in Colombia.

Natural gas demand for electricity generation in the country is subject to a large volatility. It is highly seasonal due to the nature of the Colombian power system which has a large hydroelectric component. River discharges are substantially affected by El Niño phenomenon. Its occurrence implies large thermoelectric use to compensate the decrease in hydroelectric generation. Guerrilla attacks to the transmission infrastructure are another source of natural gas demand uncertainty since it forces thermal generation in some areas without hydroelectric resources.

There has been a relevant investment from state and private companies in the later years in order to connect main production gas fields to the principal consumer centers around the country through the construction of new gas pipeline grids.

Estimates of natural gas demand in Colombia in sectors different from electricity generation assume that the Atlantic Coast regions have the largest and most developed markets. Under such assumption highest demand increases would occur in the Colombian Interior region as a result of natural gas penetration that would occur in residential, industrial and transportation sectors.

The forecasted natural gas demand in the industrial sector is being influenced by strict environmental regulation on emissions since year 2000 it has substituted environmentally aggressive fuels formerly used for industrial consumption.

III. Electricity market

Colombian Power Sector structure at the beginning of the 80's was the result of a long process of state intervention, which started in 1928 declaring hydroelectricity of public interest. Since then, the structure was centralized at regional levels, until the reforms made in 1994. During the old scheme, state companies maintained monopoly of service in specific regions and were vertically integrated providing services of electricity generation, transmission and distribution. This type of monopolistic company in an area was in line with the regional development of the country and created isolated systems mainly hydroelectric in the Interior region of the country and thermoelectric in the Atlantic Coast region. In 1968 the interconnection process started. Today most of main urban markets are interconnected.

Interconexión Eléctrica S.A. (ISA, the transmission company) has served as system operator, intermediating energy exchanges between regional systems up to 1995 with the purpose of optimizing power system operation and expansion. ISA coordinated the electricity supply, following optimization processes, in which the operative cost of the system was minimized, as well as the expansion costs of the generation and transmission systems including new generation plants and transmission lines.

Colombian Power Sector went into crisis during the 80's as well as in most Latin American countries. This situation was due to tariff subsidies and to the politization of the state companies, which generated shortcomings in sector development. At the same time, large hydroelectric power plants were developed, some of them with unexpected over costs and important delays, which caused the sector to become a financial burden for the state.

On other side, the world started to doubt about the effectiveness of state monopolies to supply public services, and reforms were made in some countries, such as in the United Kingdom, Norway and Chile; the changes were radical:

- To introduce competition in the electricity sector.
- To allow private investment, including privatization of state companies.
- To eliminate vertical integration separating the transmission, distribution and generation businesses.
- To leave to the state the regulatory role.

Colombia decided to modernize its electricity sector at the beginning of the 90's fostering private participation and following a scheme similar to other countries which decided to change, specially the United Kingdom. This modernization defined a new regulatory scheme to establish the conditions allowing competition. New laws created the Wholesale Electricity Market with market rules set by CREG, a newly created regulatory agency.

In 2003 NIS peak demand was 8,257 MW and energy demand 46,112 GWH. Electricity generation in Colombia is mostly hydro with complementary thermal energy from natural gas and coal. Minimum thermal generation in the system is due to reliability requirements and transmission constraints. Recently thermal generation has been increased due to additional transmission constrains resulting from guerrilla's sabotage. The high hydroelectric component already installed in Colombia has a significant vulnerability mainly due to climatic occurrences. This fact became evident during the generalized electricity shortage that suffered the country in 1992 - 1993, during 14 months, when nearly 15% of the demand was not supplied. At that time a centralized operative planning was governing the reservoir operations in the system.

Power sector reforms issued in 1993/1994 and the Wholesale Electricity Market changed the centralized operative planning; today the reservoir operations are defined by the market evolution. Government has been encouraging an increase in the thermal capacity installation in order to improve reliability of the system. Energy supply has been normalized in the country since 1994 until now. By the end of 2003, total system net effective installed capacity is 13,269 MW (8,852 MW in hydroelectric plants, 3,633 MW in gas fired plants, 692 MW in coal plants and 92 MW in others).

IV. Main market issues

Natural Gas and Electricity markets have strong links in Colombia and therefore there are several issues related to the

interaction among them.

A. Capacity Charges

Large hydroelectric component of the Colombian installed capacity implies that some of the natural gas fired plants have very low dispatch probability but they are required to guarantee supply reliability. Main issue related to this is the design of an appropriate capacity charge mechanism to create the financial incentives for the installation, operation and maintenance of these types of plants without creating economic adverse distortions in the operation and expansion of the system.

B. Power transmission and gas transportation charges

Achievement of optimal integrated operation and expansion of power and gas transportation systems require correct incentives given by an appropriate scheme of regulated charges. Colombia has a simplified stamp and deep connection charge scheme for power transmission while complex distance related charges are applied to gas transportation, creating perverse incentives to integrated power-gas system optimal operation and expansion. In addition gas demand volatility arising from hydroelectric generation randomness constitutes a challenge to be solved.

C. Natural gas vs. Electricity markets

Colombian electricity market is a price bid based highly competitive market with more than 30 generators participating while the Colombian natural gas market is reduced to a few participants requiring regulated wellhead prices. Even though the regulatory agency has given the signal to open the gas market this constitutes a regulatory challenge given the related market power issues. Also, the complexity of the natural gas based electricity generation cost structure within a main hydroelectric bid based market constitutes an issue to be addressed to incentive optimal power system operation.

D. Market surveillance

International experience of bid based power markets demonstrates the need of a market surveillance mechanism to prevent inefficiencies due to eventual market power actions and to guarantee appropriate market development. In the Colombian case the inclusion of the gas market in the surveillance scheme is a critical issue needing to be solved.

V. Biographies

Alberto Brugman M. is an Electrical Engineer from Universidad de los Andes in Bogotá, Colombia. He obtained a M.Sc. degree from Illinois Institute of Technology. He is partner of Estudios Energéticos Ltda.. He has participated in several consultant studies related to the reorganized power and natural gas sectors in Colombia as well as several other countries in Latin América. He is also a former Vice Minister of Energy and Mines of Coilombia.

José Manuel Mejía A. is a Civil Engineer fron Universidad Nacional de Colombia in Medellín, Colombia. He obtained M.Sc. and Ph.D. degrees from Colorado State University. He is partner of Estudios Energéticos Ltda. He has been a consultant in the water and energy sectors both locally and internationally. He has conducted extensive research in hydrology published in well known international journals

The Role of Natural Gas as an Instrument for the Energy Integration in Latin America

Marco Aurélio Tavares

***Abstract*--this presentation discusses the problems and specific solutions for the ongoing obstacles for the development of an integrated natural gas industry in the Southern cone of Latin America, as well as a perspective of the achievement of an integrated regional energy planning.**

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

I. Introduction

DESPITE of its oil reserves, Latin America has enormous natural gas reserves of its oil reserves, Latin America has enormous natural gas reserves, larger than both real consumption and the predicted future demand for the next twenty years. The already known natural gas reserves of 110 TCF (trillions of cubic feet) in the Latin America Southern Cone are enough to guarantee the supply for 55 years based on the actual production rates. Bolivia, Argentina and Brazil, after the Santos basin discoveries, are the big "stars" of this market.

By looking to the energy per capita consumption of each country of the region, or to the natural gas participation on the primary energy matrix, with the exception of Argentina, one can observe a (still) long path towards the insertion of the natural gas both in the industry and in the power sector.

However, this apparent "tranquility" to develop the natural gas market on this region faces several difficulties; some caused by a poor economic regional condition in some countries, others resulted from bad institutional and commercial regional relationships, and others because of the non adequacy of the natural gas-electricity integration process.

Differently of petroleum and oil products, the natural gas market needs long-term contractual relations. For a region known by severe economical and political instability, gathered with the disrespect of some contractual relationships between public and private agents, the need of long-term contracts may sound "utopist".

By looking to the Southern Cone map, it seems that an "energetic puzzle" among the countries is perfectly arranged. While some countries such as Brazil and Argentina, besides Chile and Uruguay, have increasing needs (and shortages) of energy and gas, Bolívia has enormous natural gas reserves still to be developed and a poor internal market perspective.

In this region however, nothing seems to follow a rational and logic behavior, as well as market signals, regional affinities or even binational agreements established through or long-term contracts. Some questions are constantly repeated:

- How can we expect the contract juridical security on a region of non-equality relationships and non-personal security?
- How can we develop a long-term contract relationship where social and personal relationship between government and the population are disrespected?
- How can millions of dollars of investments be attracted to the region when every new government changes all the economic rules and regulatory framework?
- How to construct international agreements when in the large cities the universal declaration of the human rights is constantly disrespected?

Who has the answers?

Maybe nobody but we can look for solutions to the regional electricity and gas supply problems and try to bring the benefits of the natural gas industry development to the population of these countries in the region.

These solutions must overcome the paradoxes that this industry has created and survived with so far.

In order to do so, a precise diagnose of the structural main problems that prevent the harmonic development of the natural gas industry. They are:

- Insertion of the natural gas in the electricity generation matrix;
- Difficulties in the price formation that support the investments in the developments of the gas reserves;
- Unsuccessful restructuring of the businesses of binational and internal transportation in the countries of the region;
- Inadequate insertion of the natural gas in the region, especially in Brazil;
- Lack of a restructuring and adequate framework to deal with the security of the electricity and natural gas supply.

Each of these topics deserves a specific approach, with a description of the current situation and the "ideal"

M.Tavares is with Repsol/YPF Brazil, Rio de Janeiro, Brazil (email:

perspectives for a regional integration.

The insertion of the natural gas in the energy generation matrix in a region with high predominance of hydroelectricity deserves an evaluation by not only a set of specialists, but also by a set of psychologists. This theme has been focus of several paradigms resulting from wrong evaluations, such as minimum thermal dispatch against water spillage, lower final energy costs of hydro plants against the smaller construction time of the other energy resources, etc

The natural gas prices, as well as the basic prices of the other relevant products of the economy, such as oil derivatives, electricity, telecommunications, water supply, etc have always been disturbing elements for the well-functioning of a market economy in the countries of the region. The controlling of basic prices in order to avoid the inflation increase and to meet inflation targets have always been "remedies" used by governments of the region, even though these practices have resulted in unmanageable public-debts faced by those governments. The example of how the Argentinean government has collapsed a mature and growing market of natural brings up many lessons of these mistakes, which however seems to be (unfortunately) contaminating the other energy authorities of the countries of the region.

The transportation sector, including gas pipelines, binational and internal electrical transmission lines, with different types of regional regulations, unbalanced tariffs and, in some cases, companies that technically had already ran out of business, prevent the harmonic growth and the establishment of useful and intelligent relationships that could allow for the better use of the existing regional complementarity and seasonality on its resources.

In Brazil, the high participation of the electrical energy in the energy matrix (through the subsidized supply to large industries) and the no consideration of the environmental friendly aspects of the natural gas creates some barriers to its effective insertion in industries, urban centers and form the backbone of the obstacles to a more aggressive increase of natural gas in the country.

Besides these internal problems of the natural gas industry in the region, the lack of an adequate structure to plan the security of the electricity and natural gas supply is one of the most important obstacles that takes the region to specific crises in each of its countries. These crises could be avoided if an integrated vision of the particularities and complementarities of each market, the knowledge of the demand growth drivers and the drivers for electricity supply were known in a common basis.

The discussion of the problems and proposal of specific solutions for each of these obstacles for the development of an integrated natural gas industry in the Southern cone of Latin America, as well as an optimistic perspective of the achievement of an integrated regional energy planning will be the main objectives and topics of this panel presentation.

mtavares@repsolypf.com).

II. Biography

Marco Aurelio Tavares has a BSc in Chemical Engineering from the Federal University of Rio Grande do Sul, Brazil. Since 2001 he is the director of Gas Trading of REPSOL-YPF in Brazil, where he is responsible for the negotiation of gas selling contracts (Argentinean and Bolivian natural gas reserves), for the analysis, follow up and management of gas pipeline and thermoelectric projects and for the negotiation of strategic partnership with Petrobras for Bolivia, Argentina and Brazil and joint ventures in general. He has the participation in more than 30 Brazilian and Foreign congresses and seminars related to gas, power and regional integration within the year 2004, gas an expert to give lectures and debate on gas and energy issues. He is also the chairman of the Gas Sellers Committee and member of the Gas Consulting Committee of IBP – Brazilian Petroleum Institute