Series or Parallel – Tailor Made Design or a General Rule for a Compressor Station Arrangement?

by

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Abstract

This subject is always present when designing a gas pipeline that requires compressor stations to optimize the transportation and also capital and operation costs. On the Bolivia-Brazil gas pipeline project original design the technical economic analysis, thermo-hydraulic studies and failure analysis determined a selection of a parallel arrangement for the fourteen (14) compressor stations with four (4) 7000 hp ISO gas turbines per station. The project schedule considered the installation of three (3) initial compressor stations that were necessary for three (3) years of operation.

With more accurate information from market development, transportation contract ramp up changes and the experience acquired from the original design a new set of studies were done. The results obtained allowed a better understanding of compressor station operation and also allowed the selection of the size and arrangement of units to be adopted for the expansion.

The new studies considered bigger turbocompressors with series and parallel arrangement and electric driven compressors as an alternative for the project since there is an electric transmission line parallel to the gas pipeline in Brazilian side.

The optimization study proved series arrangement to be a better solution for the configuration with electric driven compressor taken benefit of the driver sizing and speed.

Economics aspects including capital cost, although considered in detail for the Bolivia-Brazil gas pipeline project, will not be addressed in this paper because of their particularities in terms of logistics, market competition and labor costs that will vary differently depending on the location of the project.

The purpose of this paper is to underline the need to simulate different sizes and arrangements for compressor station units and not selecting a off-the-shelf solution that might not be the best one in terms of capital investment, fuel usage and optimal energy management.

The simulation tool used to perform all the simulation analysis for the Bolivia-Brazil expansion project was PipeLine Studio 1.2 from Lic*Energy.*

This paper adds more information over the previous one presented on the PSIG Annual Meeting of 1997 entitled “Transient Analysis – A Must in Gas Pipeline Design”.

1 Introduction

The Bolivia-Brazil Gas Pipeline project required a capital investment of around US$ 2 billions. Natural gas is taken from proved and probable Bolivia reserves of around 23.37 TCF (0.66 trillions of cubic meters) to the Brazilian market in expansion.

The gas pipeline started operation on July 1st 1999 for the northern leg with DN 32" and 1127 miles (1813 km), from Rio Grande, Bolivia up to the city of Campinas in the state of São Paulo, Brazil. The southern leg, with diameters varying from DN 24" to 16" and with 683.5 miles (1100 km), goes from Campinas to the city of Porto alegre in the south of Brazil that started operation on March 21st 2000.

Gas demand growth along 20 years of operation (figure 2) and flow demand profile for each city gate defined the scenario for the hydraulic studies covering different size and arrangements for compressor stations units.

Transient simulation including failure analysis for compressor station units was fundamental for the selection of compressor units and configuration which best fulfilled technique and economic requirements as well as reliability and availability of equipment in addition to other relevant aspects of the transportation company.

The original design condition considered compressor stations with 4 turbo compressor units of 7000 ho ISO for a maximum transportation capacity of 1043 MMSCFD (30 MMm3/d) delivered at the city of Campinas.

The table below shows the simulated configurations:

2 System Configuration

The Bolivia-Brazil gas pipeline interconnects to the existing gas pipelines in the southwest states of Brazil e becomes a gas transportation network (figure 1) with 4 supplies of natural gas. The on going gas importation contracts from Bolivia totals 1043 MMSCFD (30 MMm3/d), from Argentina totals 312.9 MMSCFD (9 MMm3/d), under construction, from Campos Basin varies from 278 to 625.7 MMSCFD (8 to 18 MMm3/d) and from Santos Basin varies from 41.7 to 62.5 MMSCFD (1.2 to 1.8 MMm3/d).

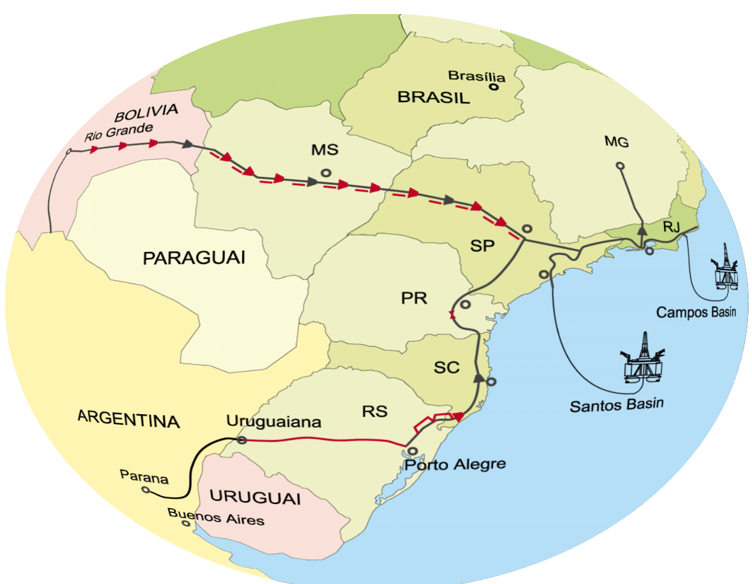


Figure 1 – Bolivia-Brazil Gas Pipeline Network

3 Basic Design Data for Compressor Station

3.1 Gas Composition (Molar %)

Methane	91.80
Ethane	5.58
Propane	0.97
i-Butane	0.03
n-Butane	0.02
Pentane and heavier	0.10
Nitrogen	1.42
Carbon dioxide	0.08

Molar Weight	17.367
k = Cp/Cv	1.295
Specific Gravity	0.600
Low Heat Value	1033 BTU/ft3 (9193 Kcal/m3)

3.2 Operation Conditions

Maximum Discharge Pressure	1420 psig (99.84 kgf/cm2g)
Maximum Compressor Ratio	1.8
Header Pressure Drop @ 30 MMm3/d	5 psi (0.35 kgf/cm2g)
Site Temperature for Summer	82.4 to 87.8 °F (28 to 31 °C)
Site temperature for Winter	62.6 to 69.8 °F (17 to 21 °C)
Compressor Station Elevations	341 to 2750 feet (104 to 838 meter)

3.3 Gas Demand Ramp Up

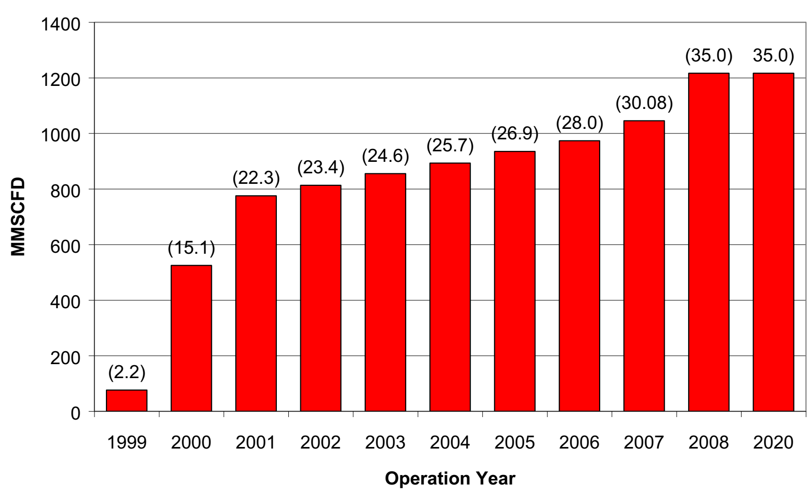


Figure 2 – Gas Demand Ramp Up

4 Design Approach

The procedure adopted to select the compressor station units and configuration follow a sequence of steps to save engineering and simulation time:

Step 1. Run steady and transient states for the model with generic compressor and driver at each new compressor station and for each operation year. Set a maximum power available for maximum capacity at each station and compare with market availability in terms of compressor and driver. From figure 3 it can be seem the effect of putting a limit on the maximum power available. The station discharge pressure drops when maximum power is reached and more capacity is demanded from the system. As long as contractual minimum pressure is not achieved on the delivery points and keeping a reasonable margin for the pipeline operation line pack this will optimize the driver sizing.

Step 2. With the adjusted power profile and compression ratio taken from the maximum capacity transient run a pre-selection of compressor and driver was made based on manufacturers availability. A transient analysis with the pre-selected equipment was done and adjustments discussed with manufacturers so as to guarantee the selection process.

Step 3. With the equipment pre-selected and adjusted for maximum capacity the previous operation years was checked in terms of installed units requirements and necessary changes in compressor impellers.

Step 4. Series and parallel arrangement were then tested for fuel usage and failure analysis.

Since the Brazilian side of the pipeline has a high tension line running in parallel to the pipeline (figure 4) the alternative using variable speed electric motor drive was considered for both parallel and series arrangement for the stations.

Series arrangement was not considered for gas turbine driver since the power requirement for the station was not match by the available gas turbines.

Considering the above mentioned, simulation analysis was made for the following alternatives:

A. Three turbocompressor units per station in parallel arrangement
B. Three electric driven compressor units in parallel arrangement
C. Two electric driven compressor units in series.

The electric drivers presented the characteristic of being modulated to the station power requirement and together with electric power availability became an attractive option.

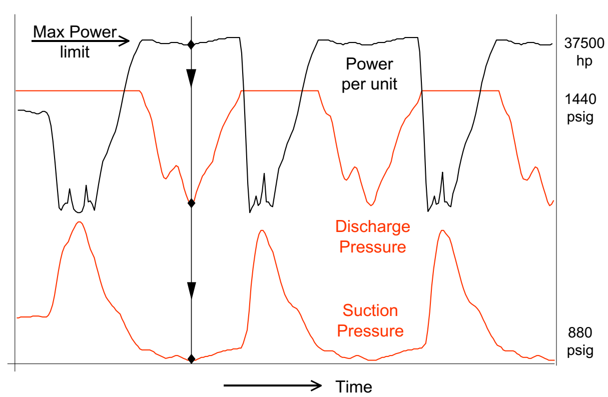


Figure 3 - Typical Power Limit Effect on Discharge Pressure

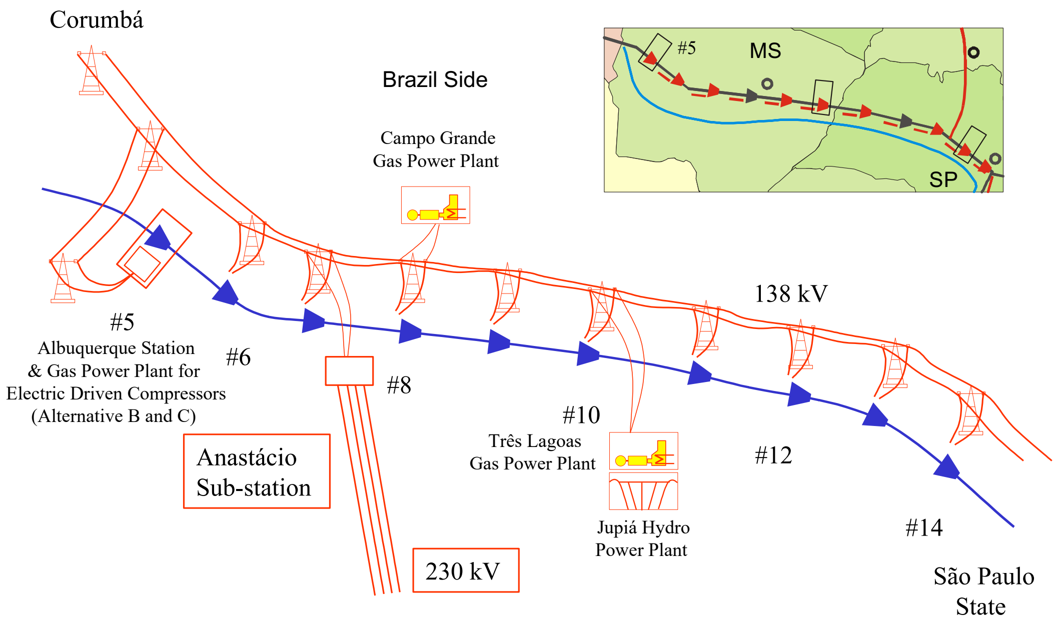


Figure 4 - Gas Pipeline and High Tension Line

5 Pre-selection of Equipment

To allow the pre-selection of equipment a text file from the transient run for each year of operation including the variables necessary to size centrifugal compressor and drivers was sent to the manufacturers. This approach proved to be efficient and prompted for detailed technical discussions between project engineering and manufacturers representatives resulting in a good understanding of the gas transportation system needs and saving time. Some but no all equipment pre-selected is presented in the following paragraphs.

5.1 Alternative A – Three Turbocompressors per Station in Parallel

Pipeline Maximum Capacity:	1.1819 Bcf/d (34 MMm3/d)
Compressor type:	Solar C452 C2F-B3R
Gas Turbine:	Solar Mars 100 – 15000 TMF-2

5.2 Alternative B – Three Electric Driven Compressors per Station in Parallel

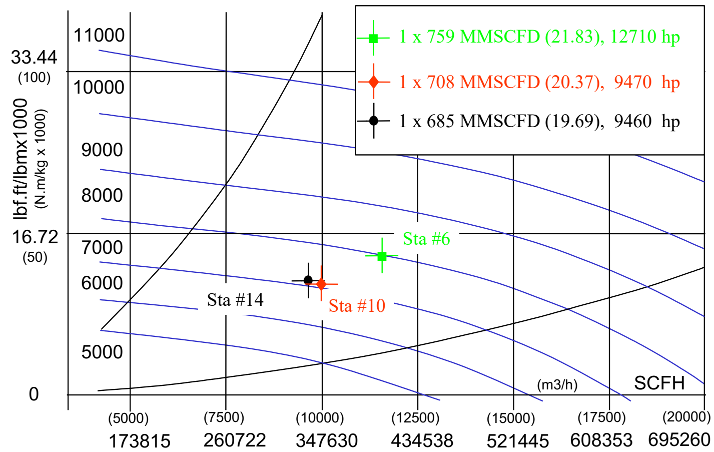
Pipeline Maximum Capacity:	1.2167 Bcf/d (35 MMm3/d)
Compressor type:	Solar C452 C2F-B3R
Electric Motor (Variable Speed Driver):	Siemens – 10 MW

5.3 Alternative C – Two Electric Driven Compressors per Station in Series

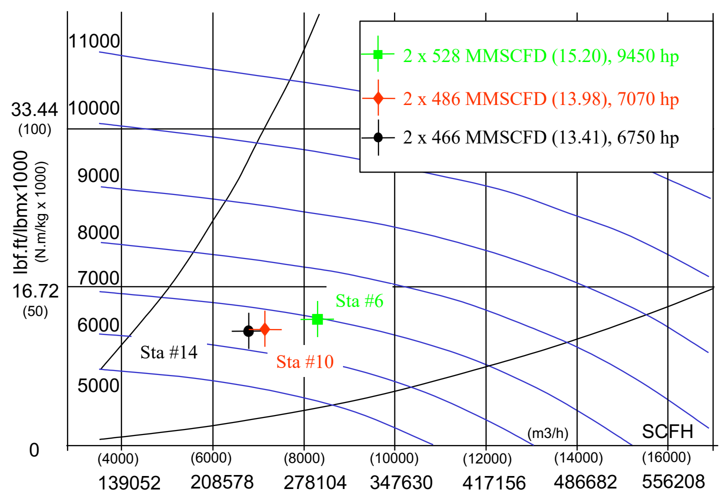
Pipeline Maximum Capacity:	1.2167 Bcf/d (35 MMm3/d)
Compressor type:	Cooper RFA36
Electric Motor (Variable Speed Driver):	Siemens – 16 MW

6 Compressor Station Performance Results

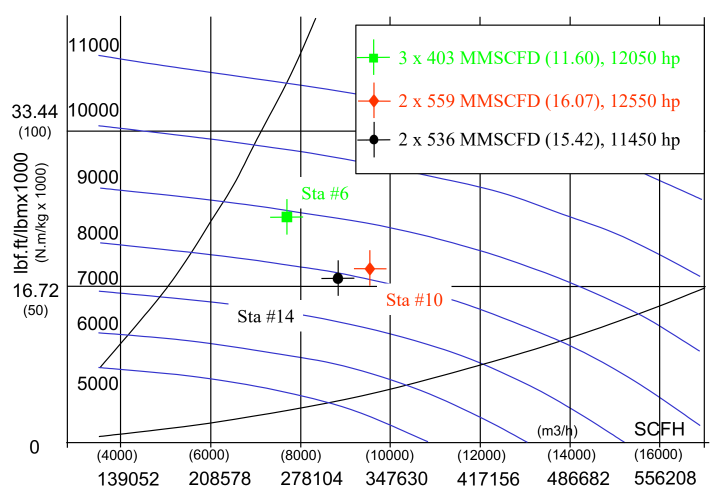
6.1 Alternative A – Three Turbocompressors per Station in Parallel



year 2001 – Gas pipeline capacity of 775.2 MMSCFD (22.3 MMm3/d)

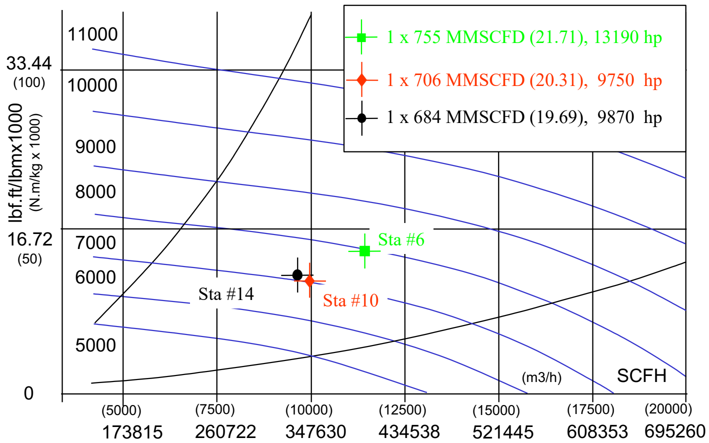


year 2007 – Gas pipeline capacity of 1043 MMSCFD (30.08 MMm3/d)

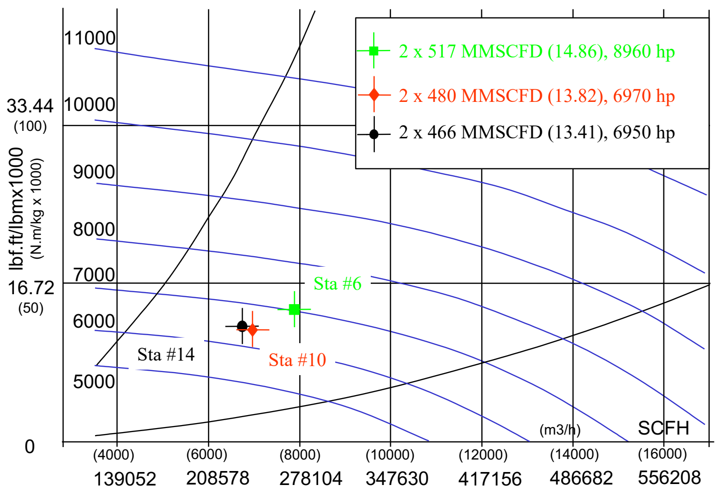


year 2008 – Gas pipeline capacity of 1182 MMSCFD (34.0 MMm3/d)

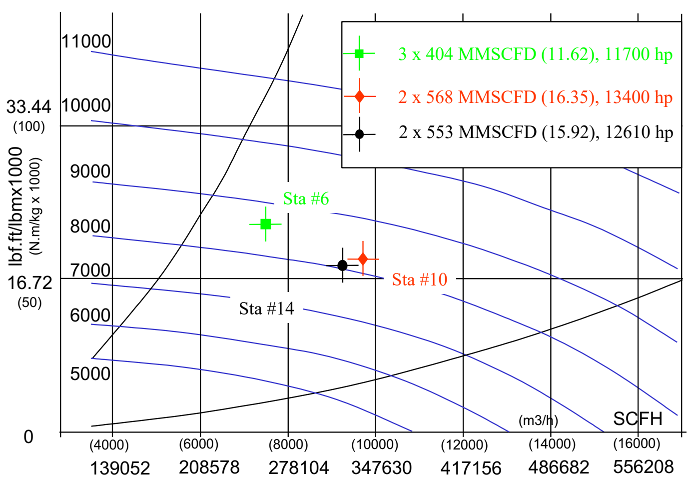
6.2 Alternative B – Three Electric Driven Compressors per Station in Parallel



year 2001 – Gas pipeline capacity of 775.2 MMSCFD (22.3 MMm3/d)

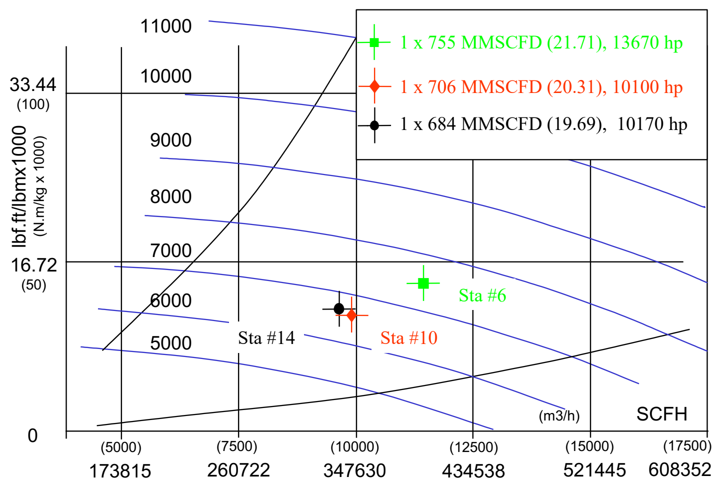


year 2007 – Gas pipeline capacity of 1043 MMSCFD (30.08 MMm3/d)

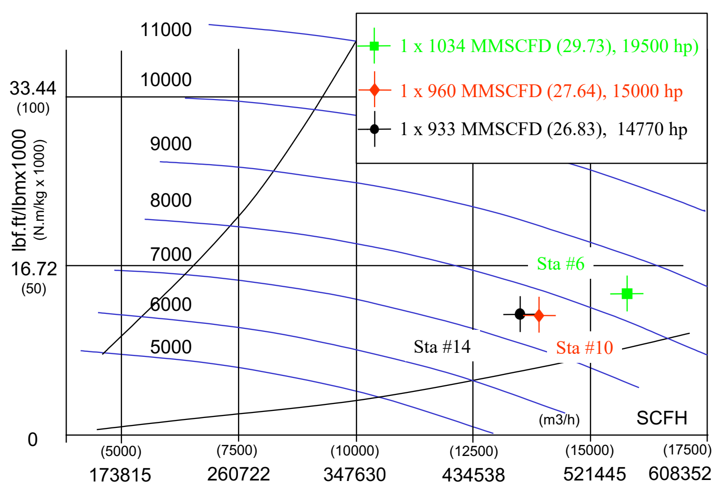


year 2008 – Gas pipeline capacity of 1217 MMSCFD (35.0 MMm3/d)

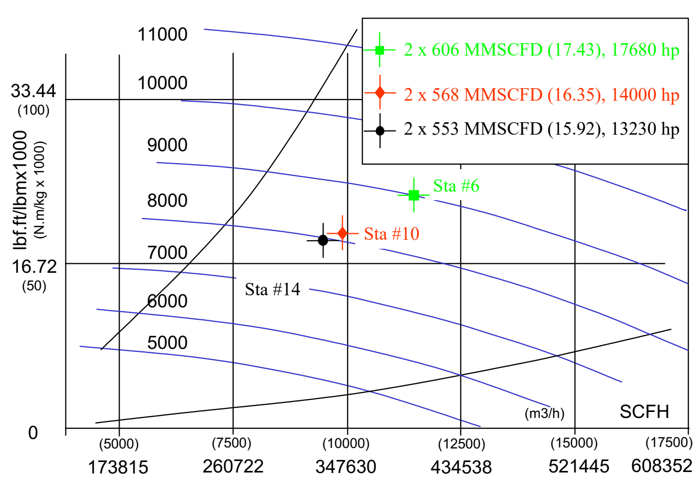
6.3 Alternative C – Two Electric Driven Compressors per Station in Series



year 2001 – Gas pipeline capacity of 775.2 MMSCFD (22.3 MMm3/d)

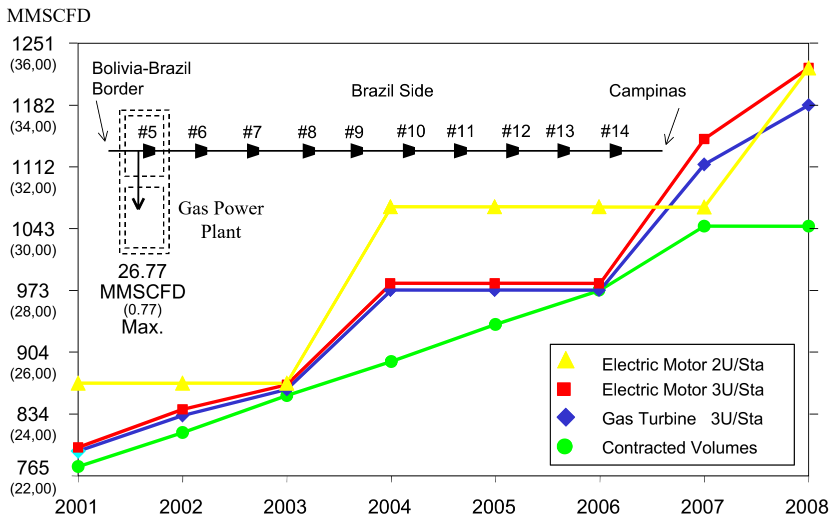


year 2007 – Gas pipeline capacity of 1043 MMSCFD (30.08 MMm3/d)



year 2008 – Gas pipeline capacity of 1217 MMSCFD (35.0 MMm3/d)

7 Gas Pipeline Capacity Comparison



8 Failure Analysis

The failure analysis performed for alternative presented the following results for after failure steady state capacity presented in the table below. Series arrangement with 2Units/Sta. and electric motor (variable speed driver) is the best performance selection.

Failure of Unit	Electric Motor		Gas Turbine
	MMSCFD (MMm3/d)		
	2Units/Sta.	3Units/Sta.	3Units/Sta.
U5A	1088 (31.3)	1172 (33.7)	1140 (32.8)
U7A	1119 (32.2)	1192 (34.3)	1158 (33.3)
U9A	1161 (33.4)	1015 (29.2)	1175 (33.8)
U11A	1175 (33.8)	1015 (29.2)	991(28.5)
U14A	1168 (33.6)	1032 (29.7)	1005 (28.9)
Minimum	1088 (31.3)	1032 (29.2)	991 (28.5)
Average	1144 (32.9)	1085 (31.2)	1095 (31.5)
Maximum	1175 (33.8)	1192 (34.3)	1175 (33.8)

9 Final Considerations

The outcome of all of the work performed during the expansion design of the Bolivia-Brazil Gas Pipeline Project is that *we can not overlook the importance of* steady state and transient simulation as a optimization tool for a gas pipeline and compressor station design. The adequate selection of compressor units and arrangement definition whether series or parallel requires transient analysis.

Although someone might say that this approach would be time consuming the reality says different. Every work performed in the design phase will help defining technical, operational and economical aspects that will save a lot of time and doubts along the project implementation. It is also important in defining parameters for the pipeline operation to be included in the transportation contracts.

We come to a conclusion that compressor unit sizing, arrangement definition and driver selection are part of a technical and economic study that will identify which alternative is the best one on *a tailor made design* and not based on *general rules*!

Reinforcing what was sad in the previous paper “Transient Analysis” is really “A Must in Gas Pipeline Design”!

10 References

(1) Santos, Sidney Pereira dos, Transient Analysis – A Must in Gas Pipeline Design. PSIG – Pipeline Simulation Interest Group, October 15-17, 1997, Arizona, USA.
(2) Reid, David E., Gas or electric compressor choices dictated by economics – Pipeline and Gas Industry, July 1998 Vol. 81 No. 7

11 About GASPETRO and the Author

Petrobras Gás S.A. – GASPETRO, Petrobras' integral subsidiary, responsible for commercialization of natural produced in Brazil and imported from Bolivia and Argentina, with joint ventures and partnership in gas pipeline projects and natural gas Power Plants.

Sidney Pereira dos Santos, the author, is a technical consultant at GASPETRO, has a Mechanical Engineering degree and a MBA in Corporate Finance, has 13 years of experience in shipbuilding design, and also 13 years in the oil and gas pipeline design at Petrobras . Has been deeply involved in most of the gas pipeline projects such as the Bolivia-Brazil project. Has been conducting technical-economic studies and basic/conceptual design for the upcoming projects. He also participated as Project Manager in the first two years of operation (1998-1999) of the Bolivia-Brazil transportation company in Brazil side.

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