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THE RELEVANCE OF THERMAL HYDRAULIC PIPELINE SIMULATION AS A REGULATORY SUPPORT TOOL

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Abstract

The capacity definition of a pipeline, along with its allocation, is very relevant to assure market transparency, non-discriminatory access, security of supply, and also to give consistent signs for expansion needs. Nevertheless, the capacity definition is a controversial issue, and may widely vary depending on the technical and commercial assumptions made. To calculate a pipeline's nominal capacity, there are a variety of simulation tools, which include steady state, transient and on-line computer programs. It is desirable that the simulation tool is robust enough to predict the pipeline's capacity under different conditions. There are many variables that impact the flow through a pipeline, like gas characteristics, pipe and environmental variables. Designing a thermal model is a time-consuming task that requests understanding the level of detail need, in order to achieve success in its application. This article discusses the capacity definition, its role and calculation guidelines, describes ANP's experience with capacity calculation and further challenges according to the new regulation, and debates the role of thermal hydraulic simulation as a regulatory tool.

1. Introduction

Developing countries, with immature pipeline infrastructure, usually face the challenge of stimulating infrastructure development while providing non-discriminatory access. The pipeline transportation capacity is a key information in this scenario and Regulatory authorities must be prepared to analyze and verify the information given by the market agents (carries, transporters).

In order to find an objective proposal for a model for calculating pipeline capacities, a search was made over the international experience. It was seen that there is no common sense over the subject, unless that it is controversial. Regardless of it, the European Union is searching for the appliance of common rules at least for capacity allocation and congestion management. It has also been seen that, despite of the adopted methodology, it is mandatory that it is transparent, comprehensive and reasonably documented.

This article is divided in seven sections, including this introduction. The second section presents a discussion over the natural gas pipeline capacity definition and calculation, emphasizing the role of capacity information transparency, capacity definition controversy and some guidelines on capacity calculation and allocation. The third section describes two capacity modeling proposals, one from a regulatory authority and the other from a transmission operator. Then the fourth and fifth sections describe the Brazilian regulation over the issue and its experience with the use of thermal hydraulic models. The sixth section brings a comparison among parameters used in Brazilian TSO's simulation reports and the necessity of establishing a report standard. The last section presents the conclusions.

2. Capacity Definition and Calculation

Yet controversial, capacity definition is a key issue for developing competitive markets, and providing transparent and non-discriminatory access to transmission networks. Further on, it will be described the international discussion related to capacity definition, with focus on the European example and proposed guidelines on capacity calculation.

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2.1. The Role of Capacity Definition Transparency

The European Parliament Directive 2003/55/EC – Gas Directive establishes that, among other tasks, system operators[1] should (Article 8) refrain from discriminating between system users or classes of system users, particularly in favor of its related undertakings[2] and should provide system users with the information they need for efficient access to the system. With respect to refusal of access, it defines that (Article 21) natural gas undertakings may refuse access to the system on the basis of lack of capacity or where the access to the system would prevent them from carrying out the public service obligations, which are assigned to them or on the basis of serious economic and financial difficulties with take-or-pay contracts. In that case, duly substantiated reasons shall be given for such refusal. With respect to regulatory authorities, Article 25 establishes that Member States shall designate one or more competent bodies that shall be wholly independent of the interests of the gas industry and be responsible for ensuring non-discrimination, effective competition and the efficient functioning of the market, with the following highlighted functions: (a) monitoring the rules on the management and allocation of interconnection capacity, in conjunction with the regulatory authority or authorities of those Member States with which interconnection exists; (b) monitoring any mechanisms to deal with congested capacity within the national gas system; (c) checking for the level of transparency and competition.

With the objective of establishing conditions for access to the natural gas transmission networks[3], European Parliament's Regulation (EC) No 1775/2005 considers that for network users to gain effective access to gas networks they need information in particular on technical requirements and available capacity to enable them to exploit business opportunities occurring within the framework of the internal market. Common minimum standards on such transparency requirements are necessary and the publication of such information may include electronic means. It considers that the management of contractual congestion of networks is an important issue in completing the internal gas market, and it is necessary to develop common rules which balance the need to free up unused capacity, in accordance with the 'use-it-or-lose-it' principle, with the rights of the holders of the capacity to use it when necessary, while at the same time enhancing liquidity of capacity. Also, as physical congestion of networks may become a problem in the future, it is important to provide the basic principle for the allocation of congested capacity in such circumstance.

For PINON and CUIJPERS (2006), because of the natural monopoly and other particular features of networks, specific procedures are needed to convert a given transmission capacity into marketable services. Network users, large and small, want assurance that easy entry on the network for any reasonable demand is guaranteed, whatever the chosen route, and that their contractual commitments will be respected. These requirements are especially important during the market opening phase and their fulfillment may need some provisions in order to smooth out possible comparative disadvantages of newcomers. The requirements of efficient services and efficient operation of the network become even more stringent when networks are faced with situations of congestion. Network users need transparent and accurate information on the provision and the quality of these services. Open access regimes to networks are successful in the creation of market liquidity only if the provision of transmission capacity is adequate.

Also, the dynamic nature of networks as well as the natural monopoly situations, without industry-wide standards, gives a large flexibility to transmission system operators (TSOs) for calculating and providing capacity. These circumstances do not necessarily guarantee that networks are efficiently operated and that capacity is offered on a fair and non-discriminatory basis to all network users, large and small. In order to meet the capacity needs of all network users, non-discriminatory third party access arrangements to transmission capacity are being developed and implemented throughout Europe in accordance with the Gas Directive. In this context, the Council of European Energy Regulators (CEER) agrees that TSOs need to provide better documentation and greater transparency for their capacity calculation processes. The authors suggest a number of recommendations to achieve more consistency among capacity calculations.

The European Regulators Group for Electricity and Gas - ERGEG (2009), points out that competition in natural gas markets is based on opening essential facilities to all suppliers in a transparent and non-discriminatory way. Rules for third party access are therefore a key element of market functioning, in particular as far as transmission is concerned. Transmission capacity is indeed a scarce resource that must be shared among market participants in a way that promotes competition and security of supply. Capacity allocation mechanisms (CAM) and congestion management procedures (CMP) have an important influence on the nature of competition and on the development of trading mechanisms, prioritizing stability and security of access and short-term flexibility, enhancing the utilization of infrastructure and removing contractual congestion.

2.2. Discussion About Capacity Definition

For Gas Transmission Europe - GTE (2001) there is no uniform definition of capacity and in a specific grid it depends on a set of complex parameters resulting from the actual flow pattern in the grid. While capacity in a single linear pipeline could be stationary determined, the respective determination in a pipeline grid is by far more complex

[1] System Operators: includes transmission, storage and LNG system operators.

[2] "*'natural gas undertaking' means any natural or legal person carrying out at least one of the following functions: production, transmission, distribution, supply, purchase or storage of natural gas, including LNG, which is responsible for the commercial, technical and/or maintenance tasks related to those functions, but shall not include final customers*"

[3] Does not apply to upstream or high-pressure local distribution pipelines.

and has to be based on a number of assumptions. They also argue that the capacity of a pipeline or a transmission system can be analyzed from a technical and from a commercial perspective. From a technical perspective, capacity is mainly a function of delivery and redelivery pressures based on a number of design parameters as well as the underlying flow scenario. Consequently the determining parameters are not only pressure, temperature etc. but also gas quality to meet safety specifications at the end consumer level and shippers' use of the system. Off-takes from the system are mainly determined by temperature, whereas deliveries into the system are the result of commercial decisions of the shippers and thus depend on contractual provisions in general as well as on price differentials between different delivery sources and on supply security considerations. It is against this background that capacities are determined by technical standards applicable to the transporter rather than regulation or law.

There are different approaches with respect to the commercial perspective. Neither model is superior nor inferior in principle, however they have to be considered as the solution that fit best to the individual circumstances of infrastructure and customer needs as far as demand and supply patterns and especially security of supply[4] are concerned. The models applied can be characterized as notional path models at one end of the scale and entry-exit models with pool characteristics at the other end of the scale, as illustrated in Table 1.

Table 1. Capacity Models (*sources: GTE, 2001 & GTE, 2002b adapted*)

Notional path model (point-to-point)	Entry/exit model
- Guarantee of capacity to protect security of supply - No operational congestion management - Importance of transits through the system - Short-term trading possible, but not essential - Capacities calculated: on basis of complex demand/supply simulations (most severe scenario over the years); for each part of network; determined for transportation from each point to another - Mainly applied in Continental Europe (e.g. Austria, Germany)	- Disconnection of entry and exit - Need for operational congestion management (short-term congestion may occur) - Short-term trading may be prerequisite - Limited transits - Large number of end users supplied by one TSO (UK) - Capacities calculated: at specific entry/exit points; wide range of models - Applied in the UK (pool based, i.e. nationwide hub) and with restrictions in Italy

According to PINON and CUIJPERS (2006), the transmission capacity available in the network varies continuously because of the dynamic elements, which are becoming more and more important because of the shift from a single-shipper environment to a multi-shipper one. Furthermore, the uncertainty of dynamic factors increases drastically in a competitive market. Also, the calculation of available capacity is generally based on computer simulations of the operation of the interconnected transmission network under a specific set of assumed operating conditions. The more interconnected and meshed the network, the more dynamic its physics and consequently the more complex the calculation of available capacities. Making adequate assumptions about the variables is therefore necessary to estimate properly the capacity available in the network. System users have to be aware that available capacities vary as function of these determinants. The dynamic and probabilistic nature of system simulation outcomes regarding available capacity calculation necessitates transparent calculation procedures in order to inform the market correctly about the transmission services offered. With respect to the market power of a new project, the authors suggest regulators to watch for six problems: a) deliberately designing the project to offer less total capacity than optimal b) pre-emptive expansion to deter competitors, c) deterring other efficient projects, d) introducing inappropriate vertical integration, e) monopolization of capacity, and f) charging excessive prices.

On the other hand, a study from NERA (2002) affirms that in most Member States the tendency to favor central planning and a reliance on short-term reservations of capacity will be unsustainable, once the existing pipeline monopolies are abolished. Europe must either adopt a contractual regime like that found in North America[5], or innovative swiftly to find a substitute for these monopolies. As they are abolished, the gas sector will need to find alternative means of securing cost recovery, otherwise the industry will find it difficult to raise funds for investment and will have a strong disincentive to allow secondary markets that might undermine the value of their services. Using long-term contracts to fund investments drives pipelines towards a system in which the capacity is defined and allocated by reference to physical capacity on real, point-to-point routes. Other schemes (such as entry-exit arrangements) would have to rely on other means of cost recovery.

2.4. Guidelines on Capacity Calculation and Allocation

GTE (2002a) suggests that the calculation of transmission capacity requires a network model and flow simulations in which due account is taken of the fact that non-firm and/or interruptible transmission contracts if any

[4] Security of supply has been a cornerstone of the gas market in Europe in the past. In order to improve security of supply and thus to avoid interruptions of supply to the market huge investments have been made and supplies have been diversified by sources (GTE, 2001).

[5] In North America, the federal authorities decided to favor pipeline-to-pipeline competition over monopoly provision of gas transportation infrastructure – even if it meant losing some economies of scale. Long-term contracts between a pipeline and shippers became the primary means of securing cost recovery. They also intended to reduce the exposure of pipelines to short-term fluctuations in the value of their capacity. The federal authorities were able to order pipeline companies to facilitate secondary markets (NERA, 2002).

allow to alleviate the peak flows. The methods for the calculation of available capacities should take into account the capacity commitments for the years ahead. Also, the minimum data to be published by the system operators on their web-sites should be the capacities at each LNG facility and each major interconnection point of interconnected cross-border networks, in both directions (if applicable): (a) the technical capacity, (b) the quantity of available firm capacity on the primary market or, in the form of a traffic light system (for confidentiality reasons that should be explained on a case by case basis to the relevant national authority), (c) the total contracted firm and interruptible capacity, and (d) reasonable instruments for calculating final tariffs for a case specified by the system user. Finally, if the system operator denies a firm capacity because it exceeds the available firm capacity, this shall be considered as a due substantiation of refusal as far as the regulator has the competence to approve the calculation method of the published available capacities and the anti-hoarding mechanisms and congestion management rules that are applied. The system user retains the possibility of appeal to the relevant national authority on any decision of the system operator.

LAPUERTA and MOSELLE (2002) prepared for the European Commission the so-called “Brattle Report”, on non-discriminatory tariffs and congestion management systems. Capacity definition systems should be analyzed using gas flow models that estimate the interaction between capacity availability and different degrees of flexibility[6]. TSO should share these models with regulatory authorities, and regulators should develop their own modeling capabilities. The Commission and CEER should share their experiences concerning their analyses of the tradeoffs between alternative capacity definition systems. They also distinguish contractual congestion from physical congestion. They recommended the publication of continuous updates of available capacity on a network, historical and forecasted annual peaks and demand for major entry and exit points or zones and investment plans. Regulators or TSOs should develop computer models of the major pipeline networks in Member States that shippers could acquire.

Regulation (EC) No 1775/2005 stands the “Principles of capacity allocation mechanisms and congestion management procedures” (Article 5) where: (a) the maximum capacity at all relevant points[7] shall be made available to market participants, taking into account system integrity and efficient network operation, (b) TSO shall implement and publish non-discriminatory and transparent capacity allocation mechanisms, (c) when capacity contracted under existing transportation contracts remains unused and contractual congestion occurs, TSO shall offer unused capacity on the primary market at least on a day-ahead and interruptible basis, unless this would infringe the requirements of the existing transportation contracts and (d) if physical congestion exists, nondiscriminatory, transparent capacity allocation mechanisms shall be applied by the TSO or, as appropriate, the regulatory authorities. Relating to transparency requirements (Article 6) it requests that: (a) for the services provided, each TSO shall make public information on technical, contracted and available capacities on a numerical basis for all relevant points including entry and exit points on a regular and rolling basis and in a user-friendly standardized manner, and (b) the relevant points of a transmission system on which the information must be made public shall be approved by the competent authorities after consultation with network users. It also presents an Annex with more detailed guidelines on third party access services, principles underlying capacity allocation mechanisms and congestion management procedures, and the definition of the technical information necessary for network users to gain effective access to the system, the definition of all relevant points for transparency requirements and the information to be published at all relevant points and the time schedule according to which this information shall be published.

As a result of GTE’s guidelines and the Gas Directive, on November 2008 GTE launched online the GTE+ Transparency Platform (*http://www.gas-roads.eu).* The Platform is based on information that is already published by individual TSOs on their websites. The Transparency Platform offers to its users to search for a route across the European gas transmission networks by selecting only the starting entry and the ending exit points. A route summary is consequently generated giving the users an overview of available monthly capacities along the route and other information. The Transparency Platform also publishes links to individual TSOs´ websites.

PINON and CUIJPERS (2006) state that the capacity of a transmission network depends on static and dynamic elements, as well as on operational constraints. Static elements are the technical characteristics of the network itself, including its architecture and the specific properties of the arcs and other equipments, that include: (a) the diameter of the pipelines on each arc or portion of arc, (b) the roughness of the pipeline material on each arc and (c) technical characteristics of other equipments (valves, compression and heating facilities). Dynamic elements refer to the way the network is being utilized and operated: (a) properties of gas (pressure, temperature, composition), (b) the distribution of the nominations along the network, (c) flexibility services offered, (d) gas demand, and (e) the operating mode of the ancillary equipments. Operational constraints are the boundaries set on each variable by the different parties: (a) minimum/maximum pressure at interconnection points, (b) gas supply and off-take required to be the same within certain margins, (c) minimum gas pressure at each exit point varies from costumer to costumer, and (d) respect of operating limits of the ancillary.

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[6] The choice between different capacity types entails a fundamental trade-off between allowing shippers greater flexibility in system use and maximizing the amount of firm capacity that can be sold. As there is not an absolute guarantee of physical delivery, physical firmness is inherently a probabilistic concept: a service with a very low probability of interruption (Lapuerta and Moselle, 2002). Network scenario determines the firmness and the associated amount of available capacity declines with the level of firmness (Pinon and Cuijpers, 2006).

[7] See the Annex of Regulation no.1775/2005 for definitions.

3. Pipeline Capacity Modeling Proposals

As a result from the research about international standards for thermal hydraulic simulation reports, it could be seen, from the section above, that the discussion in Europe focuses on defining more general guidelines on capacity transparency, allocation and congestion management. Nevertheless, two examples from developing countries will be described below. It is also important to mention that the Pipeline Simulation Group of Interest – PSIG (2000, 2004) efforts to propose a dictionary of commonly used terms and a simulation configuration format and terminology recommendation that could be used to transfer input data among various software tools.

3.1. India's Regulatory Authority Proposal

Indian Petroleum & Natural Gas Regulatory Board – PNGRB (2009), recently established in 2006, published on April 2009 a draft regulation on "Determining Capacity of Petroleum, Petroleum Products, Natural Gas Pipeline" for comments, that are intended to apply to all new and existing petroleum, petroleum product, and natural gas pipelines including dedicated pipelines for the purpose of declaration of pipeline capacity under Steady State conditions. The capacity of the natural gas pipeline so determined shall be used for providing access to available capacity on non-discriminatory basis under the relevant regulations on their Access code. On the determination of capacity for the pipeline system and for each section of the natural gas pipeline it will be taken account of the selected software package (history of software, international presence, usage by regulators world over, Indian presence etc.) and approved flow equation. The entities may continue to use or operate the system based on the previously installed software but shall have to determine the capacity of the system based on the recommended flow. The entity shall furnish a declaration that the capacity has been calculated using approved flow equation and indicate the calculations of the capacity in the software used.

The parameters for running the steady state simulation for determining the pipeline capacity, in the case of natural gas pipelines, are detailed in the document with respect to: (a) constant parameters: internal diameter, length, roughness, efficiency, formula (the Panhandle Modified flow equation shall be used), velocity, standard temperature and pressure, and (b) variable parameters: operating temperature, inlet temperature, outlet temperature, inlet pressure, outlet pressure, source supply flow, delivery flow, elevation difference, gas properties (from this, the input parameters shall be worked out for the following parameters, for necessary input to the flow equation: (i) Heat Content (ii) Specific gravity (iii) Viscosity). The regulation also describes the step-by-step procedure of the calculation methodology, including assumptions to be made about pressure, flow, section wise capacity in case of multi entry pipeline, etc. The entity shall submit the details of maximum achievable system capacity and section wise capacity of the natural gas pipeline so determined, under the steady state simulation with the details of variable or constant parameters, along with the hydraulic gradient and system flow diagram for the pipeline system. The constant parameters and the variable parameters for the pipeline shall be declared on the first day of every month, or whenever there is any addition or subtraction of the gas supply source. The entities shall also provide on first of October and first of April every year the hydraulic gradient and system flow diagram for the pipeline.

PNGRB shall decide to reject or accept the capacity so determined and it shall be declared by PNGRB as the capacity of the system and specific sections and the same shall be available to the shippers or consumers. The entity shall publish the same on their web site, and it shall be determined whenever: (a) there is a major change in the injected or off taken quantity, (b) the contract quantity period expires, (c) there is a change in gas composition or product quality or in other operating parameters as defined under the relevant regulations on the Access code, or (d) there is a addition or subtraction of entry or exit point.

3.2. Argentina's TSO Proposal

ALVAREZ et al. (2006) propose that the transmission capacity of a natural gas pipeline is generally a definition based on certain assumptions made by the operator, while the design capacity is based on an assumption made before the pipeline construction. The first one is defined after the commercial pipeline operation, verifying real performance, and assuming sometimes arbitrarily, certain hypothesis. It is necessary to set a state of reference to share and communicate a common understanding of the capacity or capability of a pipe or a system of pipes. The usual procedure implies a design based on steady state simulation with further verification and adjustment for extreme cases using transient analysis. However, the uncertainties of capacity required in the future, behind the initial contracted, the behavior of the demand and the risks assumed, produce an unbalance between the accuracy of the method chosen and the data uncertainties. The model or technique of choice of simulation could also modify the results.

They propose that the nominal transmission capacity is the total gas quantity that can be injected in a gas pipeline system, to give a firm transmission service to a group of clients, in agreement with the assumptions described in a "Nominal Transmission Capacity Technical Report (NTCTR)". Without the NTCTR the capacity would lose its meaning. The proposed Report should content: (a) introduction, purpose, description, (b) general information: company, gas pipeline system, date, (c) vocabulary, definitions; (d) system description: topology, technical data, compression facilities, reception and deliveries facilities, (e) demand: contractual capacity required, type of services, boundaries of contractual obligation (minimum, maximum), relief clauses, demand curve shape and contractual obligations, gas specification, and special clauses, (f) hydraulic model: description of the model adopted, description of the simulation methodology utilized, main assumptions of the model (equation of state, roughness, heat transfer coefficients, etc), (g) operational philosophy: gas control and dispatch criteria, operational flexibility standards, operational reliability standards, border conditions assumed (set points): (i) reception and delivery nodes, (ii) flow rates and pressure by nodes, (iii) gas specification by reception nodes, (iv) contractual obligations in delivery nodes, (h) simulation: results of the simulation, calculated nominal capacity chart, (i) conclusions and notes, (j) third party additional comments, and (k) report improvement procedures.

4. Brazilian Regulations and the 11.909/2009 Law

The Brazilian regulatory framework concerning to natural gas transportation is defined by the Federal Laws 9.478/1997 and 11.909/2009, and the National Agency of Petroleum, Natural Gas and Biofuels (ANP – Agência Nacional do Petróleo, Gás Natural e Biocombustíveis) regulations. The first law, known as "Petroleum Law", establishes general principles for pipelines construction, third party access and tariffs definition. Most recently, a "Gas Law" has been promulgated. The Law 11.909/2009 is more detailed with respect to pipeline transportation services and ANP's responsibilities related to this issue, with highlight to auditing pipelines' technical and available capacities, and capacity transfer rights.

Even before the recent law, ANP had established on its Regulation no. 1/2003 that natural gas transporters must regularly publish their thermal hydraulic simulation reports in order to identify their transportation capacity. Nonetheless, as every pipeline had to have ANP's authorization for construction (according to Law 11.909/2009 from now on the construction will be preceded by an auction), expansion and operation, according to Regulation no. 170/1998, the agent's solicitation must be accompanied by the documentation and information that characterize the transportation capacities along with the project's life.

5. The Use of Thermal Hydraulic Simulation by ANP

In order to have resources to exert the regulation of the natural gas transportation market, ANP acquired a computational tool to simulate the operation of gas pipelines networks, Pipeline Studio® from Energy Solutions. This software composes the computational infrastructure of the Center for Supervision of Natural Gas Flow, situated at ANP's central office at Rio de Janeiro, since 2001. The main application provided for the tool was the verification of capacity of Brazilian gas transmission pipelines, existent or in construction. Furthermore, it would be used to compare the simulation data with operational data sent by TSOs to ANP. Many limitations were faced up like the absence of design data, such as pipe thickness for pipelines in operation prior to the Agency creation. It was only possible to simulate data of pipelines for which documentation was available in observance of ANP's Regulation no. 170/1998. This regulation is under revision and the presentation of thermal hydraulic simulation report will possibly become mandatory, along the analysis process for new projects or project's upgrades, like the addition of a compression station.

Two important subjects arise related to capacity calculation publicity. The first is related to the verification of declared values against results from calculations associated with the operational situation of an old pipeline (e.g. performance of a modified compressor). The second one is related to the verification of unused capacity[8] that is subject to third party access as foreseen in ANP's Regulation no. 27/2005.

Furthermore, ANP's technical team has been participating at training courses related to thermal hydraulic simulation, like Pipeline Studio Training – Induction e Gas Advanced, provided by Energy Solutions in 2007, and Pipeline Simulation training provided by the Mechanical Engineering Department of Pontifícia Universidade Católica – PUC-RJ, in 2008. Since then, ANP is looking forward to improve the monitoring of gas transportation service in Brazil, performing simulations and analysis related to new and preexistent gas pipelines. Hereafter some of this analysis will be presented:

- **Bolivia – Brazil Pipeline (GASBOL) Capacity Audit:** In 2001 a contract was celebrated between ANP and PUC-RJ with the aim of performing a technical audit of the available capacity of GASBOL, operated by Transportadora Brasileira Gasoduto Bolívia-Brasil S/A – TBG. The activities involved implementing a thermal hydraulic simulation model with Pipeline Studio software, verifying linepack (strategic stock), evaluating technical viability for transporting the volumes demanded by British Gas do Brasil - BG, verifying the pipeline's project ramp-up based on its design condition (build up condition), estimating capacity for each year considering a sort of scenarios like, for example, the thermoelectric plants consumption. As a result of the study, ANP granted access for BG in the GASBOL.
- **Development of a model to simulate TRANSPETRO's southeast network:** In the last quarter of 2002 the contract between ANP and PUC-RJ was renovated in order to develop new pipeline models, for pipelines operated by TRANSPETRO, at the Brazilian Southeastern region: GASVOL, GASPAL, GASAN, GASBEL, GASDUC I

[8] Difference between maximum daily transportation capacity (considering reception and delivery pressures) and daily transportation requested volume under firm service contract.

and GASDUC II. TRANSPETRO provided the data related to the pipelines design and gas specification. Nowadays a substantial portion of the data needs to be revised, as many alterations in the real infrastructure were implemented.

- **Cabiunas – REDUC Pipeline (GASDUC II) Flow Monitoring During Thermoelectric Dispatch:** In January 2008, concerned if the natural gas offer at the Brazilian Southern region, specifically between the Cabiunas' Terminal and the Duque de Caxias Refinery – REDUC, would be sufficient to simultaneously supply the Refinery and two thermoelectric plants (Mário Lago and Norte Fluminense), ANP performed a thermal hydraulic simulation of GASDUC II pipeline using the model developed by PUC-RJ. The minimum pressure delivery values and the Refinery's demand have been updated. Different scenarios of dispatch simultaneity were considered, once there is a great variability of the thermoelectric plants operation (number of generators in operation). The study showed that if the thermal plants operated at maximum generation capacity, the REDUC's delivery would be affected, that means reduced, once the delivery pressure at this point would be very close to the design lower limit.
- **Campinas-Rio Pipeline Monitoring:** In October 2008, after comparing the daily flow reports from two TSOs, TBG and TRANSPETRO, at an interconnection point between GASBOL and Campinas-Rio Pipeline (GASCAR), ANP noticed that the flow injected at GASCAR was above than that authorized[9]. Based on the design characteristics documentation, ANP developed its own model for the GASCAR pipeline, and compared the simulation results with those presented by TRANSPETRO. It was noticed that the value adopted by the TSO for the maximum allowed operational pressure (MAOP) at the reception point was inadequate. After that, the TSO requested ANP to review of the maximum flow capacity authorized. The revision is not yet concluded due to additional questions presented by ANP about the new thermal hydraulic simulation report presented.

6. Brazilian TSO's Simulation Reports - The Need for a Standard

As described in the previous section, as a result of its regulations, ANP continuously receives thermal hydraulic simulation reports, prepared by Brazilian TSOs. In the last years those reports have been analyzed in order to identify positive aspects and aspects that need to be improved, as shown in Table 2. The analysis reinforces the necessity of establishing a standard to be adopted by the different agents, and even among the reports prepared by the same agent at different moments and for different projects. This is important for the regulator to keep track of flow capacities evolution.

Table 2. Thermal Hydraulic Simulation Reports Analysis

Observed Aspect	Description	Analysis
Pipe Friction Factor	While some reports use the Colebrook model, most suitable for the design step, others use the American Gas Association (AGA) model, applicable for operational stage.	According to FAUER (2002) the Colebrook model results in lower flow values, higher pipe efficiency and higher discharge pressure.
Rugosity	Adoption of constant rugosity values, despite of variable diameters, internal covering or operational time.	A sensibility study elaborated by ANP showed a slight increase in flow with lower rugosity values.
Delivery points flow scenarios	Adoption of minimum pressure and maximum design flow for delivery points against adoption of recent historic average flow. In some cases the maximum flow is not adopted because of the existence of thermoelectric plants intermittent operation.	A sensibility study indicated that scenarios that do not reflect the flow profile (amplitude and periodicity) at delivery points contribute to hide operational bottlenecks.
Entry points maximum pressure	Some reports adopt the MAOP as the pressure limit at the entry points, while others consider the maximum discharge pressure of the compression station that supplies the entry point.	A sensibility study indicated that the maximum flow results are significantly affected by the value adopted for the pressure.
Uncounted Gas and System Gas	Some simulations consider only the compressors' drivers consumption, while other add the consumption at delivery points. Some reports also present a fixed percentage value for uncounted gas.	SANTOS & BISAGGIO (2007) and SANTOS et al (2008) concluded that the definition of calculation of system gas and uncounted gas is essential for the verification of elevated extraordinary and operational losses.
Steady state and transient simulations	Some reports only present steady state simulation results, considering that it represents appropriately point-to-point transmission, a small number of delivery points and a flat demand profile. Others	According to SANTOS (1997), the transient simulation is essential to properly calculate capacities, reflecting the operational scenario, with variable

[9] Before the Law 11.909/2009, every transportation infrastructure construction and operation was granted an authorization by ANP. From now on, except for projects involving another country, every new pipeline construction will be subject to an auction procedure.

Observed Aspect	Description	Analysis
	apply transient simulations for integrated networks.	demand profiles.
Environment and Soil temperatures (Summer and winter)	It was observed the use of ambient temperature distinct from those published by climate monitoring entities.	The temperature must be adequately defined. According to FOX (1995), viscosity increases with temperature and, consequently, reduces flow.
Global heat transfer coefficient	The use of constant global heat transfer coefficient was observed, despite of variations in pipe diameters and thickness.	DELMÉE (2003) mentions that the global coefficient affects the gas temperature and, consequently, the flow.
Gas composition	Some reports do not present percentages for CO_2, N_2 and H_2S. Others adopt standard values of density and heating value.	The linepack calculation is significantly affected by gas composition values.

7. Conclusion

Transparency is a keyword for the development of natural gas transportation market. The divulgation of flow capacities of a transportation system plays a major role in providing non-discriminatory access, appropriate allocation mechanisms, congestion management and foreseeing infrastructure expansion needs.

The Brazilian transmission network is composed of ca. 7000 km of pipelines, clearly underdeveloped if compared to its continental dimensions. But it is experiencing a significant growth, almost doubled in the last ten years. This growth has to be accompanied by reinforcement of regulatory tools that can assure a plain path for the action cited before. The tools that provide flow capacity (allocated or available) monitoring will play a crescent role in the transmission service industry.

However, as presented by this article, the capacity definition in itself can be a variable concept, and the methods for its calculation are heterogeneous around the world. Nevertheless, the Agency must define new mechanisms and improve the existing ones to accompany the market activities. The thermal hydraulic modeling and simulation is a recognized and well-established tool to support pipeline capacities calculation. ANP intends to keep using it and will continue to study the development of procedures that help increasing information transparency.

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