Security of Gas Supply to a Thermoelectric Using Gas Cave Storage

J.D. Amaral Netto & L.F. S. Oliveira
DNV GL, Rio de Janeiro, RJ Brazil

D. Faertes
Rio de Janeiro, RJ Brazil

Abstract

For natural gas underground storage the following types of caves can be used: depleted oil and gas reservoirs, aquifers and salt caves. The oil and gas depleted reservoirs are the most common types of cave mainly due to low initial capital expenditure. The storage capacity, injection flow, removal flow and cave features vary between types of caves. The use of caves for natural gas storage increases the flexibility of production and transportation decisions. An important use of caves is to take advantage of the LNG (Liquefied Natural Gas) seasonal prices pattern. This study illustrates the evaluation of the security of gas supply to a thermoelectric with gas cave storage. The modelling of this problem using discrete event simulation not only incorporates the failures of the normal supply source, gas vaporizer and compressor stations, but also the variations of the gas source production, variations of thermo plant demand, the LNG ships travel times and possible travel delays.

Logistic problems related to LNG supply chain, such as travel time, first LNG ship call and storage restrictions cause great impact over the security of gas supply to the thermo plant. Our results also showed that the change of LNG ship travel time from 25-30 days to 5-30 days increased the thermo plant gas supply efficiency of 3.53%. By calling the first LNG ship in advance of one month before the start of the peak season caused an increase of about 10% on efficiency. Considering both measures together, the total gas supply efficiency increase was of around 13.5%. Doubling the cave volume did not increased the thermo plant gas supply efficiency but reduced the LNG ship docking time from 80.2 days to 33.7 days. This by itself may represent an important impact on the operational results of the use of caves for gas storage.

1. INTRODUCTION

For natural gas underground storage the following types of caves can be used: depleted oil and gas reservoirs, aquifers and salt caverns. The depleted oil and gas reservoirs are the most common types of cave mainly due to low initial capital expenditure. The storage is already in place and also most of the surface facilities and necessary infrastructure. Thus, depleted oil wells have high storage capacity and the advantage of lower cost. In addition, geological data are known, and the risk of leaks is low. The main drawback is the amount of gas cushion required for operation.

The gas storage in aquifer requires conducting seismic, with higher risks and costs than depleted oil wells. The storage in aquifer, besides the seismic survey, requires a gas cushion of 80 to 90% for operation and its development is slow and expensive [1]. This type of cave is used where there is no depleted reservoir of oil and gas. One advantage of this type of cave is the relatively high withdrawal flow rate.

In underground salt caverns water is used to dissolve the salt rock and shape the natural cavities. These cavities have impervious walls allowing high pressure of the stored gas withdrawal at a high flow volume and low gas cushion (about 25% of the total gas stored). The salt dissolution process and cave molding makes this type more expensive than the aquifer, which in turn is more expensive than the depleted oil and gas reservoir. Salt caverns typically have high costs. The maximum in- and outflow rates of the storage varies with the current storage level. The maximal injection rate is a strictly decreasing convex function of the storage level. Likewise the outflow rate can be given as a strictly increasing convex function of the storage level.

LNG storage tanks at the surface can also be used for storage of natural gas, but the capacity is limited. The storage capacity, injection flow, removal flow and cave features vary between types of caves. The storage capacity is limited by the physical characteristics of the cavern. The volume of stored gas is the total gas volume of natural gas at a given time. The gas cushion is the volume of gas needed to create sufficient pressure to raise the gas. The amount of gas cushion varies with the type of cave and the local geological conditions. Working gas is the volume of gas available during normal operation of the cave, being equal to the total volume of gas stored minus the gas cushion.

The use of caves allows gas storage close to the consumer market and can meet the demand variations or failures in the normal supply sources. They can also be used for storing excess production in periods of low demand. Thus, the cave functions as buffer stock to minimize bottlenecks of the gas network during periods of high demand or in situations of failures.

The use of caves for natural gas storage increases the flexibility of the decisions of production and transportation. An important use of the caves is to take advantage of the LNG prices seasonal pattern. Since the main use of natural gas is for heating and electricity production, the determining factor in the price are the weather conditions. The demand is typically higher in winter than in summer. The difference between peak demand and natural gas production can be to some extent supplied by the use of gas storage. In the event of faults or problems in production sources or in the transportation facilities, storage can be used to supply the downstream consumers. With the development of LNG market short-term and volatile local prices, the cave can be used to take advantage of price fluctuations.

This work presents an illustrative example of a simplified gas network in order to show the application of discreet event driven simulation using the program TARO Total Asset Review and Optimization [2]. This simplified gas network has only one normal supply source, a pipeline, one compression station and two city gates: one for a residential/industrial consumer and the other for a thermo plant (see Figure 1).

The source supply diary fluctuations were represented by a normal distribution with mean of 1000mscm and a standard deviation of 100mscm. As the residential consumer has higher priority to receive the gas than the thermo plant, the source fluctuations affects the thermo plant supply. Normally the consumers demand is supplied by the source, being eventually disturbed by failures at the compressor station or at the source. All failure rates were considered to be exponentially distributed and the repair duration were represented by rectangular distributions. The compressor station shutdowns occur in average once in a year with time to repair varying between a minimum of 24h and a maximum of 48h. The gas source has two different types of failure: total shutdown and flow reductions. It is being considered that source shutdowns occur in average four times in a year with duration between 48h and 72h. The gas flow reduction by half occurs also 4 times in a year with duration between 24h and 48h. In case of source failure, the pipeline has normally a volume of gas stored that is enough to supply the consumers around ten hours after the failure (line-pack volume of 500mscm).

Due to hydro power plant generation water shortage in the months of May up to September of the following year, the thermo plant would have to increase its demand from 800mscm/d to 2800mscm/d. In order to supply this extra demand it was envisaged the use of Liquefied Natural Gas (LNG) supply from an underground storage such as a depleted field. This underground storage would have its integrity monitored in order to avoid stored gas leakages or third part interference. The additional gas stored in this underground storage would be supplied by imported gas by LNG ships and by offer surplus due to lower industrial consumption during weekends. LNG would be vaporized and stored at the cave before the peak demand period. From this cave the gas would be used to supply the extra consumption by the thermo plant during the peak demand season and all the consumers during source failures and during source flow reductions or fluctuations, as show in Figure 1. In this model it is being considered that the cave injection and outflow rates do not change with cave level, cave compressors do not fail and the required cushion volume is already in place.

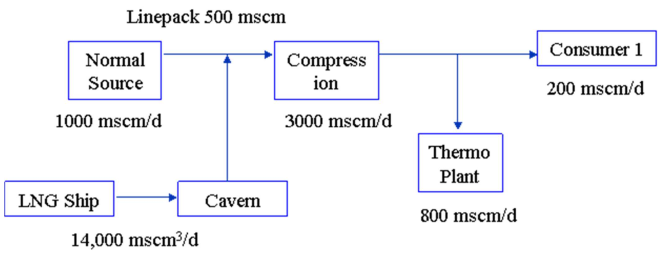


Figure 1 LNG Supply through Cave Storage

In a previous work [3] three alternatives of LNG supplying the thermo plant extra demand were analyzed: In the first alternative, LNG ships would supply directly the thermo plant. In the second, a LNG Terminal would receive the LNG and would supply the thermo plant. In the third alternative, LNG ship would unload to an underground storage that would supply the thermo plant. The present work has the objective to analyze the last alternative using discreet event simulation in order to evaluate possible constraints due to logistic problems. As the LNG would be bought from different sources, the main concerns would be related to LNG ships travel time variation, possible travel delays and the required underground storage volume. As ship delays can vary, a sensitivity analysis was done in order to determine the required net underground cave volume to minimize ship dock time [4].

The parameter used for comparison was the thermo plant production efficiency, which is obtained by the ratio between the annual gas volume delivered and the demand required by the thermo plant.

2. BASE CASE RESULTS

In the base case it was considered a travel time evenly distributed between 25 and 30 days and a cave storage capacity of 100,000mscm. Running this base case simulation model during one year for 250 lifecycles an annual average value of 80.83%, as shown in Figure 2.

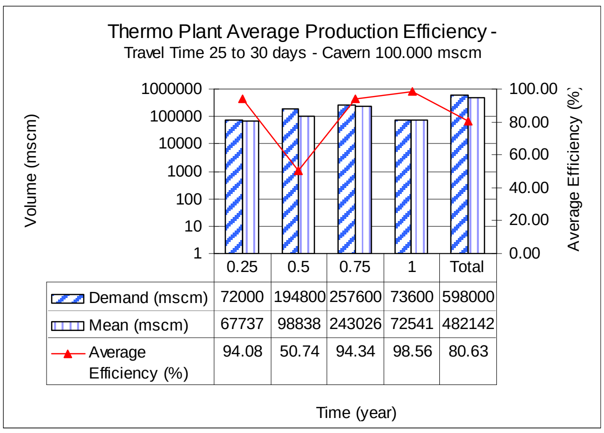


Figure 2 Volume Delivered and Thermo Plant Average Efficiency – Base Case

Before the LNG starting, the gas flow rate to the thermo plant is affected by the normal source failures and flow rate fluctuations. With the LNG supply the thermo plant demand is attended during great part of the peak demand and is not affected anymore by the source flow rate fluctuations, as shown in Figure 3.

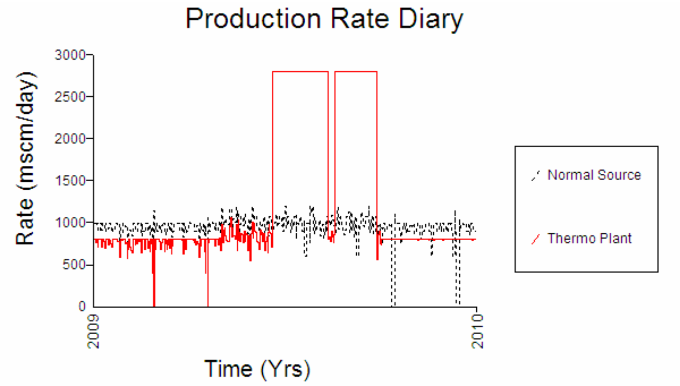


Figure 3 Source and Thermo Plant Flow Rates – Base Case

Figure 4 presents the usage of the line-pack to cover the first hours after a source failure or flow reduction. Figure 5 shows the LNG ships and cave volume variations along the year. It can be observed that for some time during the peak season the cave is empty and the thermo plant is supplied only by the normal source. It means that the LNG ship travel time of 25 to 30 days is too long, being necessary to reduce it.

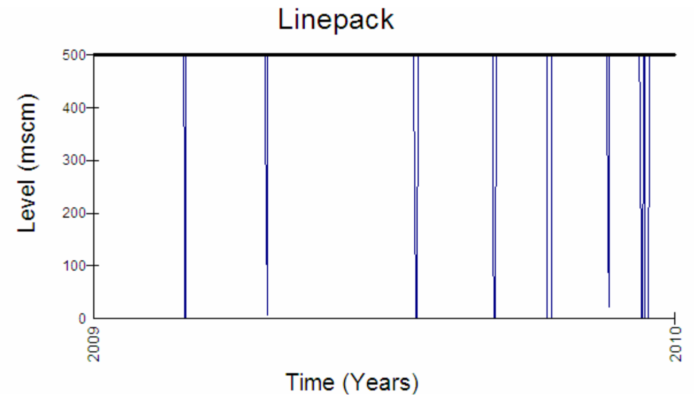


Figure 4 Use of Line-pack After Source Failures or Flow Reductions

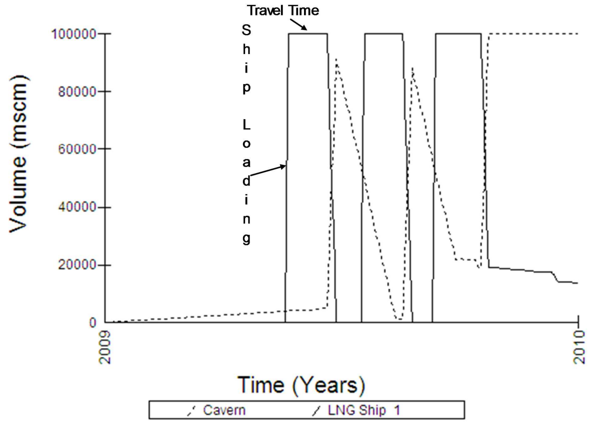


Figure 5 LNG Ships and Cave Volume Behavior – Base Case

3. SENSITIVITY CASES RESULTS

As the base case results indicated a need to reduce LNG ship travel time, some sensitivity cases were simulated considering variation on LNG ship travel time, cave capacity and date of starting calling the LNG carriers, as shown in Table 1.

Table 1 Sensitivity Cases Changing Travel Time and Cave Volume and First LNG Ship Call

Case	Travel Time (days)	Cavern Size (mscm)	LNG Ship Starting Calling Date
Base case	25 to 30	100,000	May first
Case 1	5 to 10	100,000	May first
Case 2	5 to 10	200,000	May first
Case 3	5 to 30	200,000	May first
Case 4	5 to 30	200,000	April first

The first sensitivity case (Case 1) considered an optimistic estimative of the LNG travel time between 5 and 10 days. In this case, the thermo plant annual average efficiency increased from 80.63% to 88.2%. However time spent by LNG carriers to unload is increased due to lack of space to store LNG, as can be seen in Figure 6. In the period that cave is full the LNG ship unloading rate is reduced to the difference between consumer demand and source supply. This indicated the need to increase the cave volume in order to reduce LNG ship docking time.

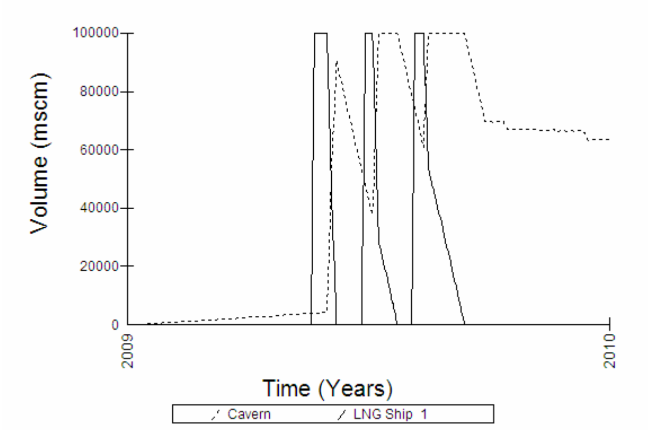


Figure 6 LNG Ships and Cave Volume – Case 1

The second case considered the increase of cave volume to 200,000mscm and the LNG ship travel between 5 and 10 days. In this case, there were no restrictions to LNG ships unloading time, as can be seen in Figure 7.

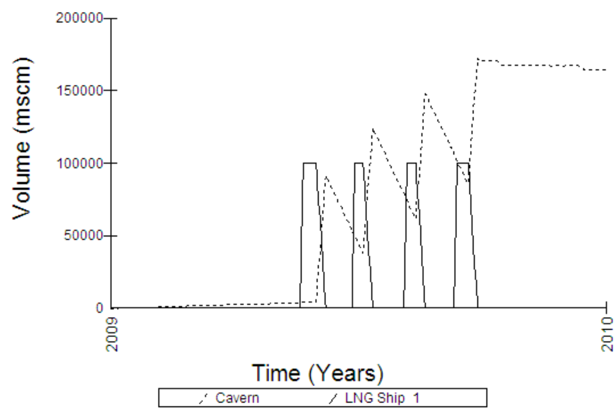
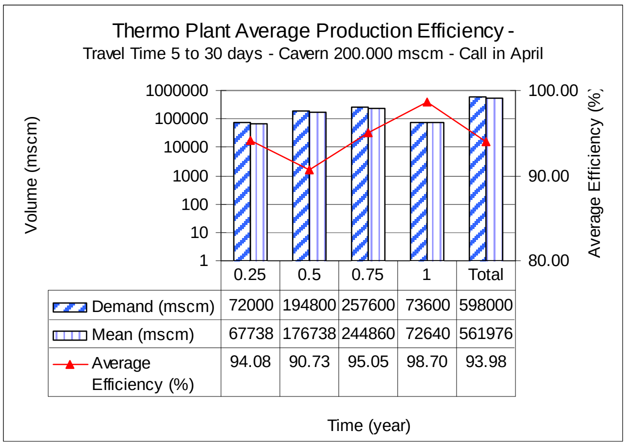


Figure 7 LNG Ships and Cave Volume Behavior – Case 2

LNG supply sources are localized in different parts of the world. Considering the uncertainties from which place the LNG would be supplied, it was found more reasonable to consider a travel time evenly distributed between the minimum of 5 days and the maximum of 30 days. By considering that in case 3, the average annual thermo plant efficiency decreased from 88.2% to 84.16%. The major efficiency loss is associated to the beginning of the peak demand period due to waiting time for the first LNG ship to arrive. In order to solve this problem, the LNG ship calling should start well in advance the peak demand period.

Case 4 considers LNG ship start calling date at April first, travel time between 5 and 30 days and cave volume of 200,000mscm. In this case, the thermo plant annual average efficiency increases from 84.16% to 93.98% (see Figure 8). After LNG ship starts feeding the cave, there is no reduction on the flow rate delivered to the thermo plant (see Figure 9) and there are no LNG ship docking time increase (see Figure 10).



	0.25	0.5	0.75	1	Total
Demand (mscm)	72000	194800	257600	73600	598000
Mean (mscm)	67738	176738	244860	72640	561976
Average Efficiency (%)	94.08	90.73	95.05	98.70	93.98

Figure 8 Volume Delivered and Thermo Plant Average Efficiency – Case 4

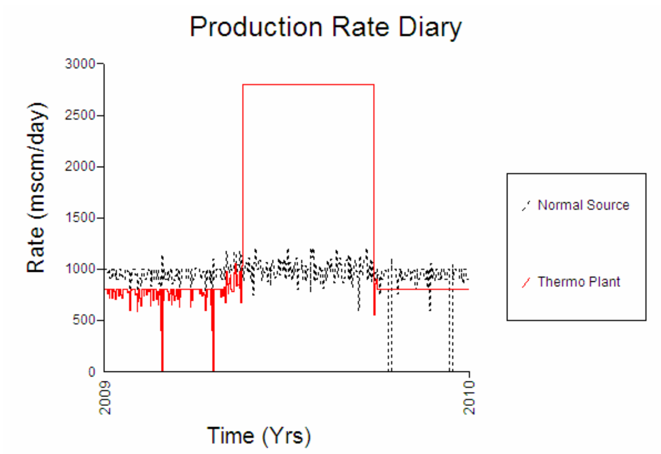


Figure 9 Source and Thermo Plant Flow Rates – Case 4

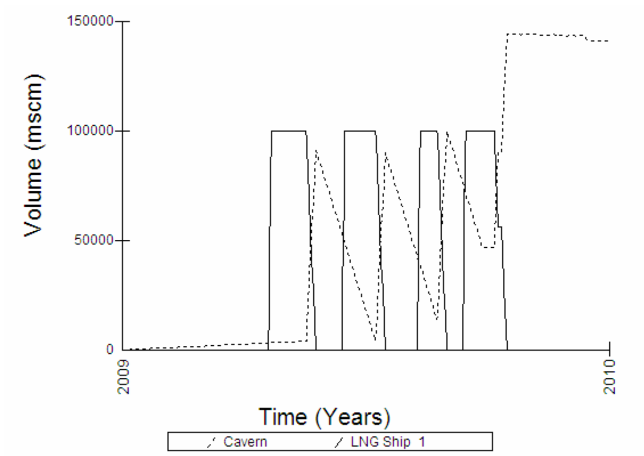


Figure 10 LNG Ships and Cave Volume – Case 4

4. CONCLUSION

The use of discreet event driven simulation allowed consider not only the failure and repair rates of the gas network, but also the logistic related to LNG ship travel time, cavern volume and ship calling date. Table 2 summarizes the thermo plant mean average annual efficiency obtained for each case and the difference in relation to the base case.

Logistic problems related to LNG supply chain, such as travel time, first LNG ship call and storage restrictions cause great impact over the security of gas supply to the thermo plant. From Table 2 it can be seen that the change of LNG ship travel time from 25-30 days to 5-30 days increased the thermo plant gas supply efficiency of 3.53%, while the first LNG ship call in advance of one month before the peak season caused an increase of 9.82%. Considering both measures together, the total gas supply efficiency increase was of 13.35%. Doubling the cave volume did not increased the thermo plant gas supply efficiency but reduced the LNG ship docking time from 80.2 days to 33.7 days.

Table 2 Thermo Plant Average Efficiency Variation

Case	Travel Time (days)	Cavern Size (mscm)	LNG Ship Starting Calling Date	Average Eficiency (%)	Eficiency Variation (%)
Base Case	25 to 30	100,000	May first	80.63	
Case 1	5 to 10	100,000	May first	88.20	7.57
Case 2	5 to 10	200,000	May first	88.05	7.43
Case 3	5 to 30	200,000	May first	84.16	3.53
Case 4	5 to 30	200,000	April first	93.98	13.35

5. REFERENCES

[1] TOMASGARD, A., RØMO, F., FODSTAD, M., MIDTHUM, K., "Optimization Models for the Natural Gas Value Chain", Chapter in G. Hasle, K.-A. Lie, E. Quak (eds.): *Geometric Modelling, Numerical Simulation and Optimization*, Springer Verlag, 2007.
[2] DNV GL, "TARO – Total Asset Review and Optimization Program", version 4.04, 2012.
[3] AMARAL NETTO, J.D., OLIVEIRA, L.F.S. FAERTES, D., "Avaliação de Alternativas de Segurança de Suprimento de Gás Através de Simulação por Eventos Discretos", RIO PIPELINE, 2007.
[4] AMARAL NETTO, J.D., OLIVEIRA, L.F.S. FAERTES, D., "A Security of Gas Supply to a Gas Plant from Cave Storage Using Discrete-Event Simulation", ESREL, 2008.