PLEXOS Study of the Italian Power System and Market in the Medium-term: Realities and Expectations of Renewables Integration

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***Abstract*— One of the main developments of the last few years on the Italian power market has been the significant increase of renewable capacity in the form of wind and solar power plants. Using a PLEXOS dataset based on data available from Terna and various utilities, we have modeled the Italian power market considering the six geographical zones and created the medium term expected scenarios from the Terna information available for 2012 and the published 2013 grid development plan. Wind capacity is expected to account for the largest increase among renewable sources. The Southern zones (namely South, Sicily and Sardinia), already characterised by a significant amount of renewable capacity, are expected to experience the largest concentration of renewable development, going from 11,400 MW to 15,400 MW, of which 2,800 MW coming from wind. With the new capacity coming on line, the percentage of aggregated renewable capacity from wind and solar in these zones will increase from the current 31% up to 38%. In addition, these regions are characterised by a relative lower level of interconnection with neighbouring countries compared to the Central and Northern zones. Taking into account the planned reinforcement of the Italian grid, its future adequacy is evaluated in our PLEXOS model in terms of interconnection flows between Italian zones and with neighbour countries, potential bottlenecks, system flexibility and power prices.**

Keywords- PLEXOS, Italian power market, wind integration, renewables integration, interconnections

I. INTRODUCTION

The Italian power system is experiencing a rapid development of renewable sources in the form of wind and solar capacity. Between 2011 and 2012 the wind capacity has grown by 21% from 6.6 to 8.0GW, whereas the solar capacity by 33% from 12.5 to 16.6GW. Between them, they covered 20% of the 124.3GW installed capacity in 2012.

With reference to Figure 1. , the development is mainly observed in the southern zones – South (SUD), Sicily (SICI) and Sardinia (SARD) –, leaving the northern zones – Nord (NORD), Centre-Nord (CNOR) and to a lesser extent Centre-South (CSUD) – relatively immune to the problems associated to high penetration of renewables. In fact, while in 2012 in the NORD, CNOR and CSUD zones the percentage of renewables with respect to the total installed capacity was 12%, 23% and 20%, respectively, in SUD, SICI and SARD the percentage increases to 31% in each one. Expected further development in renewables will raise these percentages to 35%, 37% and 38% in the SARD, SICI and SUD zones, with wind accounting for 22-23%.

Figure 1. Geographical zones of the Italian power market.

Given the intermittency of wind generation (Terna estimates that, on average, the 24-hour ahead forecasting has an error of about 20% [1]), the limited expansion of thermal power plants in the southern zones – a total of 800 MW in SUD –, the decommissioning of 600 MW from SICI and SARD and the limited interconnection capacity available between these zones makes them particularly vulnerable to power oversupply or shortage.

Interconnectors are planned to come online with Albania (2014) and Montenegro (2017), both connected to southern zones, and with Croatia (2017) connected to CNOR. Such developments, together with the reinforcement of the interconnectors with Austria, Switzerland, France and Slovenia, and the increase in transport capacities between the six Italian zones, should mitigate any issue related to the generation from renewable sources, and this paper analyses the effect on the power market prices, interconnectors flow, system flexibility and adequacy for some of the expected scenarios.

II. The Model

A. PLEXOS Italian Dataset

The power market simulation and analysis software PLEXOS for Integrated Systems has been used to model the Italian power market in 2012 and its development in the short-medium term, considered being the year 2017.

We built a dataset including all the relevant plants within each geographical market zone in 2012, with the poles of limited production aggregated to the surrounding geographical zones as: BRNN, FOGN and ROS to the SUD zone, and PRGP to the SICI zone (see Figure 1.). Installed capacities of conventional plants and aggregated figures of renewable generators are obtained from Terna reports and utilities websites. In addition, for each technology we have taken a representative set of operational characteristics (heat rates, ramp rates, etc.) and applied it to each of the plants of that particular technology. The resulting total installed capacity by technology in 2012 is shown in TABLE I. .

TABLE I. Installed Capacity by Technology - 2012

Generation type	Installed capacity 2012 (GW)					
	NORD	***CNOR***	***CSUD***	***SUD***	***SICI***	***SARD***
CCGT	20.6	1.5	3.9	7.6	2.1	0
Fuel+Gas	12.9	3.8	6.7	3.8	3.6	2.1
Coal	2.8	0	1.8	2.9	0	1.0
Hydro	16.0	1.1	2.7	0.9	0.7	0.5
Wind	0.09	0.09	1.5	3.6	1.7	1.0
Solar	7.2	2.0	2.3	3.4	1.1	0.59
Geothermal	0	0.7	0	0	0	0
TOTAL	**59.6**	**9.2**	**18.9**	**22.3**	**9.2**	**5.1**

Going forward to 2017, with the planned commissioning and decommissioning of conventional power plants, and the expansion of renewable generation, the installed capacity is expected to be as shown in TABLE II.

TABLE II. Expected Capacity by Technology - 2017

Generation type	Installed capacity 2017 (GW)					
	NORD	***CNOR***	***CSUD***	***SUD***	***SICI***	***SARD***
CCGT	21.4	1.5	5.1	7.6	2.1	0.0
Fuel+Gas	10.5	3.5	6.7	4.6	3.3	1.8
Coal	5.4	0.0	1.8	2.9	0.0	1.4
Hydro	16.0	1.1	2.7	0.9	0.7	0.5
Wind	0.11	0.15	2.3	5.7	2.2	1.3
Solar	9.6	2.6	2.7	4.1	1.4	0.72
Geothermal	0.0	0.7	0.0	0.0	0.0	0.0
TOTAL	**62.9**	**9.6**	**21.4**	**25.9**	**9.7**	**5.6**

B. Scenarios

The scenarios that we analysed are based on the development scenario described in [1], which outlines an expected load for Italy of 346TWh in 2017 and a peak of 62GW in 2018.

The hourly load values for each zone in 2017 are created using an in-built feature of PLEXOS that uses a given profile, annual peak and energy demand. To this aim, the load profiles were obtained from actual 2012 data, the peaks from the interpolation between historical 2011 and expected 2018 values, and the total load for each zone were extracted from the "Nord", "Centre", "South" and "Islands" values expected by Terna in 2017.

With net imported electricity in 2012 of 43.1TWh out of a total load of 324.5TWh, the interconnectors with neighbour countries are critical for the Italian power system's adequacy. To model those with France, Switzerland, Austria, Slovenia and Greece we have added the expected capacity expansion in the medium term to the actual NTC values for 2012 provided by Terna [1]. In addition to the existing ones, all connected to the NORD zone apart from the Greek one, connected to the SUD zone, three new interconnectors are expected to be commissioned by 2017: a 1,000MW one with Montenegro (connected to the CSUD zone), a 500MW one with Albania (connected to the SUD zone) and an 800MW one with Croatia (estimated to come online in 2014 and connected to the CNOR zone). The summary of the interconnectors' capacities is shown in TABLE III.

TABLE III. Interconnectors Capacities

Interconnector	Capacity 2012 (MW)		Capacity 2017 (MW)	
	Import	**Export**	**Import**	**Export**
Austria	315	100	815	100
France (cont.)	2,750	1,160	3,250	1,160
France (Corse)	900	150	900	150
Greece	500	500	500	500
Slovenia	630	180	1,130	180
Switzerland	4,240	1,910	4,940	1,910
Croatia	-	-	800	800
Albania	-	-	500	500
Montenegro	-	-	1,000	1,000

As shown in TABLE IV. also the transfer capacities between the six Italian zones are expected to increase in the medium term with the only exception of the CSUD-SARD one.

TABLE IV. Inter-zone Lines Capacities

Line	Capacity 2012 (MW)		Capacity 2017 (MW)	
	to	**from**	**to**	**from**
NORD .. CNOR	3,700	3,400	4,100	3,800
CNOR .. CSUD	1,300	2.500	1,600	2,700
CSUD .. SUD	No limit	4,250	No limit	6,000
CSUD .. SARD	870	1,050	870	1,050
SUD .. SICI	100	250	1,100	1,150

Given their capacities, to obtain a reasonable representation of the flow on these interconnectors the modelling of neighbour countries' power markets is required. The expected capacity in the neighbour countries by technology is available from Entso's SO&AF 2013 (yearly up to 2016 plus one further value for 2020) [2]. Among the various scenario options provided there, we will be using the data related to Scenario B and represent such markets in terms of generation capacity by technology and country load grouped by market block.

The prices of fuels (natural gas, coal, fuel oil and lignite) are assumed to increase 3% per year until 2017 [3] [4] [5]

and for all the renewable generators in Italy, France, Switzerland, Austria, Germany, Luxembourg, Slovenia, Croatia, Montenegro, Albania and Greece a random sampling of their generation profiles in 2012 are used where available.

III. RESULTS

The backcasting exercise for 2012 for the six Italian zones shows a good match with the market power prices published by Gestore dei Mercati Energetici (GME) [6]. Figure 2. shows how the price movements of two representative zones are captured in our model when imposing the actual 2012 flows on the interconnectors.

Figure 2. NORD and SARD prices obtained from 2012 backcasting analysis (market prices are shown in orange, PLEXOS prices in blue).

In terms of power transits between the various zones within Italy, we note **Error! Reference source not found.**a frequent congestion in the SUD to CSUD connection and an energy outflow from the CSUD to the CNOR and SARD zones during all the year. The graphs in Figure 3. Figure 3. also suggest that the reinforcement of the interconnectors with France and Switzerland require urgent action, and the planned capacity expansions shown in TABLE III. appear to address this issue.

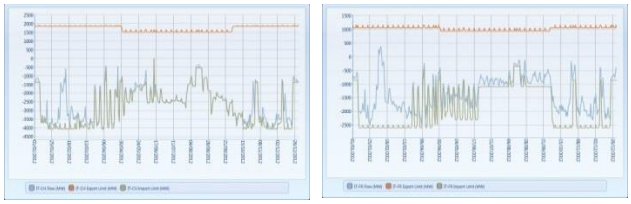

Figure 3. Flows and capacities of critical interconnectors in 2012, those with Switzerland (left) and France (right).

Moving to 2017, the fuel prices are assumed to be 16% higher than in 2012, but the average power price over all the year increases by about 19% from €79.9/MWh to €94.8/MWh, as shown in Figure 4. , with the formation of an evident weekly pattern. In terms of flow between Italian market zones, the significant increase in connection capacity between SUD and SICI shifts the flow out of SUD from 96%-4% with CSUD and SICI, respectively, to 72%-28%, easing the congestion on both connectors as shown in Figure 5.

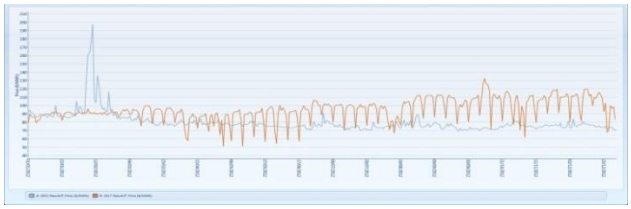

Figure 4. PLEXOS price trends in 2012 (blue) and 2017 (orange).

Even assuming to postpone the commissioning of the interconnectors with Albania and Montenegro after 2017, the profiles in Figure 5. don't change significantly.

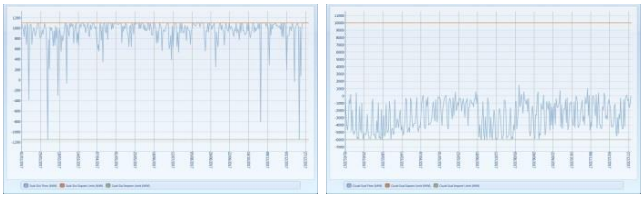

Figure 5. Flows and capacities on the SUD-SICI (left) and CSUD-SUD (right) connectors expected in 2017 (top and bottom lines represent the day-ahead NTC values, and the central line the actual flow as calculated by PLEXOS).

The opposite case applies to the interconnectors with France, Switzerland, Austria, Slovenia and Croatia. All of these appear to be critical and permanently congested in 2017, with the energy flowing into Italy of the order of 99TWh, twice as much as in 2012. The price differential with those countries is certainly part of the reason of such a large import but, all else being equal, a reduced import might result in an equal or higher price of electricity on the Italian power market, as it occurred in the middle of February 2012 (see Figure 3. and Figure 4.). To test this hypothesis we have analysed a scenario where the French and Swiss interconnectors have in 2017 the same import capacities as in 2012 (ignoring their expansion). As shown in Figure 6. , the prices on the Italian market increase by about €1/MWh to an average of €95.9/MWh.

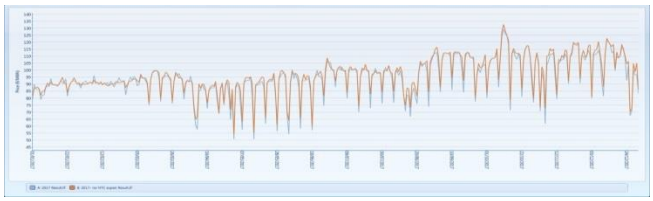

Figure 6. Price difference between the standard (blue line) and the no-expansion (orange line) scenarios of the French and Swiss interconnectors' importing capacities in 2017.

Going back to the standard development scenario of the Italian grid, in 2017 wind generation is expected to account for 13% in SARD, 15% in SUD and 25% in SICI out of the total generation in those zones. These percentages increase to an average of 20% and 29% in SUD and SICI, respectively, during the weekends and at times of reduced load.

When including also the contribution from solar generators, the renewable generation at weekends represents 18%, 29% and 41% of the total in SARD, SUD and SICI, respectively. Moreover, although a strong correlation between the various zones is expected for solar generation, (the factor was 0.94 in 2012 between nearby zones), also wind generation shows some degree of correlation between these zones (0.56 on average with the peak between CSUD and SUD at 0.75).

Regarding the effects of renewable generation on the daily power prices, the model shows an inverse correlation between the two during all of 2017 in each of the zones, with the maximum (in absolute terms) being -0.36 in the SUD zone. For this zone a similar value, -0.35, is obtained considering power prices and wind generation alone. This result suggests that given a relatively balanced capacity of wind and solar generation (see SUD zone in TABLE II.), where both resources are abundant wind is the predominant driver of power prices. If for the same SUD zone the analysis is performed at hourly resolution, and by restricting

the range to the daytime hours between 8am and 8pm, the correlation of power prices with wind and solar generation are -0.16 and -0.11, respectively. Although the effect is smaller than that at daily intervals, between the two technologies wind is confirmed to be the main driver of power prices. Similar results apply to CSUD, SICI and SARD, whereas in NORD and CNOR solar resources represent the main driver of power prices at hourly intervals (with a correlation of -0.18 and -0.15, respectively) during all of 2017. This exception is likely due to the limited expected amount of wind capacity installed in those two zones (see TABLE II.).

Besides the correlation of renewables generation with zonal power prices, given the high percentage of generation from renewables in the southern regions we have analysed two "extreme" scenarios with our model, one with low wind and low solar resources (LW LS), and the other with high wind and high solar (HW HS) resources in 2017. In both cases the wind and solar profiles are scaled by -/+ 30%.

In terms of prices over all the Italian market, the changes from the base case (which uses stochastic samples of the solar and wind generation profiles in 2012) are relatively minor, as shown in Figure 7.

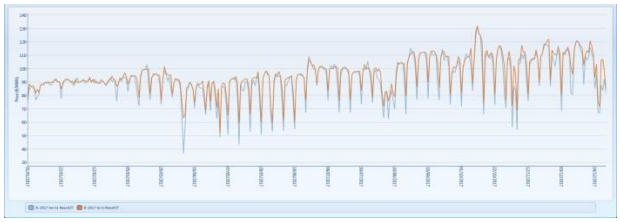

Figure 7. PLEXOS price trends for HW HS (blue line) and LW LS (orange line) scenarios in 2017.

The only significant difference appears to be related to the market prices on Sundays, which are much lower in the HW HS scenario; this result is expected given the merit order effect of renewables generators. At a zonal levelFigure 8. the price split between the three groups NORD-CNOR, CSUD-SUD-SARD and SICI remains in all three scenarios (base, HW HS and LW LS), as shown in Figure 8.

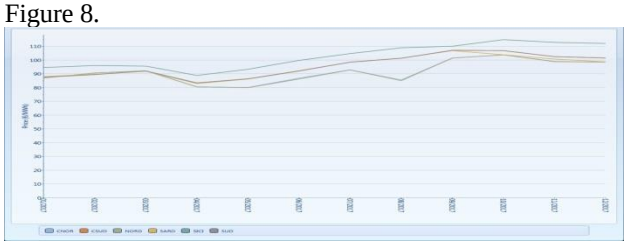

Figure 8. Price splitting between NORD-CNOR (bottom line), CSUD-SUD-SARD (central line) and SICI (top line) zones obtained for the 2017 base scenario.

Combining Figure 8. with Figure 5. it is evident that the transfer capacity between SUD and SICI is as critical for Sicilian prices as those between the neighbour countries and the NORD zone. In fact, even with the planned interconnector capacity of 1,100 MW, and additional 800MW of renewables, the average price differential between SICI and SUD is expected to remain around €7/MWh in 2017.

IV. DISCUSSION

The expansion of the Italian power system up to 2017 is expected to come predominantly from renewable generation. As wind accounts for 1/3 of the expected 10 GW increase in installed capacity, most of which in CSUD, SICI and SARD, the interconnectors between the Italian zones and with neighbour countries become critical for a reliable operation of the system, as the German-Czech situation indicates [7]. Our model of the Italian market in 2017 shows that the planned capacity expansion of the existing interconnectors and inter-zonal flow limits, and the commissioning of new interconnectors with Balkan countries, provides sufficient mitigation to the potential problems caused by the intermittent operation of wind and solar generators. However, notwithstanding that more than 2/3 of the expected development in generation capacity comes from renewables, the Italian power market continues to rely heavily on cheap electricity from France's nuclear and Switzerland's hydro plants to balance the high cost of domestic generation. The results from the scenarios of a HW HS and LW LS year in 2017 indicate that the Italian system, even with a significant percentage of renewable capacity, is not likely to experience the negative power prices that occasionally appear on the German energy market [8]. On the contrary, daily prices are expected to remain quite stable for a broad range of generation mixes from renewable sources, with the only exceptions being the weekends or potential situations of particularly low load.

V. CONCLUSIONS

We have built a dataset using information from Terna reports and utilities websites and used PLEXOS for Integrated Systems to model the Italian power market in 2017. Our model shows that the planned reinforcement of the Italian grid is capable of preventing possible system adequacy issues linked to the expected development of renewable capacity. Despite the significant proportion of renewables to come online by 2017, power prices are not affected as much as in other countries (e.g. Germany). Critical elements of the Italian grid appear to be the interconnectors with France and Switzerland. When fully utilised, these interconnectors' capacities are sufficient to accommodate the expected development of the Italian energy mix, but any disruption in the import flow from those countries is likely to cause price spikes on the Italian power market. Finally, we are planning to expand this model with the inclusion of full transmission network details, whenever these can become publicly available. Unfortunately, the scarcity of such data is a common issue, at the moment, for most, if not all European power systems and markets. This becomes more evident after a comparison with the respective data availability in US or in other similar mature power markets.

VI. REFERENCES

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