Regulation of the Wind Power Production: Contribution of the Electric Vehicles and Other Energy Storage Systems

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Abstract — **The increase in penetration of variable renewable energy sources (RES) introduced additional difficulties regarding the management of the Portuguese Power System. This is mainly due to the high temporal variability and low controllability, characteristics of these kinds of sources. There is a real need to reduce the impact of non–dispatchable RES sources; maximizing their penetration and minimizing curtailment. This is especially true for wind power and run-of-the-river hydro (ROR); as it appears beneficial to combine their variable production with added capacity of energy storage and demand side management; thereby increasing the flexibility of the power system as a whole. This paper aims to assess the excess wind generation (and other non–dispatchable sources); this for periods of production's excess in a 2020 timeframe, and assuming different weather scenarios. The adjustment of wind power generation (WPG) profile to the load profile is also addressed; the result is computed in the form of the value of the energy temporally deferred, using Pumped Hydro Storage (PHS) power plants as well as electric Vehicles (EVs).**

I. INTRODUCTION

In 2011, the Portuguese power system reached an annual wind energy penetration of 18%. Nowadays Portugal has the second largest wind penetration in the world, only overcome by Denmark; additionally there are also a large number of ROR hydro plants. Both these RES are non–dispatchable and highly variable power sources. It's expected that in the coming years, the main renewable power sources that will be used on a large scale are wind power, photovoltaic and hydro power, including its high component of ROR hydro capacity – this scenario is not only for Portugal but several other countries. Portugal is only grid–interconnected to its geographical neighbor, Spain; thus, the limit for the large integration of wind generation in this power production system is the expected excess of renewable generation during the no–load periods, in wet windy winter days [1].

The winter of 2009/2010 was extremely rainy and windy; the non–dispatchable power generation (mainly wind and ROR) overcame the no–load power in several periods. That surprised the planners that forecasted such an occurrence only with a wind installed capacity of 4500 MW, since in that period only 3500 MW were operating [2].

When variable RES exceed 20% of the energy supply on an annual basis, there is usually a need for additional power system's flexibility in order to adjust the variable power production to the load consumption patterns. In this situation, the variability can be managed by increasing the power reserves or installing additional reversible storage capacity. The "storage" of energy has the additional advantage of allowing the absorption of excess energy (acting as a negative reserve), however this has technical constraints in what concerns energy supply (positive reserves) since the energy storage capacity is also limited.

It is important to underline that exporting the excessive RES generation is not generally an option, since the wind and hydro conditions in Portugal generally correspond to similar conditions in Spain, creating a simultaneous problem of surpluses. This scenario makes the hydro power stations with pumping (PHS) the most appropriate solution to complement wind generation; as they have optimum characteristics, presenting a fast response compatible with the wind power fluctuations and high degree of flexibility of operation. With an adequate strategy of operation, PHS stations can be used as accumulators for wind energy and other variable RES.

Another method, complementary to PHS for the regulation of non-dispatchable RES, comes from a fleet of electric vehicles (EVs). According to actual deployment plans, in the coming decades there will be an ever increasing number of vehicles with this type of technology; so it is expected that this fleet will reinforce flexibility of the power system, especially during no–load periods, where the batteries of parked automobiles may store the excess energy produced in windy night periods. This method of storage will be maximized with the dissemination of Demand Side Management (DSM).

II. METHODOLOGY AND DATA USED

The wind generation in Portugal is usually higher during no–load period overnight. To ensure the safety of the electrical system in a scenario of high wind production, there are solutions to regulate the contribution of non-dispatchable sources. In an initial stage, this regulation will be achieved by increasing the capacity of reversible PHS; this will help drain the excess of wind power production during no–load periods, thus contributing to integrate higher amounts of wind generation, without need for curtailment and the consequent wasting of the productive potential of this renewable source. Within a few years, it is expected that projects of smart grids and electric mobility to play a significant role in the grid; transferring power consumption from peak periods to no–load periods [3].

In order to identify how relevant will the role played by EVs and other energy storage sources be in regulating the variability of wind production in the 2020 horizon for Portugal; the following data series of the Portuguese power system were analyzed [4]:

- Load;
- ROR hydro power production;
- Wind power production;
- Combined heat and power (CHP) production;
- Small hydro power production;
- Photovoltaic (PV) power production.

All these series have a frequency of 15 minutes provided by the Portuguese transmission system operator (TSO), REN, on their website (www.ren.pt).

A. *Characteristics of the Power System*

a) *Non-dispatchable Production*

To fulfill the goal of this work a non-dispatchable production was simulated for the "virtual" year of 2020. The installed capacity for this year was set out as stated in the National renewable energy action plans (NREAP), [5]. In order to perform such a simulation, it was considered that in 2020, the component of non-dispatchable electricity generation system will have the capacity set out as show in Table I.

To create the "virtual" year of 2020, regarding a power system with high penetration of non-dispatchable sources, three scenarios of extreme weather conditions were designed.

Firstly the year 2010 was chosen as a reference to construct the run-of-the-river and small hydro plant power production, since this is the year with the highest rate of hydro power production in the period (2003-2010). The same year was used as a reference for wind generation due to the high wind regimen experienced. The year 2006 was considered as reference for an average year for hydro, and the year 2008 was taken as reference for the average year in terms of wind generation. For CHP and PV, 2010 was used as the reference for data representativeness reasons.

The next step of the analysis was to create the series of non-dispatchable RES production for the year 2020 [4]. To construct those series, it was necessary to normalize sets of each type of generation of the reference year, with an installed power of the same year (Table I). Then it was necessary to resize the series obtained, using as value forecast to be installed in 2020 (Table I).

TABLE I
Installed/planned capacity in Portugal.
Sources: REN – Technical Data, 2006, 2008,2010. PNAER, 2010; REN- PDIRT 2009-2014, 2008

INSTALLED/FORECASTED CAPACITY (MW)				
Generation Equipment	Ano			
	2006	2008	2010	2020
Run-of-the-river	2179	2182	2182	2583
Wind Power	1515	2624	3705	6950
Independent Thermo	1295	1463	1698	3000
Small hydro	365	379	410	750
Photovoltaic	0	50	122	1500

b) *Load*

The reference series used to simulate the series of load for 2020, were from the year 2010; the most recent year available at that the date of this work. It was chosen to apply an annual growth rate of 2% to the target load reference series.

c) *Electric Vehicles Loads*

It was estimated that in 2020 there will be 250 000 EV, and they can only be loaded in no-load period (between 10.00 p.m. and 08:00 a.m.). The power required for 80% of simultaneous charging of these vehicles was set at 400MW.

d) *Dispatchable production and surplus*

Conventional dispatchable generation was computed as the balance generation between load and RES generation. There is only a surplus in non-dispatchable production when power production directly exceeds power consumption. In terms of power balance the power reserve was not taken into account.

e) *Pumping*

As far as this study is concerned, pumped storage occurs only when there is a surplus of non-dispatchable production, (i.e.: after considering the baseline and the EVs loads). This means that energy storage is prioritized by EVs. It’s considered that the only technical limit to the PHS is the total planned installed capacity for this purpose, i.e.: 4442 MW for the year 2020.

f) *Import and Export*

It is assumed that electricity import in the "virtual" year of 2020 will not exist, this for a high wind and hydro power production. By 2020 it is very likely that Portugal will become an exporter of electricity [1]. As for the present study, it’s considered that export of electricity will occur only when the pumping capacity is not sufficient to absorb the excess of non-dispatchable production, i.e.: when surplus after consumption of EVs exceeds 4442 MW.

B. *Scenarios for the Portuguese power system in 2020*

As previously stated, three scenarios were built for the profile generation of the Portuguese power system in 2020. These scenarios were:

i. An extreme scenario regarding the wind a hydro power production (extreme RES scenario);

ii. An extreme scenario of wind power production and medium hydro power production (extreme wind scenario),
iii. An extreme scenario of hydropower production and average wind production (extreme hydro scenario).
iv.

Each of these scenarios contained the following series:

- Wind power production;
- Others non-dispatchable (including series for: independent thermo, small hydro and photovoltaic power);
- Run-of-the-river hydro power production;
- Dispatchable production;
- Loads;
- Loads together with EV loads;
- Loads together with EV loads and pumping.

The analysis of each scenario is made in two ways: a daily basis, allowing to determine the day with the highest penetration rate of non-dispatchable production, and an annual base, to determine the amount of excess energy that the non-dispatchable sources could produce with respect to the annual power consumption.

With these results it was then calculated the excess energy regulated by the storage units (EV and storage reservoirs with pumping) determining in this way the reduction of the initial surplus.

The present work has also the purpose of performing an economic analysis of the energy surplus from non-dispatchable sources; determining the value of the curtailed energy; this if that is the approach followed by the power system operator. To do this analysis, it was considered the power surplus value in an hourly rate.

The data was obtained from OMIP (The Iberian Energy Derivatives Exchange) in 2010. The last step was to perform the economic/energy surplus analysis during the assumed no–load period (22.00 p.m. – 08.00 a.m.), in order to assess the economic profit obtained with the energy transfer from the no–load period to the peak period using storage. In this scenario it was considered that the surplus energy is only regulated by PHS with an efficiency of 0.65 [1]. For simplicity, the energy surplus is sold at the most valuable period i.e.: between 20.00 – 22.00 p.m (Fig.1.) [6].

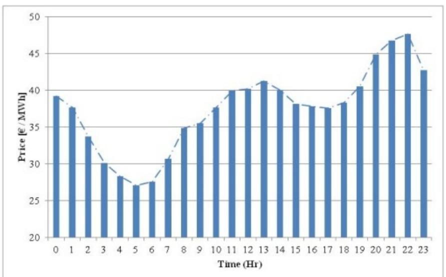
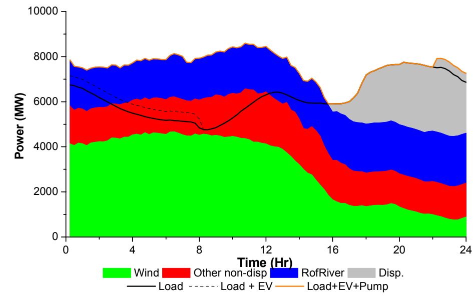


Figure 1: Daily price profile in 2010 for the Portuguese electric market. Source: Junior, 2011.

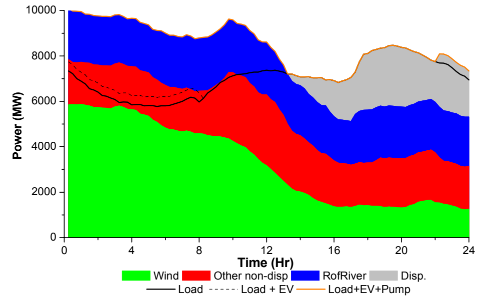
III. EVALUATION OF THE EXCESS OF RENEWABLE PRODUCTION IN THE VIRTUAL YEAR 2020

A. Daily analysis

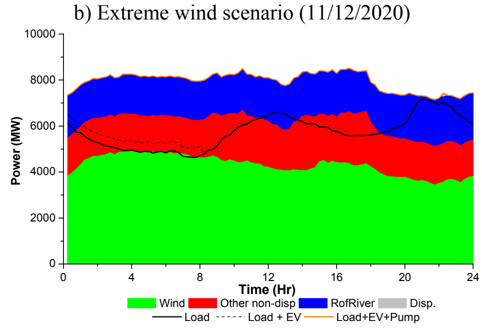
An analysis of the day with the highest penetration rate of non-dispatchable production is show in Fig. 2.



a) Extreme RES scenario (01/01/2020)



b) Extreme wind scenario (11/12/2020)



b) Extreme hydro scenario (18/04/2020)

Figure 2: Daily profile of the power system for the day of 2020 with the higher penetration of non-dispatchable production for three wind/hydro scenarios.

Regarding load, it can be seen that production is higher than load between 00.00 and 14.00 H, this in the extreme RES scenario; between 00.00 and 16.00 H, for the extreme wind scenario; and during most of the day in extreme hydro power production scenario. During the period with excess energy, there is only regulation by EV load between 00.00 and 08.00 hours hence much of the regulation will be made by pumping. Those high values of non–dispatchable power production were obtained by the simultaneous combination of high amounts of wind power and hydropower.

B. Annual analysis

Excessive energy production made by non–dispatchable production (Table II) in 2020 ranges from 823.7 GWh for Extreme Hydro scenario to 1156.3 GWh for the Extreme Scenario. The contribution of EV consumption for the absorption of the surplus in the extreme scenario is 23%. In an extreme wind scenario, the contribution of EV is 18%, and in a hydro extreme scenario is 21%. When it is necessary to turn to the storage regulation using PHS and EVs, the energy surplus is fully absorbed.

TABLE II
Surplus energy produced by non-dispatchable production; value, maximum power, EV load and pumping for 2020, in the considered scenarios.

		Excess	Consumption by EVs	Pumping
Extreme Scenario	Máx. Power excess(MW)	3 357	-	-
	Energy (MWh)	1 156 261	263 305	892 956
	Value (€)	19 939 634	4 611 705	15 327 929
Extreme wind scenario	Máx. Power excess(MW)	3 876	-	-
	Energy (MWh)	1 051 503	187 458	864 045
	Value (€)	27 174 204	4 463 362	22 710 842
Extreme hydro scenario	Máx. Power excess(MW)	3 428	-	-
	Energy (MWh)	823 671	173 314	650 357
	Value (€)	19 655 014	3 830 840	15 824 172

The value of energy load by EV and pumping, regarding the energy surplus delivered by non-dispatchable production (Table II), in 2020, in the extreme scenario is 19.9 M€. For the extreme wind scenario, the annual total is 27.2 M€, and in the extreme hydro scenario is 19.7 M€.

C. *Annual analysis of no-load period*

The transfer of energy from the no-load period to the peak period using PHS (Table III) results in a reduction of 35% in energy, due to the pumping efficiency (0.65).

As for the value of energy transferred (Table III), this presents a valuation ranging from 3.233.868€ in a hydro extreme scenario, and 10.110.500€ in the extreme scenario, corresponding to an added value tax between 26% and 77%.

TABLE III
Surplus energy produced by non-dispatchable production in the no-load period (22.00H – 08.00H); transfer to the peak period using PHS, annual value in 2020, for the considered scenarios.

		Excess in no-load (22H – 08H)	Transfered (stored) energy (20H-22H)	Added Value
Extreme Scenario	Energy (MWh)	820 857	533 557	-
	Value (€)	13 158 508	23 269 008	10 110 500
Extreme wind scenario	Energy (MWh)	646 886	420 476	-
	Value (€)	16 205 503	20 413 260	4 207 757
Extreme hydro scenario	Energy (MWh)	520 788	338 512	-
	Value (€)	10 756 683	13 990 551	3 233 868

IV. CONCLUSIONS

The expected increase of wind power penetration by the end of the decade, together with the daily profile of generation of this renewable energy source in some European regions, will contribute to an increase in power production during no–load periods; this scenario will represent a relevant surplus of renewable energy during windy wet winters.

This study showed that power regulation based on the distributed storage of EVs may have a relevant contribution for the absorption of the excessive energy delivered by the non–dispatchable fleet; this in respect to the power consumption forecasted for 2020. Although important, EVs are not fundamental, since the maximum power surplus in the three scenarios will not exceed the PHS capacity planned for the 2020 timeframe.

On the other hand there is also a considerable uncertainty as to the execution of some reservoirs with pumping. This factor will increase the importance of EV in the regulation of surplus of non–dispatchable production by the end of the decade.

Not taking into account market strategies and procedures, under MIBEL (Iberian Electricity Market), this study showed an added value brought by daily regulation, that may ensure the profitability of new PHS power plants. For instance the installation of pumping in the Baixo-Sabor power plant has a cost of 95M€ [7], meaning that, according to the used models, the investment will be recovered within an acceptable period.

The severe economic crisis in Portugal that erupted in 2011 and will extend until 2013; will likely have implications in the RES capacity values planned for 2020. Namely, with the reduction of the wind capacity value of 6.950 MW that was already announced by the Portuguese Government. Thus the energy surplus calculated in the three given scenarios, with the currently available information is very unlikely to exist. However, the same crisis is contributing to a decline in consumption verified in 2011 and extending to 2012 (REN – Monthly Statistics, 2011). This may mean that the average consumption scenario growth (2%) in this study will not be fulfilled, which in turn implies an increase of excess of non–dispatchable production by the decrease in consumption.

With all these uncertainties in the various variables that constitute the power generation system, in the near future it will be convenient do perform a probabilistic study, introducing the latest data that over the next few years.

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