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MODELING AND SIMULATION OF THE POWER ENERGY SYSTEM OF URUGUAY IN 2015 WITH HIGH PENETRATION OF WIND ENERGY.

R. CHAER*	E. CORNALINO	E. COPPES
Facultad de Ingeniería	UTE	UTE
Uruguay	Uruguay	Uruguay

SUMMARY – *This paper presents the results of detailed simulations of the operation of the power system of Uruguay, for the year 2015 when it reached the target of 1200 MW of wind power in the system. This level of win integration will be near the 60% of de peak demand. The results show that this level of integration is manageable thanks to the large installed hydro power capacity in the country.*

KEYWORDS - Wind- Integration. Renewable, Power Systems Simulation.

1. Introduction

The system of electricity power generation of Uruguay will faces significant changes in the near future due to the incorporation of a large amount of wind power.

The stated goal is to reach 1200 MW of installed capacity by 2015. The expected demand for this year is about 1495 MW on average, with a peak of 2000 MW.

The wind penetration then will be of 60% in capacity and 33% in energy. Uruguay will be among the countries with the largest share of renewables in its energy matrix. Wind farms will be distributed nationwide so part of the inherent variability of the wind power will be filtered by the non-simultaneity involving geographic dispersion. The rest of the variations must be absorbed by the regulating system resources. The purpose of this paper is to simulate how the system will be operated in 2015 with such a high share of wind power and evaluate if the resources available to compensate the variations in wind power are enough. For this purpose a stochastic model with Gaussian Space Correlations with Histogram was identified. This model identification was carried out using series of two year hourly measures of the wind speed in seven sites distributed over the country. This stochastic model was used to perform a simulation of operation of the system in 2015 using an integration time-step of one hour with the simulator SimSEE.

In this simulation all power plants in Uruguay are represented. This includes: hydroelectric plants with their storage capacity and gas-oil, fuel-oil, bio-fuel and natural gas fired thermal units.

The detail level used is similar to that used by the National Load Dispatch agency of Uruguay for conducting the weekly generation schedule plan.

The results show that the resources available for filtering the wind power variations in the country are sufficient to allow operation of the system without problems. As expected it is verified that much of the filtering work is done by the hydraulic system and rarely have to draw on the thermal system.

* rchaer@fing.edu.uy

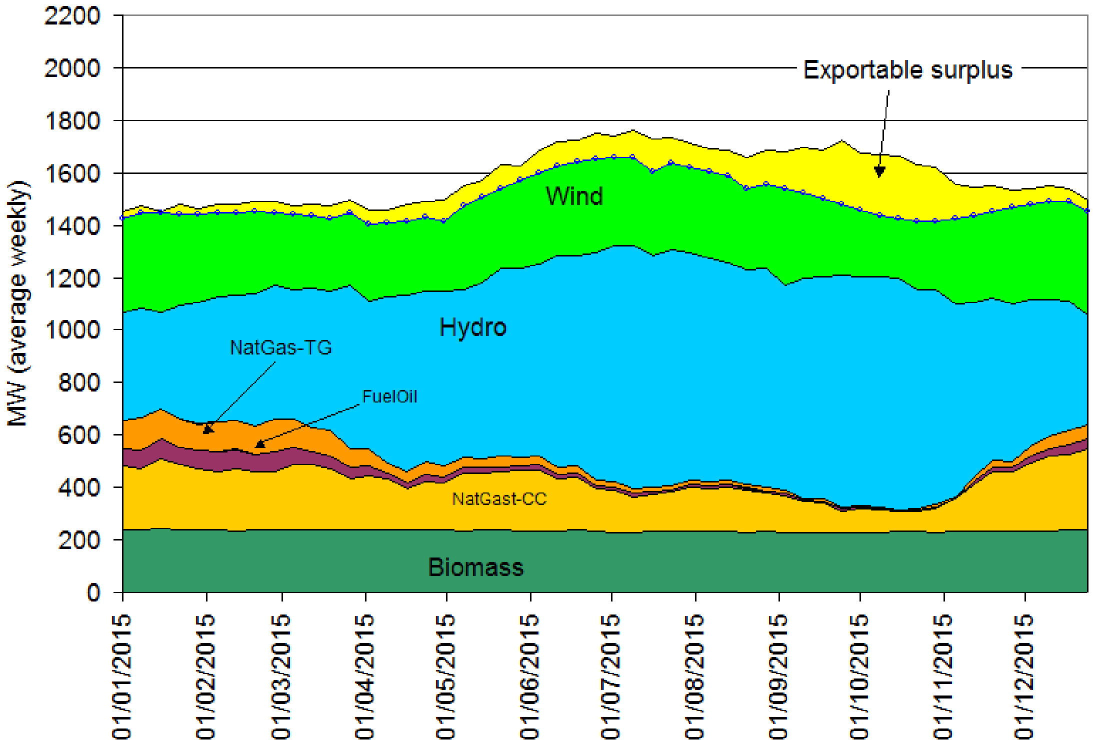

Fig. 1. Uruguay 2015. Generation by source for average rainfall.

As shown in Figure 1, according to these plans, by 2015 wind power expected value will be the second power source after hydropower.

2. Validation of the model used for long-term planning.

The modelling used to calculate the optimal wind power to be installed in the system until 2015 is a weekly step model that optimizes the system operation splitting the every week step in an array of time-slots defined depending on the demand level. [1]

In this modelling accuracy is lost for short-term variations of wind power that directly affect the release of the remaining plants. To validate the results, simulations were performed using a model with a time step of one hour that represents, more accurately, the system's operation in the presence of variable generation such as wind.

This hourly model involves time calculation that is several time orders higher than the weekly model. To carry out the optimization of the expansion of the generation, the simulation of thousands of scenarios are needed making not feasible to use the hourly model directly.

For expansion planning system was assumed to purchase all the power generated by wind farms at prices of around 65 USD/MWh; and that all the energy surplus are exported at a rate of 10 USD/MWh to neighboring countries.

The over-install wind power implies a loss to the system of 55 USD/MWh and is therefore relevant to compare the difference between the energies exported between both models.

It seeks to verify that the resulting net energy exported is about the same in both simulations, in particular for the year 2015 when the wind power stated capacity will be reached. The total amount of energy exported represents, in some way, the inefficiency of the system in handling excess wind power that could not be filtered by the operation of hydroelectric dams.

In the simulation of hourly time step the four hydroelectric plants are modelled. Three of them with its reservoirs. In the simulation of weekly time step, only one of the hydroelectric plants is modelled with it reservoir and the other three plants are treated as spilled plants.

To perform the simulations we used the Electrical Energy System Simulation platform called SimSEE. In SimSEE the stochastic process are represented by Sources. These Sources are responsible for synthesizing time series of realizations of stochastic processes during the simulation.

The modelling of wind generation in the weekly step model considers the Source of wind described in [2]. This Source of wind was obtained from the analysis of wind series of ten stations distributed throughout the country. For the hourly time step simulation a Source build using a power time series generated from simulations with the modelling of wind farms and wind time series described in [3] was used.

Comparing the resulting annual energy for wind power, hydro and exported provides a measure of the precision error of the weekly-model which was used to calculates the optimal plan for 2015 compared to the simulation with the hourly-model used for programming the day ahead system operation.

Table 1: Comparison of hourly and weekly time step simulations by energy source

Annual Energy year 2015 (GWh x 10^3)						
Wind Energy						
Exceedance prob.	Weekly		Hourly		Difference weekly-hourly	
	mean	std. dev.	mean	std. dev.		
mean	3,593	0.3%	3,620	1.0%	**(27)**	**-0.7%**
0.1	4,786	0.4%	4,451	1.0%	335	7.5%
0.3	4,042	0.4%	3,946	1.1%	96	2.4%
0.7	3,111	0.5%	3,285	1.1%	(174)	-5.3%
0.9	2,500	0.7%	2,851	1.3%	(351)	-12.3%
Exports						
Exceedance prob.	Weekly		Hourly		Difference weekly-hourly	
	mean	std. dev.	mean	std. dev.		
mean	(786)	-5.4%	(841)	-9.3%	**55**	**-6.5%**
0.1	-	-	(1)	-61.6%	1	-100.0%
0.3	(0)	-286.9%	(11)	-52.5%	10	-96.9%
0.7	(750)	-10.4%	(989)	-15.6%	239	-24.2%
0.9	(2,553)	-4.8%	(2,661)	-7.3%	107	-4.0%
Hydroelectric						
Exceedance prob.	Weekly		Hourly		Difference weekly-hourly	
	mean	std. dev.	mean	std. dev.		
mean	5,859	2.8%	6,441	1.7%	**(582)**	**-9.0%**
0.1	10,114	1.5%	10,050	2.4%	64	0.6%
0.3	7,514	2.3%	7,788	1.5%	(274)	-3.5%
0.7	3,977	5.4%	4,943	1.7%	(967)	-19.6%
0.9	2,103	6.0%	3,345	5.1%	(1,242)	-37.1%

It is concluded from Table 1 that could be in the order of 50 GWh per year of energy surplus available for export in the actual operation of the system. This surplus is achieved by the effect of better management of the lakes with short-term storage capacity.

If those 50 GWh/year are purchased at 65 USD/MWh (approximate average of the bids) and sold at 10 USD/MWh (floor price surplus supposed for expansion planning), there will be a loss of 50*1000*55 = 2 MUSD/year on a total wind generation 3600 GWh/year, this represents an increase of 0.75 USD/MWh on 65 USD/MWh.

The first estimates of the optimal amount of wind power to be installed in the system were performed initially priced at 90 USD/MWh and subsequently with 70 and 65 USD/MWh obtaining the same results in terms of the amount of power to be installed within the margin of error of the used tools. Therefore this change in price due to surpluses recorded in the hourly simulation over the weekly one, does not change the conclusions regarding the optimal amount of wind power to be installed in the system.

As shown, the economic impact of the difference between both runs, changes the price of wind power less than the price variations that were considered in the study of sensitivity. Thus are considered validated the results obtained with the simplified weekly time step model used for the optimal planning of generation expansion.

The weekly step simulation simulates wind generation of power by taking the values of a hourly time step Source and averaging the expected values in each time-slot. This is the model used to calculate the optimal investment plan.

We evaluated a possible improvement to this model seeks to represent as closely as possible the exigency of power required in each time-slot due wind variability. To do this we used an alternative way to summarize the hourly time step Source taking a random value rather calculate the average. The results show that the differences between both models are within the respective error margins.

3. TIME VARIABILITY MANAGEMENT

The previous section discussed the validity of the proposed plan regarding the amount of wind power to be installed. This section will display the analysis regarding the capacity of Uruguay's electrical system to handle the inherent variability of wind generation.

Fig. 2 and Fig. 3 show the hourly wind power generation and the resulting net demand (system demand minus wind power generation) to be supplied by the system for three chronic randomly simulated for a week of March 2015. There is a significant change from the usual conduct of the system demand in its current configuration due to the occurrence of sudden changes of significant magnitude in the power requirement.

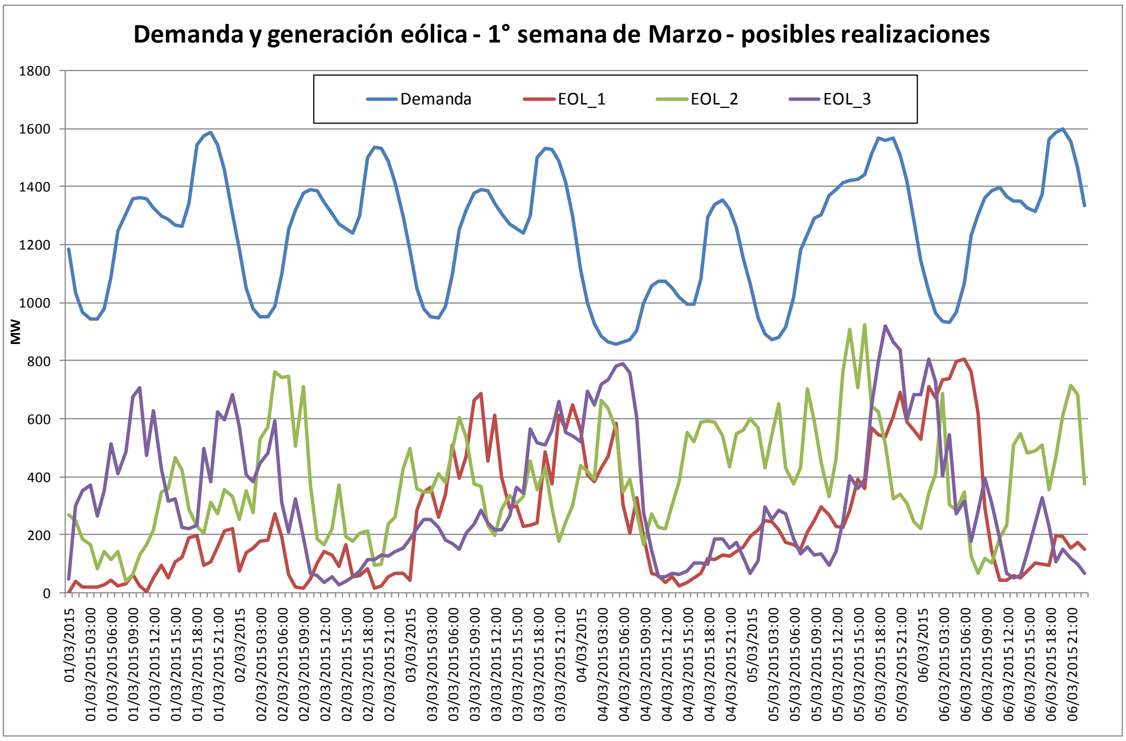

Fig. 2 Simulation of the system demand and wind power generation for a week in 2015

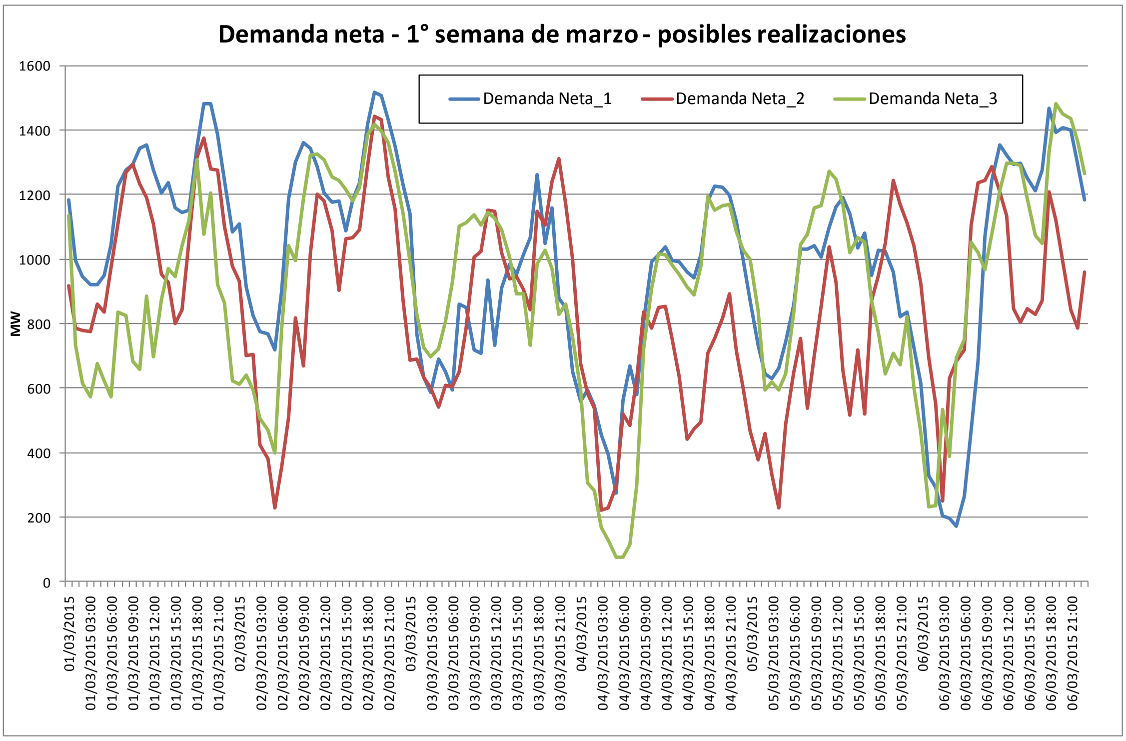

Fig. 3 Net demand to supply (demand- wind power) simulated for a week in 2015

In work [4] the authors analyzed the variability of wind power from a set of parks distributed throughout the national territory and its relation to variations in system demand. This paper evaluates the system's ability to respond to such changes of power.

To evaluate the system's ability to handle these variations the expected situation with high incorporation of wind power, with high not manageable variability, was compared with the state of the system at the same time but without wind generation. Because the planning provides sufficient support to supply the system with no wind, the release is also possible in this situation where variability is exclusively introduced by demand and by inopportune power plants shutdowns in the same way that the system is currently operating.

Simulation was then carried out for the system by 2015 considering two scenarios, one with 1200 MW wind power installed capacity and one without wind power.

Results were analyzed from the point of view of increasing variability of power generation, induced by wind generation. To do this we compared the variations in power from one hour to the following for energy sources with possibilities of fast regulation: hydraulics, gas turbines and engines.

The variability required in the operation of hydroelectric and fast thermal power plants due to the addition of 1200 MW was analyzed by comparing the cumulative probability plots of the time differences of power, P (h)-P (h-1), of the simulated cases with wind and without wind.

For the fast input thermal plants (gas turbines and engines) it shows a very slight increase in variability since the probability of large-scale variations of an hour to the next is similar that the existing in the case without wind.

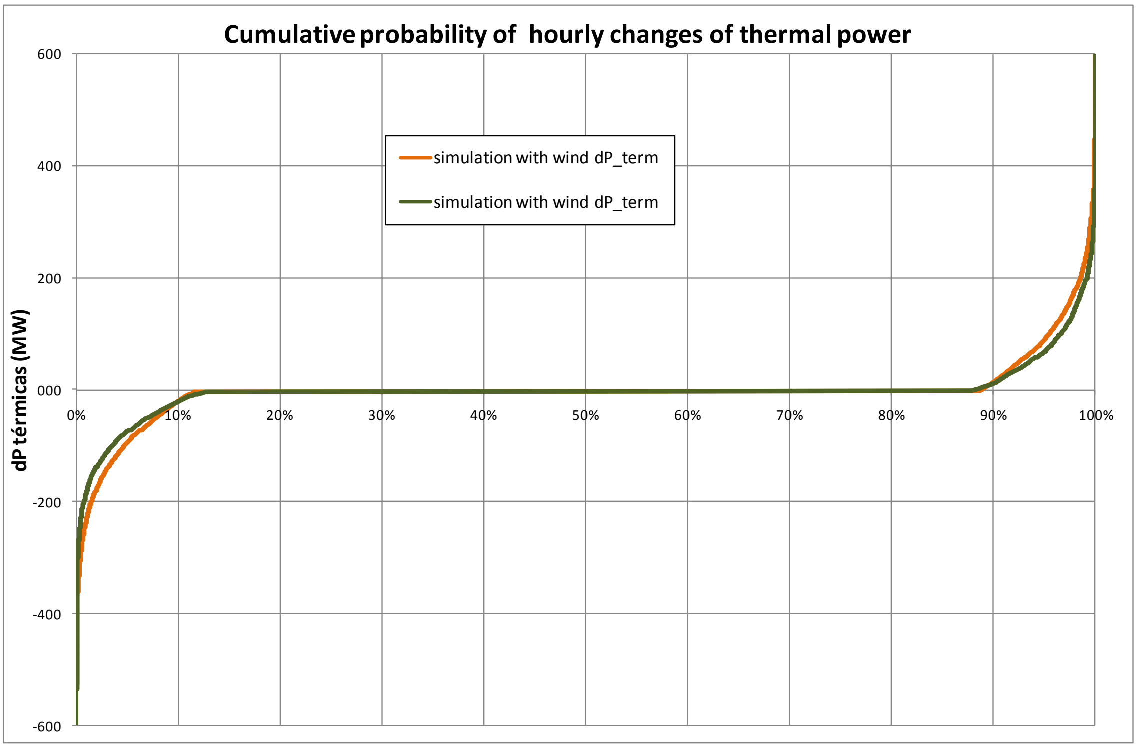

Fig. 4: Cumulative probability of fast thermal power changes from one hour to the next with wind and without wind.

It follows that the greatest increase of variability stress will be in the hydroelectric power and in power exchanges by interconnections with neighbour countries. In this sense is observed in the case of hydroelectric generation that the probability of having positive or negative variations of more than 200 MW in an hour increases by 7%.

The results obtained were compared with historical data of hourly hydro generation in the period January 2008 to August 2011. Cases were differentiated in two situations: when Salto Grande hydroelectric power plant is carrying out secondary regulation (corresponding to approximately 20% of the time during the study period) and when not.

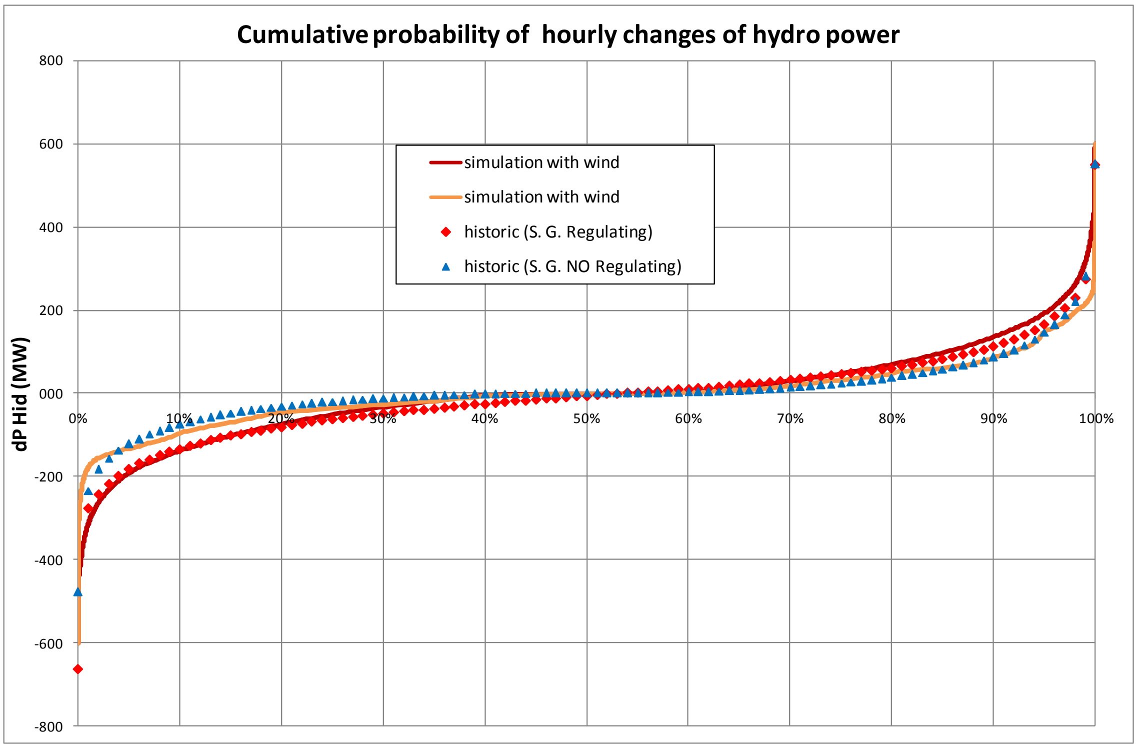

Fig.5: Cumulative probability of hydraulic power changes from one hour to the next, simulation with wind, simulation without wind, historic data with Salto Grande regulating and historic data with Salto Grande no regulating.

It notes that the expected time variations of the hydraulic power to the system without wind power are the same level as the historical variations of the periods in which Salto Grande is not carrying out secondary regulation, while the expected variations for the system with 1200 MW of wind are similar to the historical variations in when Salto Grande is carrying secondary regulation.

The export of energy is another mechanism to handle the variability of wind generation in cases of excess energy. The total energy exported in the case simulated with 1200 MW of wind power is about 730 GWh on average, equivalent to 6 times the amount of energy exported in the simulated case without wind.

Regarding the hour to hour variability of export, although it increases significantly with respect to the case without wind, it is observed that remains at low levels, being only 4% chance of reported changes greater than 200 MW in an hour.

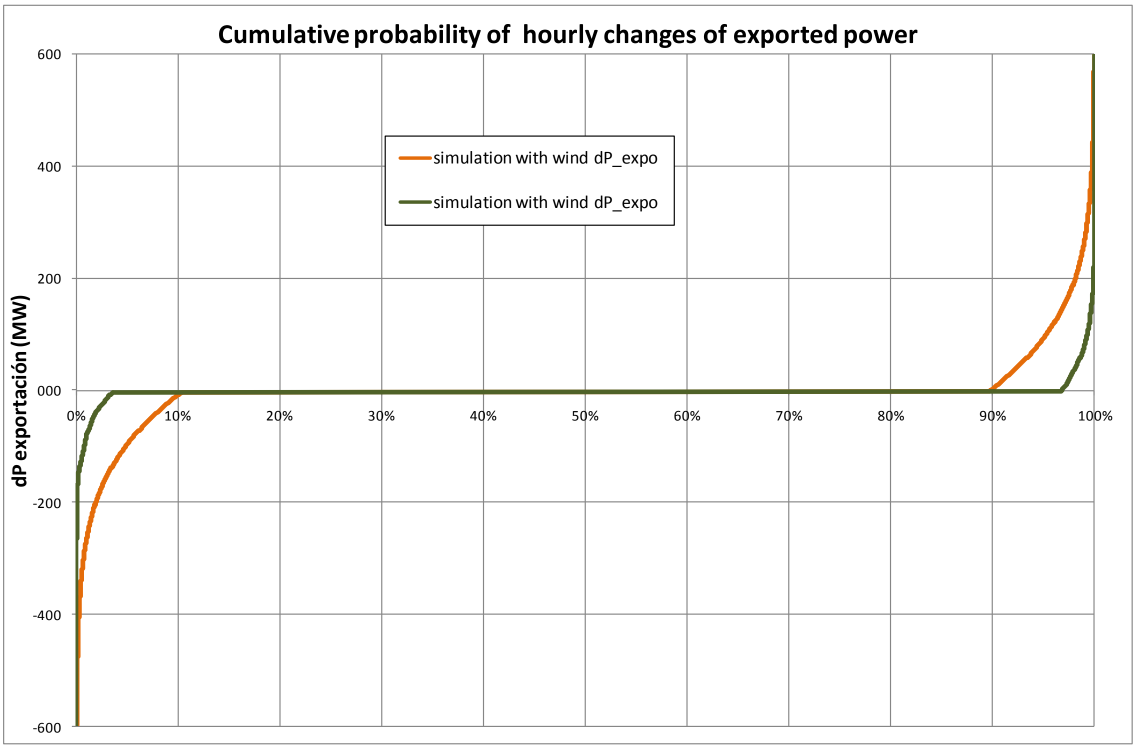

Fig. 6: Cumulative probability of exported power changes from one hour to the next with wind and without wind.

As can be seen in 80% of time is not necessary to use exporting power to regulate the system. It is remarkable that to meet the requirements in the remaining 20% of the time Uruguay has the ability to export to Argentina through the existing interconnection of 2000 MW and to Brazil through the interconnection of 70 MW already in operation plus 500 MW currently under construction.

The following graphs analyze the operation of the system in two extreme cases of drought and high rainfall which shows the ability to operate the system in such extreme situations.

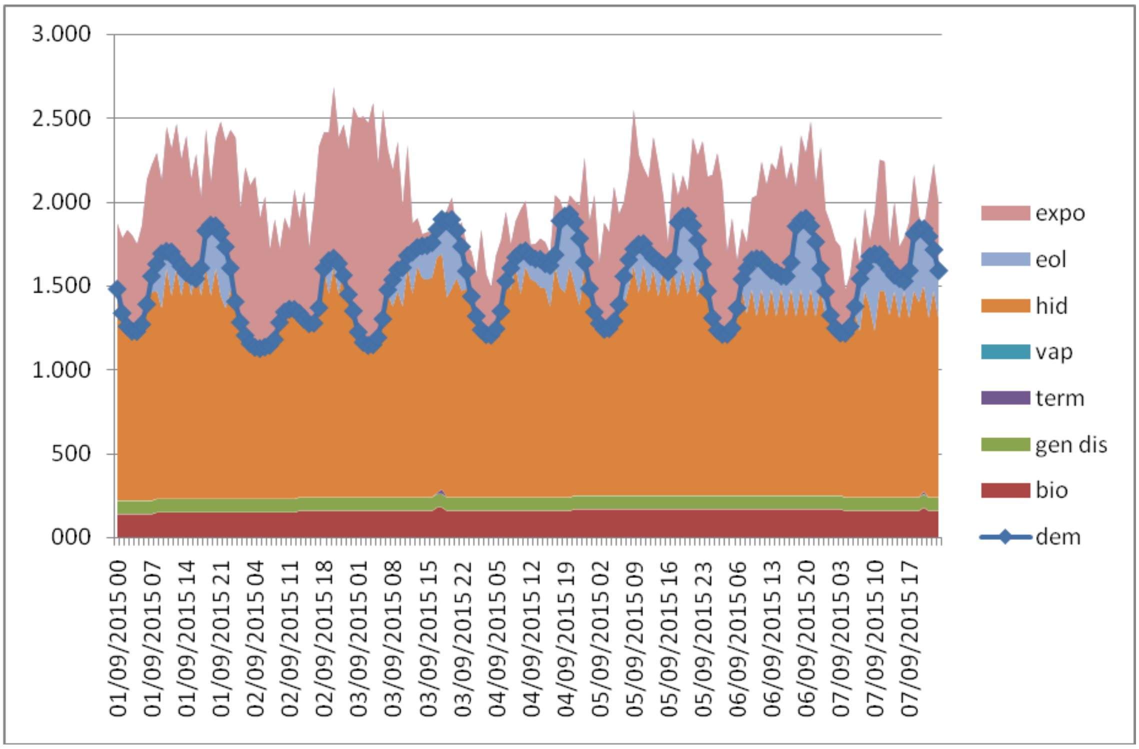

Fig. 7: Hourly simulation of a week with very high hydroelectric generation

Figure 7 shows the dispatch of the system in the first week of September of 2015 simulated with 1200 MW installed wind power and considering historical hydrological situation of very high rainfall. The result recorded export surpluses of 12 GWh per day on average for the week simulated, corresponding to a time average power of 500 MW. Considering that this is a situation of extreme rainfall and very low probability we could consider reducing wind generation as an alternative to export if it is not possible to export the power. Since the selling price of exported power in the model was set conservatively at 10 USD/MWh and the cost of wind energy can be estimated at 65 USD/MWh according to the results of last competitive process conducted, it must be economic difference between selling surpluses and reduce operating wind power is to increase the real cost of the excess wind power at 10 USD/MWh, costing from 55 USD/MWh (65-10) will cost 65 USD/MWh.

The Fig.8 shows the system dispatch on the fourth week of January 2015 with 1200 MW of wind power installed in the system and hydrological assuming historical low.

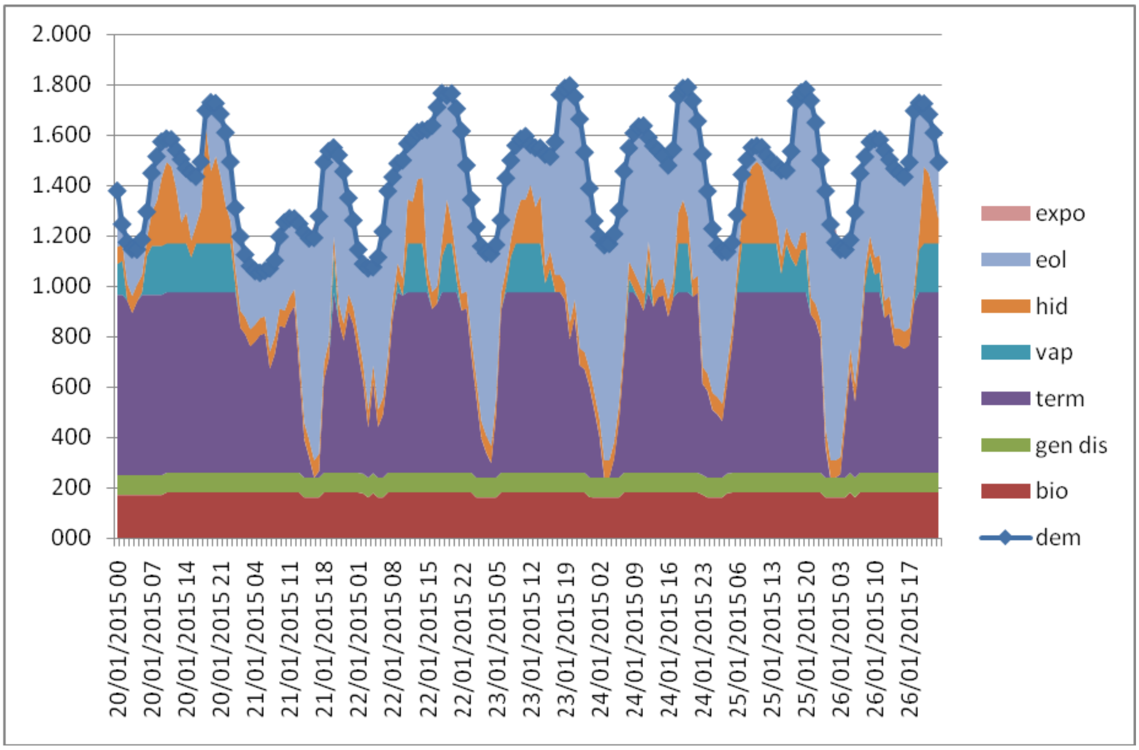

Fig. 8: Hourly simulation of a week with very low hydroelectric generation

Despite the very low hydro generation available the simulation shows that the system did not fail in fulfil the demand. In this particular week, all thermal plants available were dispatched at full power several times. For the same reason of low water availability the simulation shows that most of the regulation of power wind fluctuation was necessary to do with the thermal plants. In the particular chronicle shown in Fig.8 the steam power plants are brought into use for a few hours and then off, which is not operationally acceptable. This is due to the simplified model adopted for this group of plants, which due to its low utilization factor was not considered convenient to model in more detail as this would considerably increase the computation time after well represent a very low probability events like the case shown in the figure. As mentioned, it is important to note that the system did not fail at a critical low energy and power, whereas the actual operation in this situation should be done differently and consequently with a slightly higher cost. The possible alternatives of operation of this critical situation would to keep the steam plants generation generating in the base and regulation the variations of the wind power with the fast thermal units or in the cases that were impossible a further reduction of the thermal plants turning off the necessary wind turbines.

4. CONCLUSIONS

It was observed the variability introduced by 1200 MW of wind power in the system from a statistical point of view. Observing the large variation of generating power of the different stations units kept low probability of occurrence.

The results show that the variability required for fuel-fired units is not affected by the presence or absence of wind generation in an appreciable amount.

Regarding hydro generation is observed that the additional variability is of the same order as the historically recorded when the hydroelectric “Salto Grande” was in use for regulating the frequency for Uruguayan-Argentine integrated system.

The energy exports has an increase in the variability due to the installation of the 1200 MW of wind power, but only in the 20% of the hours and with an increase of the power variations distributed between cero and 200 MW over the operation without the 1200 MW of wind power. The management of this variability would be somehow transferred to the Argentine or Brazilian neighbouring systems. In cases where this operation is not possible, the alternative would operate by reducing wind power with the resulting additional cost, calculated with respect to the simulation of 10 USD/MWh for each MWh wind cut. This additional cost does not affect the conclusions regarding the feasibility of operating the system in the conditions studied.

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