HANDLING THE INTERMITTENCE OF WIND AND SOLAR ENERGY RESOURCES, FROM PLANNING TO OPERATION. URUGUAY'S SUCCESS.

E. Cornalino, P. Soubes, F. Palacios, M.C. Alvarez (ADME)
E. Coppes, G. Casaravilla (UTE; IIE)
R. Chaer <rchaer@adme.com.uy>(ADME; IIE)

ADME is the Electricity Energy Administrator (or ISO) of Uruguay
UTE is the country's power utility.
IIE is the Institute of Electrical Engineering of the University of the República Oriental del Uruguay.

Overview.

This work shows the planning process and the subsequent operation of the electricity energy system of Uruguay with installed wind and solar energy capacity similar to the peak demand of the system.

Uruguay is a country of just over three million inhabitants with an annual electricity demand in 2017 of 11,200 GWh. In the last two decades the Demand grew at an annual rate close to 3.5%, for the last five years close to 2.5% and for the future it is expected to grow close to 2%.

Uruguay is interconnected with Argentina (Fig. 1) by two lines of 500 kV with a capacity of 2000 MW and with Brazil by two frequency converters that total 570 MW of exchange capacity. Uruguay has excellent relations with its neighbors, which has led to the support of electric systems in emergency situations, but at a purely commercial level, the systems have not achieved fluid integration. This leads among other things that each one must plan for the expansion of their systems without being able to trust in the synergy that arises from the existing interconnections. Obviously, the greatest impact of considering these possible synergies or not is for Uruguay because it is the smallest country.

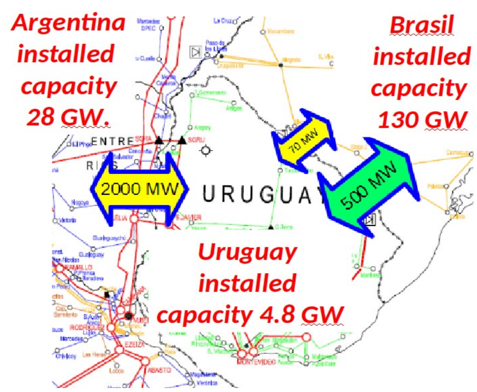

Fig. 1: The neighborhood.

Until 2010, in order to supply the electricity demand, Uruguay had a system of hydroelectric power plants with an installed capacity of 1450 MW, approximately 70 MW of energy generated on the basis of biomass and 700 MW of generation plants based on petroleum fuels.

The generation of the hydroelectric subsystem is random depending on the rainfall regime. As shown in the Fig.2, depending on whether the year is rainy or not, hydroelectric generation can vary between 3500 GWh to 10000 GWh. The energy that was not supplied by the hydroelectric and biomass subsystems then varies between 1400 and 8000 GWh, which represents a percentage variation between 12 and 66% of the Demand. If all this missing energy is covered with fuel fired generation, the variability of the volume is added to the oil price variability. The Fig.3 shows three cases of future oil prices published in the Energy Outlook 2010 of the EIA.

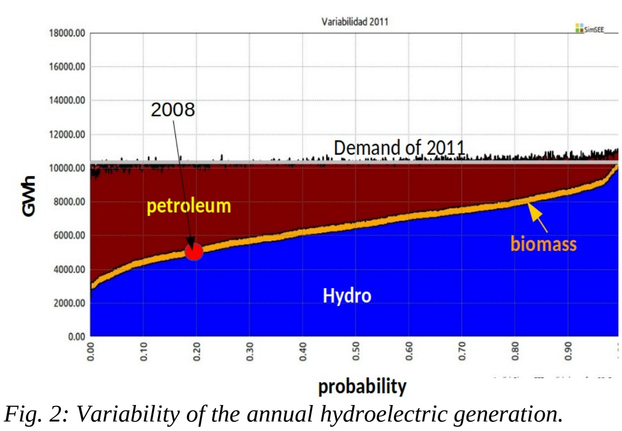

Fig. 2: Variability of the annual hydroelectric generation.

In 2008 (marked with a red circle in Fig.2), hydroelectric generation was 5,200 GWh, that meant a total of 3,400 GWh having to be produced with thermal generation based on petroleum derivatives. That year of bad rainfall coincided with a price of a barrel of oil that reached 148 US$/bbl. Spending on fuel meant an over-cost of 300% of the expected value for that year. Since Uruguay is not a producer of oil, the two above-mentioned variabilities imply a risk of in the cost of supply the electricity demand that can impact more than 1% of the national GDP.

The experience lived in 2008 was decisive for the analysis of the diversification alternatives of the generation matrix.

As a way to mitigate this risk, the country's authorities implemented policies designed to diversify the generation matrix by promoting the installation of wind, solar and biomass power plants.

For the effective incorporation of the new sources of energy into the system, it was necessary to carry out a series of studies to evaluate the pros and cons and to to establish the necessary conditions to achieve an optimal investment plan.

One of the key studies was carried out in 2010 [1]. That study showed the expansion plan of the Fig.4 based in Wind Turbines ("EOL" in the figure) and fuel fired thermal units ("TER" in the figure). It was a key study, because it showed that even considering a wind price of 90 US$/MWh, the installation of this technology was the way. It also showed that the risk of cost associated with hydro-generation and the variability of the petroleum price can be drastically reduced.

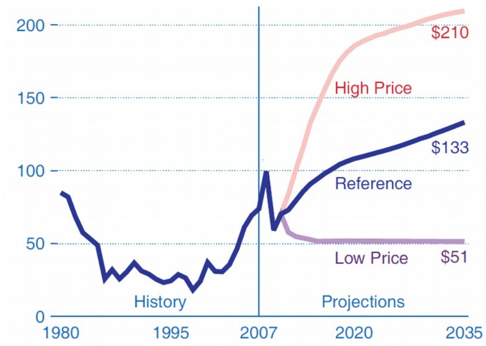

Fig. 3: Three cases of oil prices 1980-2035 (2008 dollars per barrel , source EIA EO 2010).

During 2011, this plan was updated with the new technology prices. The resulting energy generation by source is shown in Fig.5. This figure allows to appreciate that the new energy matrix generates an appreciable amount of surplus energy (area labeled Exports). The values in Fig.5 are the expected value of the generation by source but remember that the hydro generation has the variability of the Fig.2.

Then, in 2011, the optimal path was clear but there was the doubt that the system was controllable, at the operation level, with the volumes of wind that this optimum indicated. In order to address this issue two analysis were carried out.

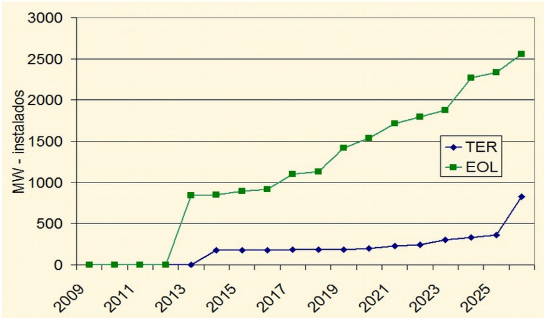

Fig. 4: Investment plan optimized in 2010.

The first [2] was a computation of the additional rotating power reserve needed to handle first 600 MW of wind power. The computation was made assuming that the 600 MW were distributed in four geographical points (where we have two years of wind measures) and shows that the additional of rotating power if of only 25 MW. Today (after two year of operation of the 1200 MW of wind power), we can say that this result was conservative because the geographical distribution of the wind farms (in more than four points) collaborate to reduce that value as.

The second analysis [3] was an hourly simulation of the optimal operation of the 2015 with 1200 MW of wind power installed capacity. The results was that the system is controllable without problems even considering the Uruguayan system isolated (that is without using the interconnections). Obviously the simulation shown that more action are required in order to follow the variations but nothing unreachable with the expertise of our operators.

From the side of the system control, to improve the operator tools to handle the variability, an Automatic Generation Control (AGC) for controlling the hydroelectric and fast thermal plants was installed. Also the new generation wind and solar plants are required to collaborate with the control of the system making available to the operator of the possibility of receiving target values of maximum generation of active power as well as target values to participate in the voltage control of the node to which they are interconnected.

As a result of that process, by the end of 2017, 1500 MW of wind power capacity and 220 MW of solar power capacity where in operation.

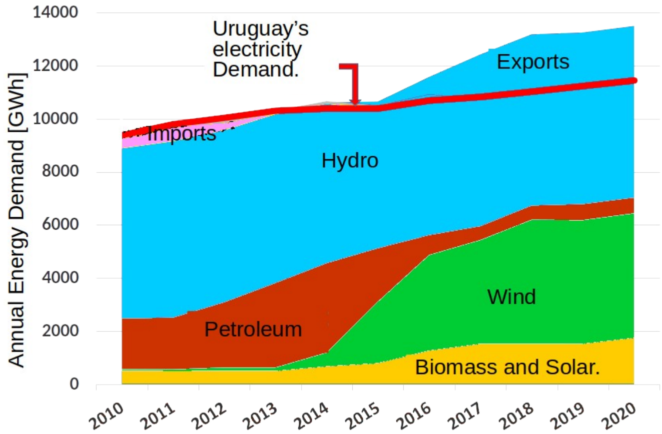

Fig. 5: Electricity energy matrix change as planned at 2011.

Figure 6 shows the installed capacity of wind and solar energy as planned in 2011 and the minimum, average and maximum of the demand power. This plan was executed with some delays, reaching the objectives by mid-2017. As you can see, wind power, when generating at full, exceeds the demand, even at its maximum.

Some people might think that there is an over installation, but that investment plan is the result of an optimization considering all the installation and operation costs and adequately modeling the variability of the resources and prices. Obviously, this result implies that there will be surplus energy blocks that cannot be absorbed by the national demand and consequently, in some cases, energy spilling, of wind and solar energy, will occur similar to what happens with hydroelectric plants.

This surplus must be seen as an opportunity to achieve additional benefits, for example, by exporting it to Brazil or Argentina.

Figure 7 shows the supply cost of demand in expected value and with probabilities of exceedance 5% and 95% from a simulation with the installation plan of Fig. 6. As can be seen, there is a reduction in the expected value of the cost of near 25% comparing 2015 against 2012. Also, the risk of cost with an exceedance of 5% is reduced about 62.5% in the same period.

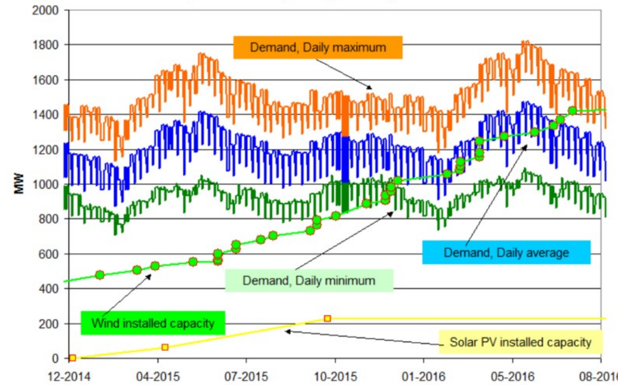

Fig. 6: Wind Capacity vs. Demand.

Survey of the resources.

With the need to diversify the matrix of electric power generation incorporating sources such as biomass, wind and solar, the first step was the survey of the availability of these resources in the national territory.

The National Energy Directorate, through different programs, carried out the necessary studies and made the information public by generating the Wind Map [4], the Solar Map [5] and the reports on the availability and viability of the generation based on biomass [6].

These surveys showed that Uruguay had an important potential in these three sources and that therefore the inclusion of them was possible if the economic equation allowed it.

As part of these survey programs, a network of measuring stations was installed, registering solar radiation and wind speed at 80 m height.

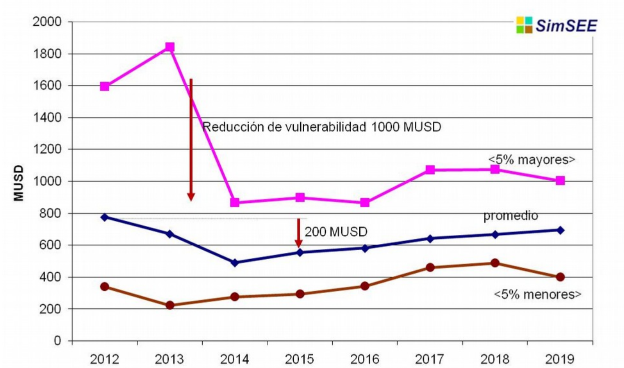

Fig. 7: Change in the cost of generation and its risk in US$ of 2011 before taxes.

Modeling the resources and the operation of the electricity generation system.

For the simulation of the optimal operation of the system, the SimSEE platform was used [7]. For the modeling of stochastic processes in SimSEE, models of Gaussian Space Correlations with Histograms (CEGH by its initials in Spanish) where used [8]. The stochastic processes modeled include the water influxes to the lakes of the hydroelectric power plants and their dependence on the El Niño-Southern Oscillation phenomenon [9], the production of wind power plants [10] and solar plants distributed in the national territory [11] and the electrical demand [12].

For the planning of investments, the Distributed Optimizer of Functions of High Cost of Evaluation (OddFace by its initials in Spanish) was used [13].

As a result of these optimizations, as shown in reference [1], it was determined that the economic optimum was to install a generation capacity of 1200 MW of wind power and 200 MW of solar power by 2015.

With these results, it was necessary to demonstrate that the system was operable with an intermittent amount of energy greater than the electricity demand.

The feasibility of the operation with different levels of wind and solar integration was verified through hourly-time-step simulations [3].

For the programming of the weekly and daily operation, the forecast of the production of the wind and solar generation is very important. We have developed an specific project PRONOS [17] with the financial aid of the Banco de Desarrollo de América Latina (CAF) in order to get the state of the art in this kind of technologies. Today we have very good forecasts of the wind and solar production for the next week as can be observed in our website (http://pronos.adme.com.uy/svg)

For programming the operation of the system integrating the forecasts and the current state of the system in quasi-real time, the VATES [14] application was developed and it is currently in operation in ADME (http://vates.adme.com.uy).

Based on the developed model and the ability to forecast in advance the availability of blocks of exportable energy and its price, a Gradual Integration Model was designed [15].

System integration.

For the incorporation of the new generators to the electricity grid, a minimum capability of handling reactive energy and control conditions of both active and reactive power were imposed. This control is exercised directly by ADME in its role as operator of the system. To ensure the controllability of the system and allow the use of hydroelectric power plants to follow the demand, an AGC (automatic generation control) was installed.

The possibility of controlling the 1700 MW of distributed generation (new wind, solar and biomass plants) and the installation of the AGC in the hydroelectric power plants, allow to follow the variations in the power demand and in the generation of the set of wind and solar generators.

VATES today, computing the exportable surplus a week ahead.

The VATES application runs continuously in ADME, integrating the forecasts of wind, solar, temperature and inflows to the hydroelectric plants and updating the system state when the information is available. The result is the forecast of the hourly operation of the system for the next 14 days. This forecast is updated continuously it is a help for the operation showing things such as the probability of the dispatch of a thermal unit in the next hours.

It is also very useful to determine the energy blocks that can be exported the next week and the price that it is enough to cover the cost of production with a given probability. This is the key to maximize the benefits of the energy surplus that the new generation matrix produces.

In the future, the development of Responsive Demands [16] would be an important help to manage the intermittence of the renewable energies. Thinking in that, we have already implemented, using then VATES application, the computation of a real-time price signal with the hourly forecast of the following days indicating the expected value and probabilities of exceedance, as can be seen on the ADME website.

Results

The main result is the success in the incorporation of 1500 MW of wind power and 220 MW of solar power during 2013-2017.

The new system has energy surplus that depends on whether the year is rainy or not, the key to monetize these surpluses is to export them to neighbor markets.

The operation of the system with the short-term variabilities added by the wind and solar geneartion creates a space to incorporate Responsive-Demands in a beneficial way.

Final words.

In a continuously changing world, planning for the long term is a challenge. Planning radical changes is even more difficult and the success in making things happen, without doubt, is to have a bit of luck and enough knowledge to make responsible decisions. The power to change things is in the knowledge.

The intermittence of the wind and solar energies turned out to be a myth. The Uruguayan system is a successful example that it is possible to operate a 100% renewable system.

The incorporation of non-conventional renewable energies as well as being environmentally friendly are an economic solution that manages to lower costs and reduces the risk energy availability and it cost of countries like Uruguay that are not petroleum producers.

References

[1] Ruben Chaer, Gonzalo Casaravilla. Optimización genética aplicada a la planificación de inversiones de generación eléctrica Encuentro de Potencia, Instrumentación y Medidas, EPIM 10. Montevideo, Uruguay. - 2010.

[2] Requerimiento de reserva rotante de los primeros 600 MW eólicos a integrar al Sistema Eléctrico del Uruguay. Eliana Cornalino, Daniel Larrosa, Ruben Chaer. Revista de la Asociación de Ingenieros del Uruguay, Number 63, page 8--10 - Apr. 2011.

[3] Modeling and simulation of the power energy system of Uruguay in 2015 with high penetration of wind energy. Ruben Chaer, Eliana Cornalino, Enzo Coppes. Simpósio de Especialistas en Planejamento da Operaçâo e Expansâo Elétrica, XII SEPOPE. Rio de Janeiro, RJ, Brasil, page SP082 - 2012

[4] http://www.energiaeolica.gub.uy/index.php?page=mapa-eolico-de-uruguay
[5] http://www.miem.gub.uy/energia/mapa-solar-del-uruguay
[6] “PRODUCCIÓN DE ELECTRICIDAD A ARTIR DE BIOMASA | PROBIO” ROYECTO URU/10/G31 http://www.probio.dne.gub.uy/cms/images/pdf/Informes/2013_07_31_Informe_Act_2_1_5_Cogeneracin_Publicable_v2.pdf
[7] Gonzalo Casaravilla, Ruben Chaer, Pablo Alfaro. SimSEE : Simulador de Sistemas de Energía Eléctrica. Proyecto PDT 47/12. Technical Report 7, Universidad de la República (Uruguay). Facultad de Ingeniería. Instituto de Ingeniería Eléctrica, Number 7 - Dec. 2008.

[8] Ruben Chaer. Fundamentos de modelo CEGH de procesos estocásticos multivariables. SimSEE. Technical Report , IIE-Fing, Udelar - 2011.

[9] Fernanda Maciel, Rafael Terra, Ruben Chaer. Economic impact of considering El Niño-Southern Oscillation on the representation of streamflow in an electric system simulator. International Journal of Climatology, Volume 35, Number 14, page 4094--4102 - Nov. 2015.

[10] Ruben Chaer, Eliana Cornalino, Milena Gurín, Martín Draper, Gonzalo Abal, Rodrigo Alonso Suárez. Modelo estocástico de aportes hidráulicos, eólica y solar aplicable a la simulación del sistema electro-energético del Uruguay con alta penetración de energías renovables. IntegraCIER 2014 : Congreso Iberoamericano de Energía, 12 - 14 nov, Punta del Este - Uruguay, page 1--7 - 2014.

[11] Milena Gurín, Ruben Chaer. Modelado de radiación solar y planta solar fotovoltaica aplicable a la planificación de la expansión de la generación. IntegraCIER 2014 : Congreso Iberoamericano de Energía, 10 - 12 nov, Punta del Este - Uruguay, page 1--9 - 2014.

[12] E. Cornalino and R. Chaer. Probabilistic Electric Load Forecasting Model for the Uruguayan Interconnected Electrical System. International Conference on Renewable Energies and Power Quality (ICREPQ'18) Salamanca (Spain), 21 th to 23 th March, 2018.

[13] Chaer et al., Memoria Final Proyecto ANII-FSE-2009-18, Mejoras a la Plataforma SimSEE, Instituto de

Ingeniería Eléctrica - FING - UDeLaR, 2009, (Cap.IV).

[14] Ximena Caporale, Damián Vallejo and Ruben Chaer. VATES. Optimal operation of power systems with consideration of production forecasts in systems with high wind and solar penetration. International Conference on Renewable Energies and Power Quality (ICREPQ'18) Salamanca (Spain), 21 th to 23 th March, 2018.

[15] Ruben Chaer, Gonzalo Casaravilla. MIG : Modelo de Integración Gradual de mercados electro-energéticos. 6th Latin American Energy Economics Meeting "New Energy Landscape : Impacts for Latin America" Rio de Janeiro, Brazil - April 2-5, 2017 - Hotel Windsor Florida, page 1--10 - 2017.

[16] L. Di Chiara, F. Palacio, P. Soubes, R. Chaer, G. Casaravilla and E. Coppes. An approach to an electricity tariff for responsive demand in the Uruguay of next years with high penetration of Wind and Solar energy. 2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM) Year: 2015 Pages: 52-56.

[17] PRONOS. Proyecto de Integración de Pronósticos de Recurso Eólico y Solar a las Herramientas de Operación Óptima del Sistema Interconectado Nacional. Website: http://pronos.adme.com.uy/