OptimA, a tool for optimization of the Agenda of LNG Cargos for a regasification plant integrated to the Uruguayan power system.

L. Di Chiara, P. Soubes, F. Fontana, S. Belendo and R. Chaer, Senior Member, IEEE

***Abstract*-- Uruguay is evaluating the installation of a Floating Storage Regasification Unit (FSRU) of Liquefied Natural Gas (LNG). This paper present the tool OptimA that is the algorithm developed for the optimization of the Agenda of Cargos for the FSRU and the integration of the new energy reservoir for the optimal operation of the power system. The algorithm is capable of determining the policy for operation of the reservoir and the policy for buying and diverting Spot Cargos. This paper shows the paths proposed to reduce the impact of the Curse of Dimensionality of Bellman.**

***Index Terms*—Optimal operation, power system, LNG regasification plant, agenda, cargos, optimization.**

I. Nomenclature

Agenda: Schedule of arrivals of LNG Cargos.
Cargo: The shipment of a vessel transporting LNG.
FSRU: Floating Storage Regasification Unit.
LNG: Liquefied Natural Gas.
NG: Natural Gas.
OOP: Optimal Operation Policy.
SimSEE: Platform for Simulation of optimal operation of Systems of Electric Energy.
SDP: Stochastic Dynamic Programming.s
TOP: Take Or Pay.

II. Introduction

THE tropical rainfall regime of Uruguay imposes a high variability of the hydro-electric generation. As shown in Fig.1, the annual hydroelectric generation varies from 3,000 GWh to 9,000 GWh with a mean value of 6,000 GWh. This variability is a challenge for the system operation that is carried out using stochastic dynamic programming in order to compute the policy for optimal operation of the reservoirs of the hydro-electric subsystem.

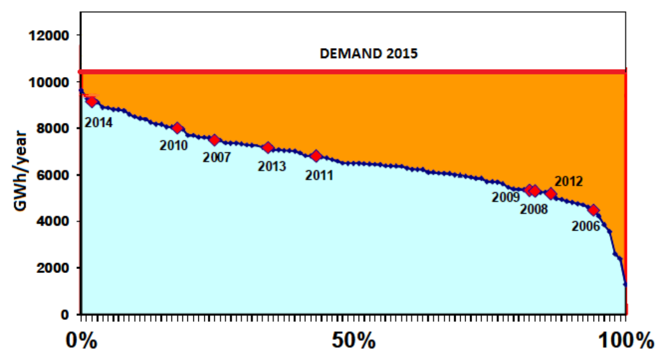

Fig. 1 Variability of hidroelectrical generation.

Uruguay is considering the installation of a FSRU with a storage capacity of approximately 250,000 m3 and a regasification capacity of 10 Mm3/day. This planned storage capacity is about 70% of the energy that can be stored in the largest dam of the hydroelectric subsystem. That is, the FSRU would be the second energy reservoir of the country and must be considered in the computation of the optimal policy for operation of the power generation system.

In addition of the storage capacity, in order to calculate the optimal dispatch, the optimization of the annual Agenda of LNG Cargos must be performed. When optimizing the Agenda, the potential costs associated with diverting Cargos to Spot market or the needing of buying Cargos from the Spot market must be taken into account.

III. SimSEE model and optimal operation

The SimSEE [1] software solves the optimal operation of an electrical system, modeling it as a dynamic system in which participate multiple sources of energy, electrical interconnections and demands.

The SimSEE uses Stochastic Dynamic Programming methodology in order to calculate the Optimal Operation Policy (OOP) for the operation. This algorithm suffers from the curse of dimensionality of Bellman [?Bellman75]. This implies that when the dimension of the state space increases, the time for solving the problem is prohibitive.

In the case of Uruguay, the NG consumption of the power system is about 3,000 m3/day when all the thermal generation units are fired. This number is one order greater than the non-electric consumption that is about 250 m3/day. If the FSRU is built, it must be considered as the unique source of NG for the country and so the availability of NG must be ensured.

Other aspect that increases the difficulty of the problem to be solved is the fact that some input data have uncertainty,

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Examples of affiliation footnotes:

J. W. Hagge is with Nebraska Public Power, District Hastings, NE 68902 USA (e-mail: author@abcd.com).

L. L. Grigsby is with the Department of Electrical Engineering, Auburn University, Auburn, AL 36849 USA (e-mail: author@abcd.edu).

such as: the energy demand, the hydrological conditions, the wind resource, availability of machines, fuel prices, etc. These uncertainties are modeled as stochastic processes.

The problem of optimization of the Agenda is incorporated to the dynamic programming optimization integrating the electrical energy demand and the NG energy demand in the same problem. The FSRU is modeled with a reservoir of energy whose operation policy is computed by the optimization solver.

IV. The Uruguayan electricity system

Nowadays, Uruguay has an installed generation capacity of about 3,300 MW, 46% of this capacity is hydroelectric generation, 26% is wind generation, 22% is thermal generation and 6% is biomass and photovoltaic generation. In addition, a combined cycle with a 540 MW capacity that can operate with Natural Gas or Gas Oil, is under construction.

The hydroelectric plants are distributed over two rivers. The Río Negro that runs from east to west in the center of the country and the Río Uruguay which runs from north to south in the frontier of Uruguay with Argentina. On the Río Negro there are three chained hydroelectric plants: Gabriel Terra (152 MW) which is located upstream and has the largest storage capacity of the country (approximately 4 months) followed by Baygorria (108 MW) that is a run-of-river plant and Constitución (333 MW) whose storage capacity is about 20 days.

On the Río Uruguay is located the bi-national (Uruguay – Argentina) Salto Grande plant with an installed capacity of 1890 MW. Half of the energy generated corresponds to Uruguay and the other half to Argentina. The reservoir storage capacity of the dam is about 10 days, shared by both countries.

The solution of optimal operation of a hydrothermal system is a classical stochastic dynamic problem as shown in [ ] and [RefMVP20031] that suffer from the Curse Of Dimensionality. A lot of efforts have been made to avoid this Curse as the Stochastic Dual Dynamic Programming proposed in [$efMVP2].
(Comentar ventajas de SDP vs SDDP para Uruguay+Regas).

The possibility of having energy stored allows to decide when to use it, according to the convenience of the system to replace more expensive resources. That is, the possibility of storing a resource is a way to move it in the time for a future use. This situation introduces linkage between present and future. The optimal solution is a balance between the benefit of using the resource (water or LNG) in the present versus its use in the future. If the benefit of using a unit of some resource in the future is greater than the benefit of using it in the present, that unit will be stored (for future use) increasing the cost of operation in the present and reducing the cost of operation of the future. The same behavior continues unit by unit until the equilibrium is reached (this is the Hamilton principle).

V. Logistic and trade of LNG

Worldwide, there are large reserves of NG and several gas producers are increasing their production capacity while new sources are explored. However, in some of these areas there are no relevant markets (e.g. North Africa, West Africa, South America, the Caribbean, Middle East, Indonesia, Malaysia and northwest of Australia). Part of the natural gas is liquefied in those locations for shipment to remote areas where the use of natural gas exceeds local production.

The transformation process of NG to LNG is performed by cooling the gas at atmospheric pressure to a temperature of -260 ºF (-162 ºC) before loading it into special LNG tankers. The volume of NG is reduced 610 times when it is liquefied. As a consequence of the volume reduction, the transport and storage is more efficient. In addition, LNG trade offers greater flexibility with respect to the pipeline transport, allowing shipments of natural gas to be delivered to remote zones where the demand is greater and commercial terms are more competitive.

As a result of the LNG market growth, the management of the supply chain has become more complex, and the need for decision support has become even more evident. A good picture of this scenario can be seen in [Roar2009_LogisticaLNG].

Therefore, to anchor the necessary investments, LNG trade is largely based on long-term contracts under the Take Or Pay (TOP) modality and mainly indexed to petroleum price.

Taking into account the characteristics of the LNG chain, particularly the high costs of transport and storage capacity, the TOP contracts usually have an Agenda with a fixed number of annual cargos. The dates of the shipments arrivals are set at an annual shipment schedule (or Agenda), which is agreed in the contract and set once a year. Once defined the Agenda, a modification of a scheduled Cargo, for example, a deviation of a LNG tanker, has heavy penalties for the responsible for that change.

VI. Optimization of the Agenda.

In the necessary fight against the Curse of Dimensionality, it is necessary to find a way to reduce the size of the state space of the system. Pursuing that, the specific problem was analyzed to simplify those aspects of modeling that have no impact relevant on the results.

Regarding the LNG logistic, due to the high costs of transport it is assumed that the vessels transporting LNG depart at full load and take between 20 to 30 days to arrive from the different terminals of LNG to Uruguay. When the ship arrives, it takes near to 72 hours to download the LNG. All these times are estimates, and may be affected by the conditions of wind, waves, etc. Based on these times, to simplify the problem, it is assumed that the arrival of a vessel is dated with an accuracy of a week and that only one vessel can arrive per weekg.

In practice, the FSRU facilities may allow that more than one vessel arrives per week, but as each Cargo is about 145,000 m3, and the regasification capacity will be 10 Mm3/Day (ten million cubic meters of natural gas per day, corresponding to 16,393 m3 of LNG per day), a vessel of 145,000 m3 of LNG would be used in 8.54 days if the regasification plant is run at full load all the time. This shows that there is no need to assume more than one shipment per week.

The cargos programmed in the Agenda are considered at the Agenda Price (AP) that is assumed to be composed of a constant price plus a variable price indexed with the Brent index.

After the Agenda is decided, the scheduled Cargos can be encoded as an array of zeros and ones. Each element of the array represents a week. A One means there is a vessel arriving that week, and a Zero that no one is programmed that week.

Due to the possibility of encoding annual Agenda completely depending on the time, as the described array of Zeros and Ones, the space state dimension of the system will not increase for the introduction of the Agenda information.

In addition to the Agenda, it is necessary to encode the Actions (or decisions) that could be taken on each week. These actions are diverting a programmed Cargo or buying a spot one.

If there is a One in a week in the future (in the array that encodes the Agenda), a vessel will arrive in that week and the operator is enabled to make a decision of diverting the cargo. If the cargo is diverted, it is assumed that it is sold at a Diverting Price (DP). The cost assigned to this decision is calculated as DP minus the AP.

In the other case, if in one week there is a Zero in the Agenda, no Cargo is expected, and therefore it is possible to take the decision of purchasing one from the Spot market. This new Cargo is purchased at Spot Price (SP) that is modeled as the AP plus a random noise.

In the proposed model, both decisions, diverting or purchasing Cargos in the spot market, should be taken with N weeks in advance. Typically N will take values between 6 and 12 weeks.

If the decision is taken with more weeks in advance, the risk of taking this decision (diverting or buying) is higher but on the other hand, the opportunity of getting better prices is higher. In the results showed in section VIII a value of $N=6$ was considered.

The decisions already taken can be encoded in a single array xd of N boolean variables. The components of this array are $xd[0]$ to $xd[N-1]$, where $xd[0]$ represents the decision that was taken N weeks ago for the current week.

If $xd[0]=0$ then no further action was taken over the Agenda for the current week.

On the other hand, if $xd[0]=1$ then the Agenda is altered for the current week. That means that if the Agenda has a programmed cargo for the current week this cargo is diverted and if the Agenda has no cargo for the current week a new cargo from the spot marked will arrive.

Every week the operator must decide if schedule a change or not for the week that comes N weeks in the future. This involves calculating the array of decision xd at every week for the next week. The computation is performed shifting left xd, and updating $xd[N-1]$ with the decision taken for the week that comes within N weeks in the future.

In the model proposed, when a vessel arrives to the FSRU, if there is no room for downloading the Cargo the LNG will be spilled (or sold at a very low price). The optimal policy would take care of this situation and when the time of arrival is coming, the price of the NG for the electrical sector goes down to fire NG in the thermal plants making room for the arriving Cargo.

The updating of $xd[N-1]$ is computed by applying the SDP algorithm, that is minimizing the incurred cost/benefit in the present week plus the expected value of the future operation from the state to which the system evolves at the end of the week.

VII. OptimA

In order to calculate the optimal Agenda, the tool OptimA [RefOptimA] was developed over SimSEE.

OptimA is a tool that can solve an optimization problem that aims to minimize the expected value of the future cost of the demand of the electricity sector and the natural gas sector. The result is the optimal annual Agenda and the Optimal Policy for taking decisions that alter that Agenda (diverting or purchasing spot Cargos) with an anticipation of N weeks.

In section VI, was described the modeling of the Agenda and the array of decisions and the possibility of changing a decision in operating time. Given an Agenda, it is possible to calculate the expected value of future operating costs with SimSEE by optimizing purchasing and diverting decisions. This allows users to build a simulator (configured in SimSEE) that, for each proposed Agenda, enables to compute the cost-to-go of the operation with the Optimal Policy for the given Agenda. Using this simulator, it is possible to built an optimization problem to determinate the optimal Agenda. This is what the OptimaA tool does. The simulator configured with SimSEE is based on the Monte Carlo technique. Each simulation covers the operation of the system of at least two years and is performed in a set about 100 random realizations. The evaluation of the cost function for a proposed Agenda takes about two hours so the search of an optimal Agenda is very time consuming. To face this challenge the *OptimA* tool is programmed using a genetic programming optimization tool called *OddFace* [??OddFace] that runs in a high performance computation hardware of the Engineering Faculty of Uruguay.

VIII. Results

Two simulations of the electrical system with the incorporation of an Agenda of LNG cargos were performed, one of them with a given Agenda with 8 cargos distributed in a year, and the second whit the Agenda optimized using *OptimA*.

The Agenda starts the first day of 2016 and the array of decisions set in zero (that is no decision are programed for the first 6 weeks).

The Fig ??? shows the two Agendas. The figures Fig. 2 and Fig. 3 shown the average LNG cartos that are discharged, diverted or spilled in the cases with an optimized and non-optimized Agenda respectively.

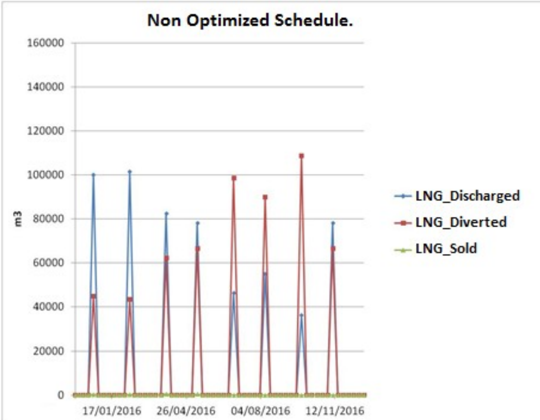


Fig. 2: LNG movements - Non-optimized schedule.

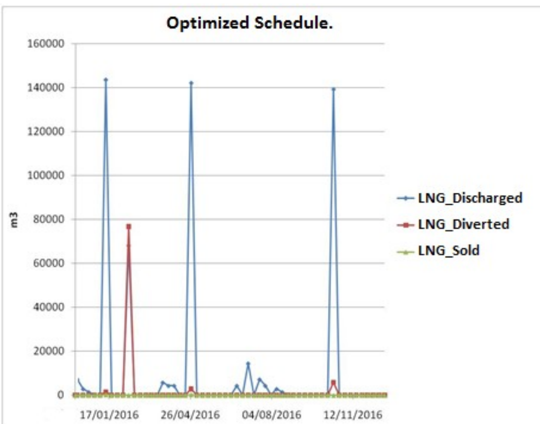
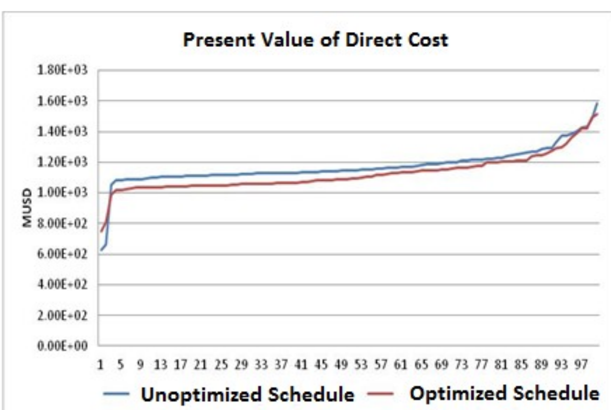


Fig. 3: LNG movements - Optimized schedule.

As can be seen in the figures, in this case, the optimized Agenda has less diverted cargos than the no optimized one.

In Fig. 4 shows the comparison of the distribution of the cost-to-go for both simulations.



It can be seen that for non-extreme conditions (extreme chronic are the first and last) of the cost-to-go is always lower in the case of the optimized Agenda.

IX. Conclusion

The proposed codification for the Agenda, as an array of boolean over the time indication when a cargo is programmed, and the diver and spot bue decisions as an array o boolean that store the alteration of the Agenda with the feasible anticipation, presented in this paper prove to resolve the problem of integrating the logistics of LNG shipment and storage to the operation of the electricity system in reasonable time.

The results obtained with the optimal Agenda have fewer detours and sales at lower prices as well as lower future cost function.

X. References

Books:

[1] Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover, ISBN 0-486-42809-5

[2]

Technical Reports:

[3] G. Casaravilla, R. Chaer, P. Alfaro "SimSEE: Simulador de Sistemas de Energía Eléctrica". PDT 47/12 – Universidad de la República – Facultad de Ingeniería – Instituto de Ingeniería Eléctrica. Dic 2008. http://iie.fing.edu.uy/publicaciones/2008/CCA08a/CCA08a.pdf

[4] E. Coppes, F. Barreto, C. Tutté, F. Maciel, M. Forets, E. Cornalino, M. Gurin, M. Alvarez, F. Palacio, D. Cohn y R. Chaer. ANII-FSE2009-18. Nov. 2012 – Montevideo, Uruguay. http://iie.fing.edu.uy/simsee/biblioteca/anii_fse_2009_18/memoria_fse_2009_18_MejorasSimSEE.pdf

[Sherkat85] V.R. Sherkat, et al, STOCHASTIC LONG-TERM HYDROTHERMAL OPTIMIZATION FOR A MULTIRESERVOIR SYSTEM. IEEE Transactions on Power Apparatus and Systems, Vol. PAS-104, No. 8, August 1985

[MVP2003] S.Granville, G.C. Oliveira, L.M.Thomé, N.Campodónico, M.L.Latorre, M.V.F. Pereira, L.A.Barroso, Stochastic Optimization of Transmission Constrained and Large Scale Hydrothermal Systems in a Competitive ramework, DOI: 10.1109/PES.2003.1270469 Source: IEEE Xplore

[MVP91DDP] M.V.F. Pereira and L.M.V.G. Pinto , Multi-stage stochastic optimization applied to energy planning Mathematical Programming 52 (1991) 359-375, North-Holland

[Roar2009_LogisticaLNG] Roar Grønhaug and Marielle Christiansen, Supply Chain Optimization for the Liquefied Natural Gas Business, pag. 195, Lecture Notes in Economics and Mathematical Systems ISSN 0075-8442, 2009 Springer-Verlag Berlin Heidelberg

[Piecher2013_MarketPower] Stephan Spiecker, Member, IEEE, Modeling Market Power by Natural Gas Producers and Its Impact on the Power System, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 28, NO. 4, NOVEMBER 2013 3737

XI. Biographies