Analysing the effects of future generation and grid investments on the Spanish power market, with large scale wind integration, using PLEXOS® for Power Systems.

Miss Peny Panagiotakopoulou,
PLEXOS Support Consultant
Energy Exemplar (Europe) Ltd
London, U.K.
Peny.panagiotakopoulou@energyexemplar.com

Abstract* - The scope of this paper is to present the results of a wind integration case study that analyses and compares the effects of the future generation and grid investments and their operations on power market prices, congestion, ancillary service requirements and generation mix using the power market simulation and analysis software PLEXOS® for Power Systems. According to the EU directives, Spain's goal by 2020 is to supply 41% of electricity consumption from Renewable Energy Sources (RES), 21% of which should derive from wind energy.

Keywords – PLEXOS; Spanish Power Market; Wind Integration; Interconnections; Balancing;

I. Introduction

Spain's overall energy goal by 2020 is to supply 41% of electricity consumption from renewables, 21% of which should come from wind energy [1].

The growth in wind energy capacity in the EU is due to increase at 9.7% per annum, from 84.9GW in 2010 to an estimated of 213GW by 2020 [1a]. This projected growth demonstrates the move by European countries towards a higher proportion of wind energy in their energy mix.

In 2011 Spain had a leading role, supplying almost 16% of the country's electrical demand from wind. It is estimated that in 2020 about 38GW of wind will be installed for a total generation of about 78.2TWh in that year [1]. This means that wind energy will supply more than 20% of Spanish electricity.

Solar is due to increase from an installed capacity of 4.6GW in 2010 to 13GW in 2020. This is estimated to provide 29TWh of electrical generation in 2020 [1].

In 2020 the breakdown of solar energy is estimated to be 8.4GW of solar photovoltaic (PV) and 5.0GW of concentrated solar power (CSP) [2]. Due to the storage capacity associated with CSP over PV, as well as the fact that the dispatch profiles of the two technologies differ for the same solar energy input, these will need to be modelled separately.

The only other significant contributors to the increases in renewable energy are hydro and biomass, which are expected to expand their current capacities.

A. Future Issues and Problems on the Spanish Grid

Under the current uncertainty of the incentive system and the changing government policies, and due to Spain having limited interconnections to its neighbours (thus the expression "electricity island" found in literature), the 2020 target for Spain seems challenging with respect to the economic incentives and operational mechanisms necessary to enable the required level of investments in RES generation and grid capacity, including smart-grid technologies and ancillary services capabilities.

A full description of the installed capacity of new renewables in 2020 is given in [1].

Overall, the Spanish power market has so far demonstrated adequate flexibility dealing with high levels of wind penetration. Nevertheless, the ambitious renewable target that Spain has set for 2020 requires a well-planned mix of flexible generation plants, demand side response initiatives, and grid investments.

Generation within the Iberian power market or else MIBEL (Mercado Ibérico de Electricidad) is divided into two categories (regimes). This is due the continued incentive to increase electricity generation from renewable means. The "Ordinary Regime" consists of the conventional generation such as the Hydroelectric, Nuclear, Coal, Fuel+Gas and Gas. The generation technologies in this regime compete against each other in the market pool based on their offers of electricity price. The "Special Regime" includes incentives in the form of feed-in tariffs for the production of electricity from renewable sources. These include: Bioenergy, Geothermal, Hydropower, Marine, Solar and Wind. The market considers these types of generation to have priority on the generation schedule. The total supply for 2010, which was used as a reference year in our study, was around 266TWh of which approximately 189TWh was the net amount of energy provided by Ordinary Regime, 90.5GWh the net amount of energy that was provided by Special Regime, 4.4TWh was consumed for Hydro-pump storage and 8.3TWh was accounted for International exchanges (net exports) [3].

The market is considered to be very isolated in terms of interconnections. The current interconnection from France to Spain is approximately 1.4GW [4], Morocco to Spain 0.5GW. This is less than to 2.0% of installed capacity.

In 2014 it is expected that the installed capacity of interconnection between France and Spain will be 2.8GW [4].

The interconnection between Portugal and Spain consists of four 400kv and three 220kv lines; however, the power transfer from Portugal to Spain was 1.5GW. It is foreseen that the interconnection capacity will reach 3.0GW in 2014.

Exchange capacity between Spain and Portugal was 2.0GW in 2010. Long-term energy transaction forecasts for MIBEL (the integrated Iberia power market) will require a transfer capability of some 3.0GW [5].

II. Aims

The aim of this paper is to present the results of a wind integration case study that analyses and compares the effects on different scenarios of future developments in the Spanish electricity system. Various estimations of the changes in power market prices, and generation mix were made using the power market simulation and analysis software PLEXOS for Power Systems. For the case study there were developed and tested 5 PLEXOS models, based on different scenarios and consisting of a 2010 base model and four future models in the simulation year of 2020.

III. The Models

A. *Base model*

PLEXOS has a proven track record in the area of policy analysis and development. Common policy analysis with PLEXOS includes:

- The design, analysis, and benchmarking of electricity market rules and effect on market participants;
- Assessing the effectiveness of renewable technology policies and resulting impact on carbon emissions, prices, transmission grid operations and investment incentives;
- Forecasting market entry and assessing future technology and fuel mixes as well as examining the development of system adequacy;
- Examining market competitiveness and market power.

The base model developed was that of the current Spanish power market system that included the existing power plants and interconnection links with their respective capacities. A summary of the installed capacities is shown in **Table 1**. The model also included a full representation of the Portuguese power market system due to the large interconnection flows that take place between the two countries.

Generation type	Installed Capacity (GW)
CCGT	24.6
Fuel + Gas	1.8
Coal	10.8
Nuclear	7.5
Hydro	16.7
Wind power	19.0
Other Special Regime	14.0
Total	***95.4***

Table 1 – Installed capacity of the Spanish generation portfolio, 2011

B. *Possible future scenarios*

There were developed four models looking ahead to the simulation year of 2020, representing possible system developments such as planned vs. required generation, interconnection to France and demand side response methods. Both conventional power plants with potential expansion capabilities and renewable projects were included in our models, and the target was to obtain the optimal required set of investments in the generation and interconnection expansion in order to integrate renewables into the power system and meet the 2020 target.

Considering the present weak cross-border interconnection between Spain and France, the effect of the planned expansion of 2.0GW on power flow and market operation in the events of wind fluctuations was investigated in detail along with the possible extra interconnection that may be needed by 2020.

IV. Results

We developed a **PLEXOS** (fundamental) Base Model with an associated **PLEXOS Dataset** of Spanish/Portuguese System that was tested and calibrated against the 2010 hourly energy prices and generation series observed at the Spanish and Portuguese nodes of MIBEL, the Iberian electricity market.

Spanish and Portuguese day-ahead and intraday electricity markets are fully integrated in the **MIBEL since 2007**.

The day-ahead average price in OMEL (Spanish side) during 2010 was 37.01€/MWh. The final weighted average MIBEL market price, including capacity payments, technical restrictions and balancing was 45.13€/MWh (about 1% higher than previous year average).

The **PLEXOS Spanish Dataset** developed for 2010 emulation testing included, among others, the following key items:

- generators capacity data and offers submitted to the day-ahead market;
- available interconnection capacities and exchanged energies;
- hourly day-ahead market clearing prices.

Figure 1 shows the comparison of the reported real MIBEL market price with the respective price obtained as an output from the PLEXOS simulation-optimisation.

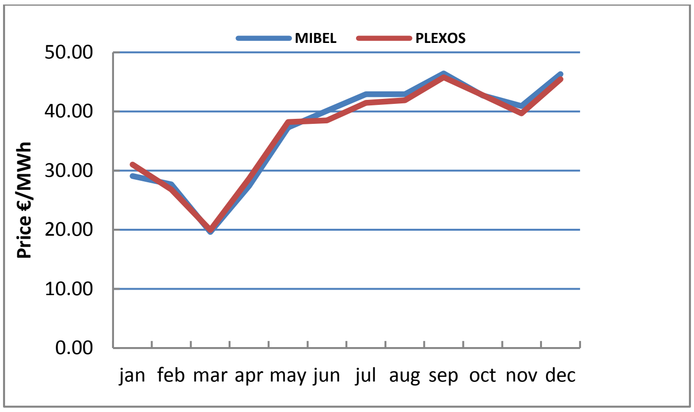

Figure 1 – MIBEL v PLEXOS (Monthly Average Electricity Prices 2010)

PLEXOS Nodal (LM) Prices

In **PLEXOS** the price at a node (transmission bus) is a calculated price and depends on the optimal power flow (OPF) model selected.
In the standard OPF the nodal price is a direct output of the optimization and is equal to the shadow price (LMP) (dual variable) on the net injection constraints at the node.
In the large-scale OPF, nodal price is not directly available and instead is computed from the system lambda and constraint shadow prices modified by the shift factors.

Given the right amount and quality of data, **PLEXOS** is able to reproduce the real market nodal price, generation profiles and associated power system and market mechanisms exceptionally well. This is also shown in **Figure 2** where the daily reported real electricity prices at the Spanish node (nodal prices) are compared with the respective calculated prices by PLEXOS.

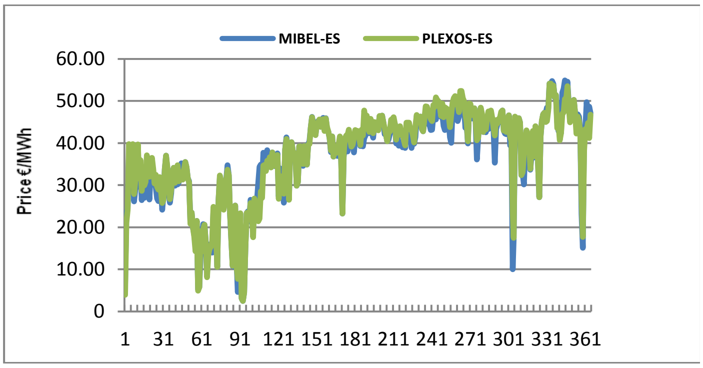

Figure 2 – MIBEL-ES v PLEXOS-ES (Daily Electricity Prices, €/MWh - 2010).

In addition, **Figure 3** shows the comparison between the reported real total generation daily profile and the respective generation profile obtained by PLEXOS. The latter is calculated given as inputs the respective demand and generation capacities and after having solved the Unit Commitment/Energy Dispatch problem by PLEXOS.

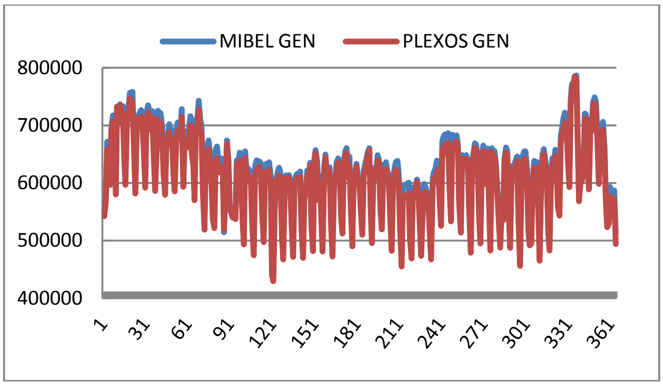

Figure 3 – MIBEL Generation v PLEXOS Generation (Daily MWh, 2010).

These encouraging results gave us the opportunity to analyse particular characteristic congestion events associated with market price collapses and to monitor more closely the particular periods of market splitting, whenever these took place in 2010, between the Spanish and Portuguese Market.
As it was also proved, PLEXOS reproduced them and subsequently the Spanish Market System in general, with very high accuracy.

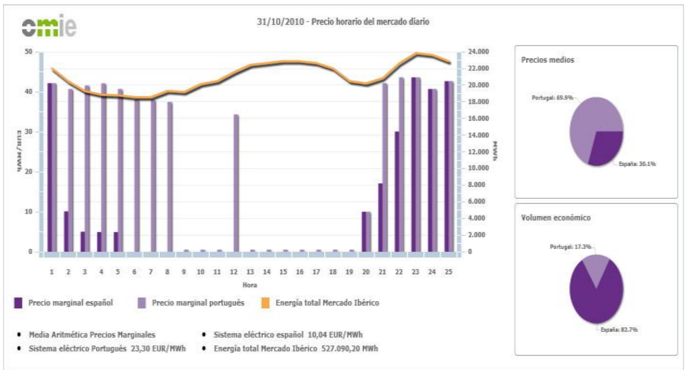

Figure 4 – Spanish nodal price collapse and market splitting on the 31/10/2010 (Source: OMIE).

Figure 5 - Spanish nodal price collapse and market splitting on the 31/10/2010 as calculated (captured) by PLEXOS.

An example of MIBEL's market splitting, which took place on the 31/10/2010 as reported by OMIE [7], is shown in **Figure 4** and is emulated by PLEXOS in **Figure 5**. Such events were quite common during 2010 but are not limited to that year.
Figure 6 demonstrates consecutive events of "dump" energy produced by PLEXOS along with the respective Spanish nodal price. "Dump" Energy is the amount of over-generation at a "node" (France in our case) due to a lack of transmission capacity out of the node and constraints on generation at the node that are forcing certain levels of generation.
Although this is not a physically feasible outcome, this variable is useful when diagnosing problems with a transmission network's setup.

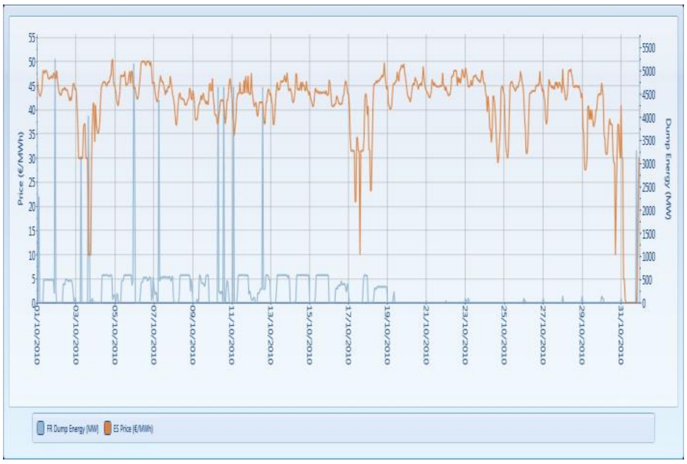

Figure 6 – "Dump" Energy in ES Region during Oct. 2010 as generated in PLEXOS.

Exchanges between Portugal and Spain are computed in reality (and reproduced in PLEXOS model) driven by offers posted at both sides of the border and constrained by available interconnection capacity. In order to implement the Portuguese electricity system in the model, there are three tasks that have to be undertaken: the modelling of the Portuguese generating system, the demand evolution and the interconnection capacity impact.

At hours when there is excess interconnection capacity the Spanish and the Portuguese markets are coupled and both markets are cleared at the same price.

When the interconnection capacity is exhausted, market splitting takes place and each node is cleared at a different price.

- In the Spanish Power System, the main congestions appear in the interconnections, especially in the French-Spanish border but also in the Portuguese-Spanish one.
- When there is congestion in the PT-ES interconnection, the MIBEL is splitted into two price areas.
- Convergence in prices was quite high in 2010 (Around 80% of the time).

ES-FR Interconnector

With Regional Initiatives, integration of day-ahead market with France (and therefore with the CWE1 region) is being pursued.

The SW2 region is heading towards the European Electricity Target Model aiming at an internal (Pan-European) energy market.

However, due to the scarce cross-border capacity, the electricity exchanges with France (and consequently, the chances for price convergence) are rather limited. Spain's price differentials with France are mainly due to:

- Different generation mix;
- Different demand patterns; and more importantly
- The limited interconnection capacity between France and Spain.

Regarding the ES-PT Interconnector, revenue from congestion on interconnections between Portugal and Spain arising from the price zone difference, after the application of market splitting, rose slightly in 2010, at 11.9Mil Euros compared with 10.7Mil Euros in 2009. This is well below the 2008 figures (64Mil Euros) as a result of the convergence of prices between Portugal and Spain and the increased use of the interconnection in the export direction (from Spain to Portugal).

In general, the very low pool price differential between Portugal and Spain during 2010 was mainly due to:

- Increasing integration of the Iberian market (MIBEL);
- Growing similarity of the marginal generation portfolio of both countries.

In the following table, reported by OMEL, are shown the monthly congestion events (in hours of congestion and % hours of congestion per month) for the Portugal-Spain interconnection during 2010. For example, for October 2010, 27% of the hours the interconnection was congested.

Table 2-2 - Monthly Congestion Figures for the Portugal-Spain Interconnection in 2010

Month	Congestion		Price Differential (€/MWh)
	No. of Hours	% Hours per Month	Average
January	108	15%	2.25
February	87	13%	2.50
March	92	12%	3.07
April	233	32%	0.36
May	56	8%	0.48
June	131	18%	0.89
July	216	29%	1.18
August	214	29%	1.36
September	236	33%	1.71
October	203	27%	2.22
November	85	12%	1.61
December	175	24%	-0.23
Average 2010	153	21%	1.95
Average 2009	181	25%	1.27
Total 2010	1836		
Total 2009	2172		

Source: ERSE: ERSE, OMEL

Long Term (LT) Planning in PLEXOS

We used PLEXOS to run various LT capacity expansion planning models and scenarios. Potential new generation units were considered for the following technologies:

- Wind
- Solar
- GT (OCGT and CCGT units)

and in relation to the study of the wind curtailment and over-generation issues already observed:

- Hydro Storage
- DSP (Demand Side Participation)

For this reason, we created a realistic load shape forecast based on the 2010 load profile using the **PLEXOS Load Forecasting Feature**.

This extended up to 2020 with 3.5% Energy growth per annum and 2.5 % Peak load growth for both Spain and Portugal as shown in **Figure 8**.

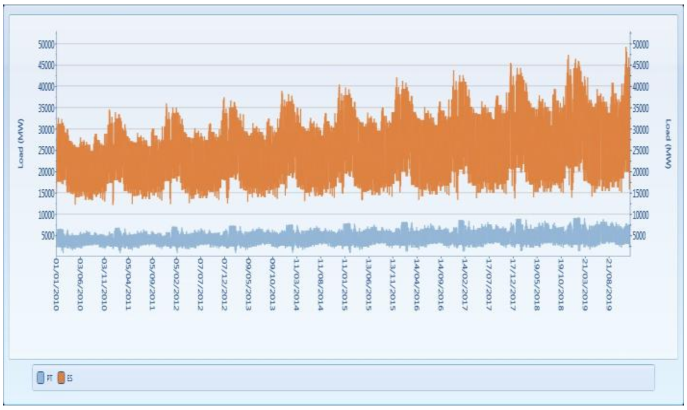

Figure 8 – PLEXOS generated ES and PT Forecasted Loads up to 2020 based on the 2010 hourly load profile.

<u>**We verified in all our scenarios runs that:**</u>
The continuous drop of operating hours of Iberian thermal plants in 2010, since the demand increase was not sufficient to compensate higher renewable production (+69% hydro generation and +17% wind generation, compared to 2009) will continue to be a major issue.
The Iberian market presents comfortable reserve margins, so in the coming years new thermal additions are not expected or else those planned will only accentuate the existing over-generation problem, given also the strong investments in renewable capacity in order to achieve the 2020 targets.
The amount of non-positive-priced generation curtailed, given here as Curtailment Factor and reported by PLEXOS, which is actually the proportion (expressed as a percentage) of No Cost Capacity (renewables) curtailed (i.e. the capacity that is not taken up for Generation), will continue to be an issue as shown in **Figure 9.**

We also verified that, in all our scenarios runs, the planned expansions (mainly of Wind Onshore/Offshore, PV but also CSP and Biomass), under the circumstances and scenarios of load growth and the existing interconnection capacity, are expected to lead to more undispached renewable energy (reporter by PLEXOS as energy available on-line but not utilised given the unit commitment solution) as shown in **Figure 10**.

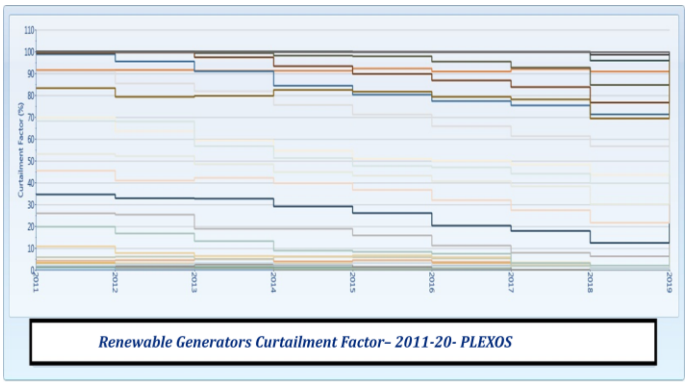

Figure 9 – Renewables Generators Curtailment factor – 2010 to 2020.

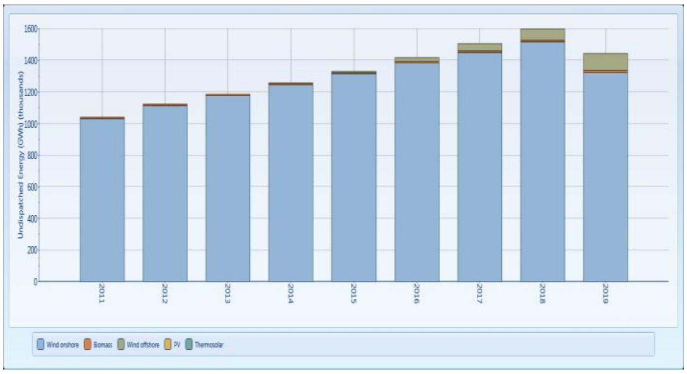

Figure 10 - Undispached Energy for Planned Renewables up to 2020.

Finally, in **Figure 11**, it is shown the interconnection expansion planning obtained by PLEXOS requires an immediate need for the expansion of Spanish-French interconnection and a future one (around 2018 to 2019) for the Spanish-Portugal interconnection given the respective load forecasts.

Figure 11 – ES-FR and ES-PT Interconnection capacity expansion planning by PLEXOS.

V. Discussion

Renewables's integration poses significant operational but more importantly, policy planning challenges.
Large RES production dramatically reduces electricity prices but also increases the cost of the ancillary services. When/if the system runs out of downward reserve, the TSO instructs some thermal units to shut down (usually CCGTs). When/if this is not enough, wind output is limited (Wind Generation Curtailed).
In the first half of 2010, **wind production was curtailed 22 times**, losing about 171GWh.
In the same period, the TSO ordered **60 CCGTs to shut down** to minimize wind losses.
In 2011 the loss accounts for just 0.2 % of wind production - Wind Curtailment.

Wind power generation in Portugal has shown a very significant growth in recent times, representing more than half of special regime generation in 2010, and increased its

contribution to the total value of generation from approximately 1.2% in 2003 to 16.4% in 2009 and 18.2% in 2010.
The lack of downward reserve in real time can currently be solved by shutting down thermal power plants, a practice that may lead to grids instability.

Although renewables priority access tend to be formulated as universal, in real time systems and respective balancing markets operations, other factors must be also taken into account such as the severity of wind generation variability and its effect on the balancing requirements. This calls for the provision of adequate reserve capacity, preferably with a high ramp up/down rate capability for the successful provision of ancillary services.
Spain currently relies on its existing high availability (around 17GW) of hydro storage capacity and on its relatively rapid deployable hydropower in similar cases.
Thus, the uptake of renewable energy such as wind can result in larger requirements for system reserves. Using the ancillary services features of **PLEXOS** the policy maker can:

- Optimise the uptake of renewables given this additional burden;
- Ensure provision of reserves in dispatch and expansion planning;
- Calculate the cost to the system and effect on energy prices of the additional reserve requirements; and
- Calculate expected ancillary service prices.

This analysis takes advantage of **PLEXOS's** ability to set dynamic reserve requirements based on generator, load and/or line contingencies.

VI. Conclusions

Planning and operational procedures will have to adapt to Renewables penetration.
Cross-border opening of power and ancillary services markets facilitate this penetration.
Power generation companies need to take into account and optimise their operations in accordance with additional generation and grid constraints but also in accordance with the provision of more complex reserves services. More importantly all of these will have to be integrated within the competitive operational framework of the day-ahead, intraday and real-time energy markets. Smart Grid and Smart Power technologies have also a significant role to play and they should be considered part of the picture in immediate future.

VII. Acknowledgement

We would like also to acknowledge the contribution of Mr Edward V. Mc. Garrigle, Postgraduate Scholar in the Department of Civil & Environmental Engineering, University College Cork, Ireland.

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