Virtual Power Player Using Demand Response to Deal with Unexpected Low Wind Power Generation

Pedro Faria
Polytechnic of Porto
GECAD
pnfar@isep.ipp.pt

Zita Vale
Polytechnic of Porto
GECAD
zav@isep.ipp.pt

Abstract

Demand response is assumed as an essential resource to fully achieve the smart grids operating benefits, namely in the context of competitive markets and of the increasing use of renewable-based energy sources. Some advantages of Demand Response (DR) programs and of smart grids can only be achieved through the implementation of Real Time Pricing (RTP). The integration of the expected increasing amounts of distributed energy resources, as well as new players, requires new approaches for the changing operation of power systems.

The methodology proposed in this paper aims the minimization of the operation costs in a distribution network operated by a virtual power player that manages the available energy resources focusing on hour ahead re-scheduling. When facing lower wind power generation than expected from day ahead forecast, demand response is used in order to minimize the impacts of such wind availability change. In this way, consumers actively participate in regulation up and spinning reserve ancillary services through demand response programs. Real time pricing is also applied.

The proposed model is especially useful when actual and day ahead wind forecast differ significantly. Its application is illustrated in this paper implementing the characteristics of a real resources conditions scenario in a 33 bus distribution network with 32 consumers and 66 distributed generators.

1. Introduction

Several countries in Europe have increased the electricity generation based on renewable, namely based on wind, in order to meet the European Union energy policy goals [1]. Portugal has followed the European Union tendencies and directives, and it is currently one of the countries with higher wind energy penetration, which is the percentage of demand covered by wind energy in a certain region, normally on an annual basis.

The evolution of wind power generation, from 2003 to 2011, in Portugal is presented in Figure 1 [2]. 8000 MW of wind power generation are expected for 2020, which corresponds to an increase of 100% in the value of the year 2010 [3].

Apart from environmental issues and from global energy policy goals, but not independent of those, let us focus on distribution power grids, and on electric power systems in general.

The increasingly intensive use of Distributed Generation (DG), the creation of Demand Response (DR) programs [4], and the increasing requirements in terms of energy quality and network reliability aim at bringing to practice the concept of smart grid (SG) [5].

A smart grid is an infrastructure able to accommodate all centralized and distributed energy resources, including intensive use of renewables and DG, storage, DR, and electric vehicles, in the context of a competitive business environment. Smart grids should put together all these energy resources, guaranteeing its most adequate management in a complex environment [5].

Aggregation of small-scale distributed resources, as well as their operation, in a competitive environment leads to the creation of Virtual Power Players (VPP) [6]. VPP can aggregate diversity of players and of energy resources, including DR, making them profitable.

An important issue regarding the increase in the DG units' integration and namely wind power generation is the large variability of wind generation and the lack of accuracy in day ahead wind forecast. Demand response can be efficiently used to address this problem [7-10].

Due to the intermittence and unpredictability of both DG and DR resources availability, adequate concerns must be given to the provision of reserve in the operation of power systems in order to maintain adequate levels of security in their operation [11].

One of the most implemented DR programs is the Real Time Pricing (RTP), in which the price of electricity is defined for shorter periods of time, usually 1 hour, reflecting the changes in the wholesale price of electricity. Customers usually have the information about prices on a day-ahead or hour-ahead basis.

This paper proposes a DR-based methodology to face situations of wind generation largely lower than the forecasted value. A VPP operating a distribution network optimizes the energy resources use, minimizing the operation costs in a smart grid context.

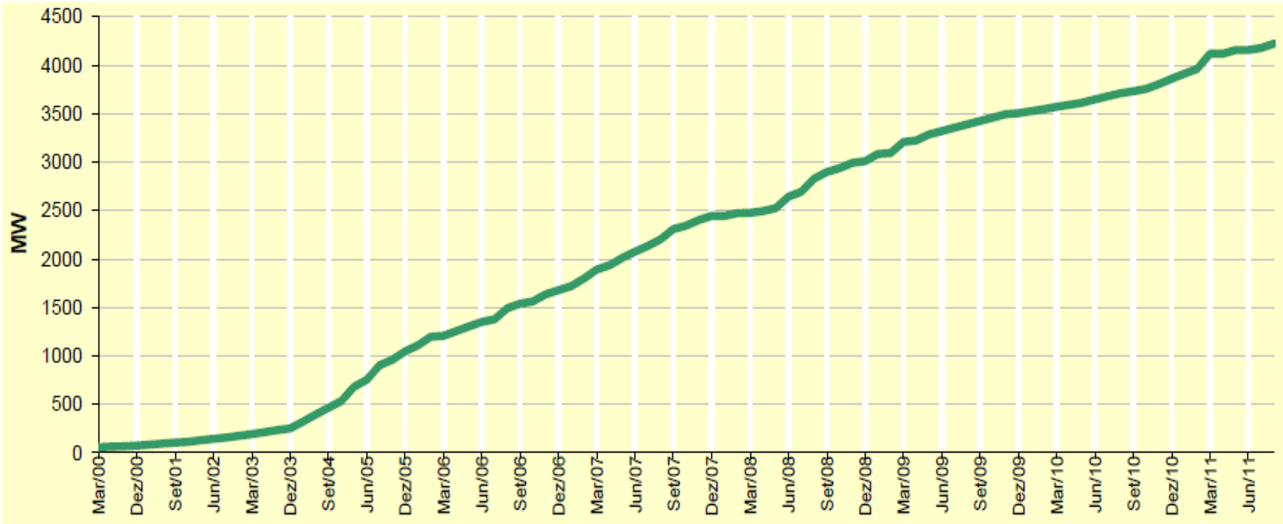

Figure 1: Wind energy use in Portugal [2].

Both demand and generation resources have contracted with the VPP the provision of energy capacity to face the referred wind variation. When such lower wind power availability occurs, the VPP can activate regulation-up and spinning reserve services contracted to consumers and generators and increase the electricity price to the consumers participating in RTP in order to induce the reduction of the consumption. Resources constraints are also considered in the methodology.

After the introductory section, Section 2 presents some facts concerning the unexpected low wind power situations in Portugal. Then, in Section 3 the mathematical formulation of the proposed methodology, and the methodology itself, are explained. A case study based on a real scenario adapted to a distribution network is presented in Section 4. The scenario reflects a special wind availability reduction day in Portuguese power system. Finally, Section 5 presents the main conclusions of the paper.

2. Unexpected low wind power

The present section includes some facts concerning the low wind power situations occurred in Portugal. An introduction to the characterization of renewables is presented in sub-section 2.1, and some examples of low wind power situations are presented in sub-section 2.2.

2.1. Renewables in Portugal

Portugal has followed the European Union energy policies and directives, and increased the electricity generation based on renewable, namely based on wind.

In order to illustrate these resources amount in the past years, Figure 2 shows the renewable-based installed power and the generated energy per year since 1995, whereas Figure 3 focuses on the wind generation since 2008.

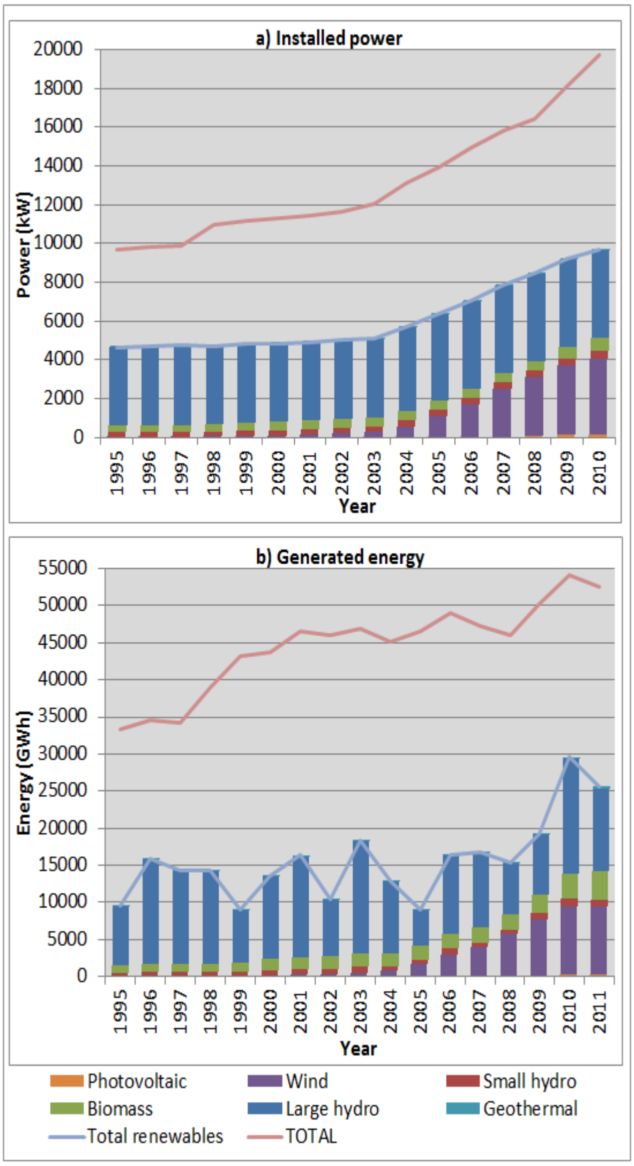

Figure 2: Renewables installed power (a)) and generated energy (b)) in Portugal in past years [12].

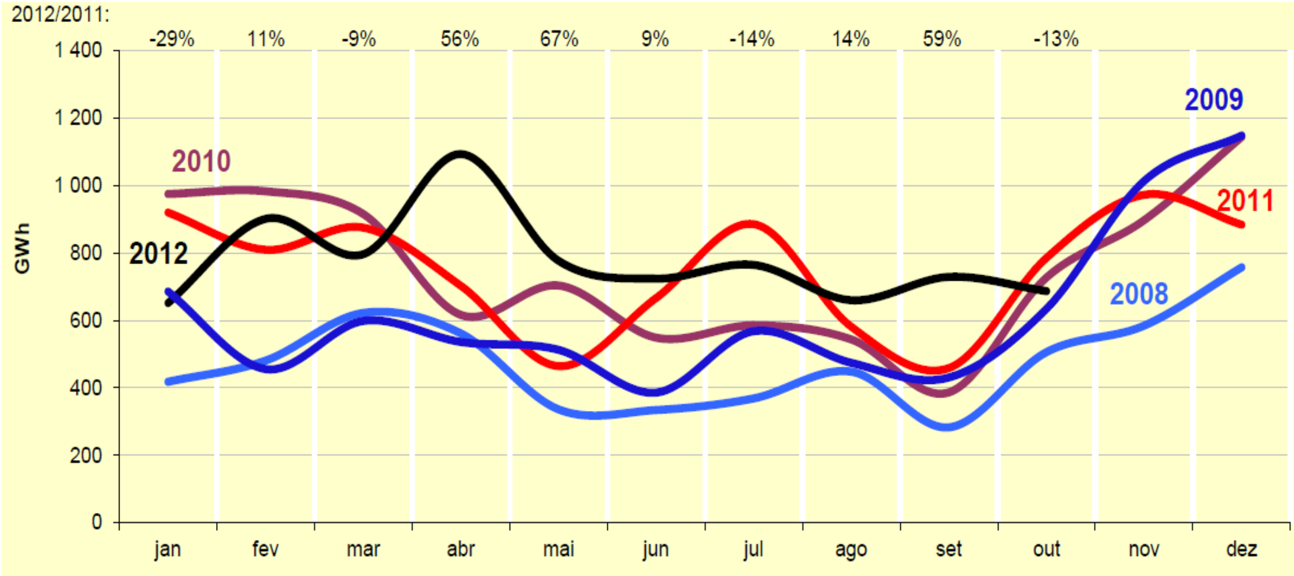

Figure 3: Wind generation in Portugal since 2008 [2].

In what concerns the renewables integration and contribution in the Portuguese power system, it can be seen that renewables are very significant. The most significant resources are the large hydro power plants, which have been installed even before the recent year's environmental concerns and policies. Looking at the remaining resources, it is concluded that the wind power is the resource with higher contribution.

Focusing on the wind power over the recent years, Figure 3 shows Portugal's wind-based electricity generation since 2008. Winter months are generally the ones with higher generation. However, it is important to note that in July 2011 there was a huge generation when compared with the values in the same month of other years. The same can be seen in April 2012. The percentage values in the top of Figure 3 correspond to the relative variation of generation comparing the values of 2011 and 2012.

For a better understanding of the energy resources context in Portugal, Figure 4 presents its generation mix. The information in Figure 4 regards the October 2012 situation [13]. The total amount of electricity generation was 3155 GWh. The installed power was 12053 MW. Portugal has exported 40 GWh of energy to Spain, while Spain has exported 852 GWh to Portugal, during October 2012. Almost half of the PRE energy in Portugal regards the wind generation [14].

In the legends of Figure 4, CCGT stands for combined-cycle gas turbine; CoGen stands for combined heat and power; and PRE represents the special producers. Those producers (denominated in Portuguese as PRE) are producers with renewables based generation technologies that make use of special condition tariffs in order to improve the use of endogen renewable energy.

It is important to note that the generation mix regarding PRE is not negligible (about 30 %). As PRE producers are benefiting from special tariffs, it is important to take the most possible advantage of the energy available from these producers.

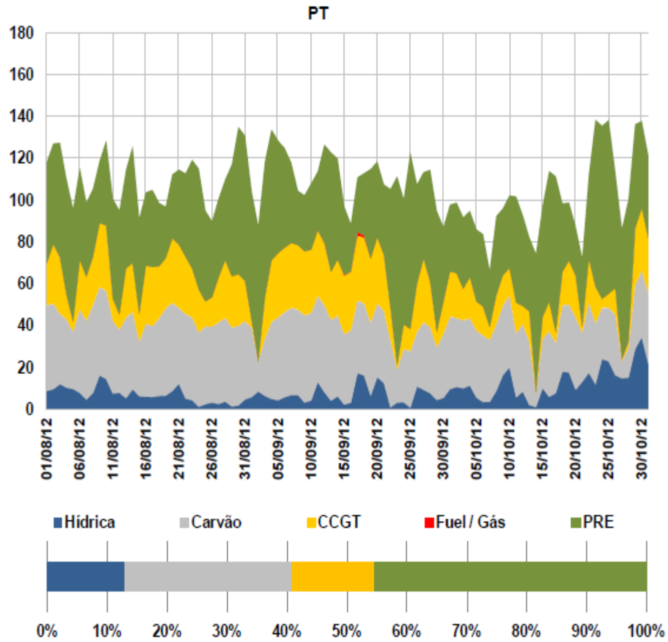

Figure 4: Generation mix (GWh) in Portugal, form August 2012 to October 2012 [13].

From the facts above, one can say that the wind power generation is not negligible and adequate importance must be given to the integration of this resource.

2.2. Specific low wind power days

The present sub-section shows some real examples of unexpected low wind power situations in Portugal.

A certain error is acceptable in the forecast of the resources based in renewables. The specific case of wind is of most difficulty of prediction. Moreover, due to its huge integration in power systems, the errors in the wind forecast are very important.

Figure 5 presents some examples of the difference between the forecast (in grey color) and the actual (in blue color) wind power generation in Portugal [14]. The three specific examples belong to a) October 17th 2012; b) October 27th 2012; c) October 30th 2012. The green line in Figure 5 represents the total installed wind generation capacity.

It can be seen that the huge differences between the forecast and the actual values can occur in any period of the day, and any wind power generation level, i.e. in periods of low and high wind power generation.

The selected examples belong to October 2012, which is the most recent month of published results in what concerns renewables statistics.

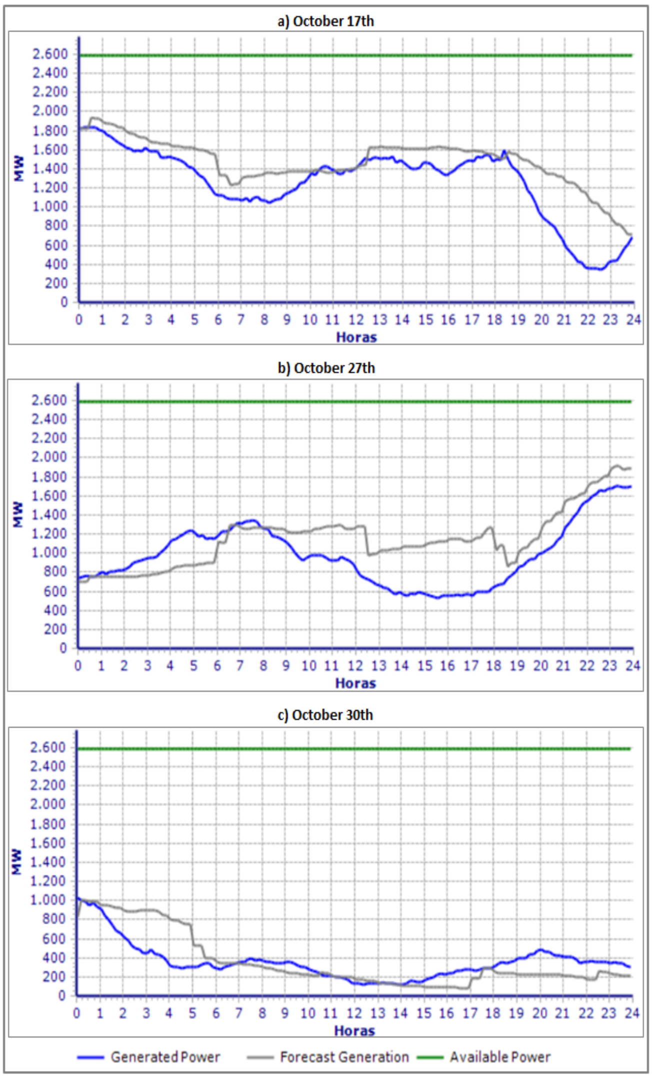

Figure 5: Examples of wind power generation forecast and actual values – a) October 17th 2012; b) October 27th 2012; c) October 30th 2012.

In the present paper, the scenario of October 17th has been selected in order to ilustrate the application of the proposed methodology, which is intended to make use of real time pricing in unexpected wind power situations in order to reduce the consumption and meet the actual wind power value.

3. Resources scheduling model

The present section explains the developed DR methodology, which is based on RTP and two incentive-based DR programs. It aims to reduce the impacts of wind generation largely lower than the forecasted value, optimizing the operation of a VPP. Figure 6 presents a scheme that represents the use of each resource.

The available resources (energy supplier, wind generation, other distributed generation units, and demand response) are participating in the resources scheduling as a regular resource, as providing regulation up (Reg. Up) and spinning (Spin) reserves, and in the case of consumers, participating in real time pricing demand response programs.

Regulation up and spinning reserves, and real time pricing are used to meet the variations in the wind power value. The regulation up service is used in lower variations in wind power, whereas spinning reserve is used for higher wind power variations. The two reserve services (regulation up and spinning reserve) when provided by consumers, belongs to the group of incentive-based demand response programs. Real time pricing belongs to the group of price-based demand response programs [4].

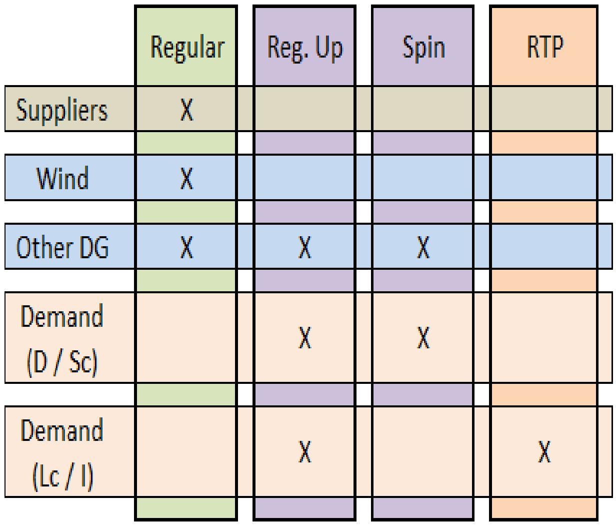

Figure 6: Proposed methodology diagram

Equation (1) presents the objective function of the proposed Mixed Integer Non Linear problem that aims at the minimization of the Operation Costs (OC). It considers the values of both generation (energy acquired from the upstream network to one or several suppliers, divided in a quantity previously obtained and additional amounts available at distinct prices; wind generators; and other generators) and demand (consumers divided in Domestic (D), Small commerce (Sc), Large commerce (Lc), and Industrial (I)) resources.

The balance constraint is the one in equation (2). The complete formulation of the problem includes maximum operation limits of each demand and generation resource. The consumer elasticity is addressed by equation (3).

$$Minimize\ \ OC =$$

$$\left[\begin{array}{l} \sum_{Sp=1}^{NSp}\left[\begin{array}{l} E_{Supplier(Sp)}\times C_{Supplier(Sp)} \\ +E_{Supplier(Sp)}^{Additional}\times C_{Supplier(Sp)}^{Additional}\end{array}\right]+\sum_{W=1}^{NW}\left[E_{Wind(W)}\times C_{Wind(W)}\right]+\sum_{O=1}^{NO}\left[\begin{array}{l} E_{Other(O)}^{Regular}\times C_{Other(O)}^{Regular}+E_{Other(O)}^{Regup}\times C_{Other(O)}^{Regup} \\ +E_{Other(O)}^{Spin}\times C_{Other(O)}^{Spin}\end{array}\right] \\ +\sum_{D=1}^{ND}\left[E_{Load(D)}^{Regup}\times C_{Load(D)}^{Regup}+E_{Load(D)}^{Spin}\times C_{Load(D)}^{Spin}\right]+\sum_{Sc=1}^{NSc}\left[E_{Load(Sc)}^{Regup}\times C_{Load(Sc)}^{Regup}+E_{Load(Sc)}^{Spin}\times C_{Load(Sc)}^{Spin}\right] \\ +\sum_{Lc=1}^{NLc}\left[\begin{array}{l} E_{Load(Lc)}^{Regup}\times C_{Load(Lc)}^{Regup}+E_{Load(Lc)}^{Spin}\times C_{Load(Lc)}^{Spin}- \\ \left(E_{Load(Lc)}^{Initial}+E_{Load(Lc)}^{Reduction}\right)\times\left(C_{Load(Lc)}^{Initial}-C_{Load(Lc)}^{Increase}\right)\end{array}\right]+\sum_{I=1}^{NI}\left[\begin{array}{l} E_{Load(I)}^{Regup}\times C_{Load(I)}^{Regup}+E_{Load(I)}^{Spin}\times C_{Load(I)}^{Spin}- \\ \left(E_{Load(I)}^{Initial}+E_{Load(I)}^{Reduction}\right)\times\left(C_{Load(I)}^{Initial}-C_{Load(I)}^{Increase}\right)\end{array}\right]\end{array}\right] \quad (1)$$

$$\begin{array}{l} \sum_{D=1}^{ND}E_{Load(D)}^{Initial}+\sum_{Sc=1}^{NSc}E_{Load(Sc)}^{Initial}+\sum_{Lc=1}^{NLc}\left[E_{Load(Lc)}^{Initial}-E_{Load(Lc)}^{Reduction}\right]+\sum_{I=1}^{NI}\left[E_{Load(I)}^{Initial}-E_{Load(I)}^{Reduction}\right] \\ =\sum_{Sp=1}^{NSp}\left[E_{Supplier(Sp)}^{Regular}+E_{Supplier(Sp)}^{Additional}\right]+\sum_{W=1}^{NW}E_{Wind(W)}+\sum_{O=1}^{NO}\left[E_{Other(O)}^{Regular}+E_{Other(O)}^{Regup}+E_{Other(O)}^{Spin}\right] \\ +\sum_{D=1}^{ND}\left[E_{Load(D)}^{Regup}+E_{Load(D)}^{Spin}\right]+\sum_{Sc=1}^{NSc}\left[E_{Load(Sc)}^{Regup}+E_{Load(Sc)}^{Spin}\right]+\sum_{Lc=1}^{NLc}\left[E_{Load(Lc)}^{Regup}+E_{Load(Lc)}^{Regup}\right]+\sum_{I=1}^{NI}\left[E_{Load(I)}^{Regup}+E_{Load(I)}^{Regup}\right]\end{array} \quad (2)$$

Both demand and "other" (i.e. not based on wind) generation resources can provide regulation-up (Regup) and spinning reserve (Spin) capacity to face generation variations. RTP is also applied to Lc and I consumers for which the initial electricity price (C_Initial) is increased (C_Increase) in order to induce the consumption reduction (E_Reduction) based on the consumer' price elasticity of demand, usually referred as elasticity (3).

$$Elasticity_{(C)}=\frac{E_{Load(C)}^{Increase}\times C_{Load(C)}^{Initial}}{E_{Load(C)}^{Forecast}\times C_{Load(C)}^{Reduction}},C\in\{Lc;I\} \quad (3)$$

The results of the application of the model are the final electricity prices and the scheduling of each one of the energy resources, including the information of the context of using the resource (regular, Reg.Up, Spin, and RTP).

4. Case study

The present section illustrates the application of the proposed methodology to a distribution network (presented in sub-section 4.1) in which the authors have implemented a scenario that corresponds to the real conditions of 17th October 2012 in Portugal (presented in sub-section 4.2). The results of the case-study are presented in sub-section 4.3.

4.1. Distribution network

The present sub-section presents the 33 bus distribution network, also used in [15] by the authors of this paper, and presented in Figure 7.

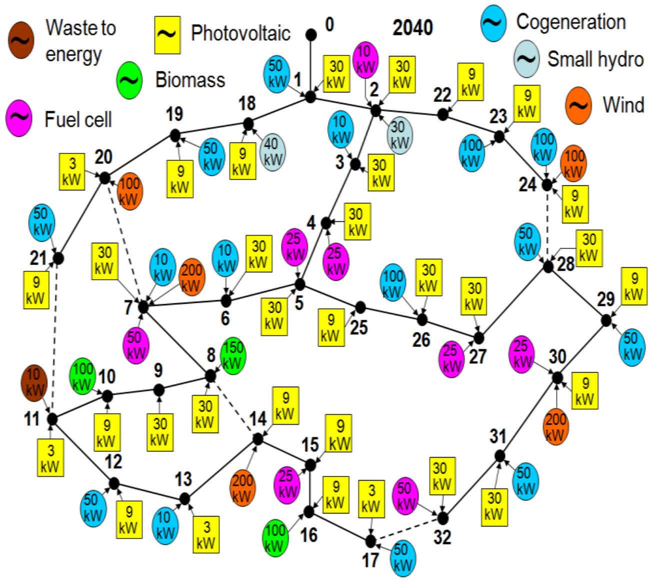

Figure 7: Distribution network.

Both the generation and the demand were updated in order to implement a scenario in the context of a especially lower wind power generation when compared with the forecasted value in the day-ahead planning. The selected day was 17th October 2012.

The virtual power player operating the network will make use of real time pricing in periods of reduced wind power. Increasing the flat rate tariff electricity price, the consumers are expected to reduce the demand value and, therefore, use the available wind power.

In this case study, the same price variation is considered for all consumers types. The values regarding the initial electricity price, the price elasticity of demand (or simply elasticity), and the initial consumption weights (W), in percent, for each consumer type, are shown in Table 1. The division of the consumers into types corresponds to the one currently in use in Portugal and generally stands for the voltage level of consumers' connection to the electricity network.

The consumer types are: Industrial (I), belonging to very high voltage level consumers in Portugal; Large commerce (Lc), belonging to medium voltage level consumers in Portugal; Small commerce (Sc), belonging to special low voltage level consumers in Portugal; and Domestic (D), belonging to low voltage distribution level consumers in Portugal. The rated demand value in this network is 6119 kW.

Consumers characteristics	Type of Consumer			
	D	*Sc*	*Lc*	*I*
Initial consumption (%)	20	30	30	20
Elasticity	0.27	0.33	0.41	0.53
Initial price (€/MWh)	130	100	80	60

Table 1: Demand parameters for each consumer type.

Regarding DG units capacities, the total amount of rated wind power in the network is 683 kW. The remaining DG has 1495 kW of rated power. There is no defined limit for the amount of energy acquired from the suppliers connected through the bus 0.

Figure 8 presents the resources availability values focusing on the last quarter of the day under study; this scenario has been updated considering the information in sub-section 4.2. The values of wind forecast are also shown in figure 8. Those forecast values have been adapted from the ones presented in Figure 5.

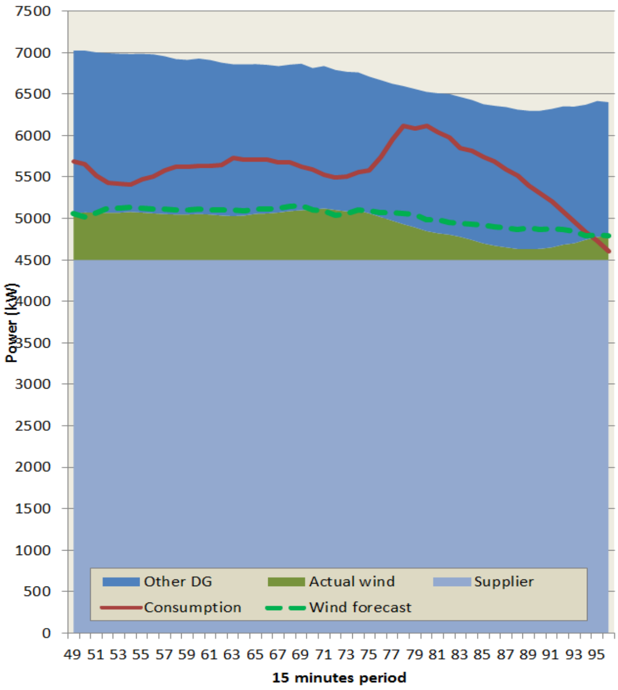

Figure 8: Resources availability values.

4.2. 17th October 2012

In order to ilustrate and validate the application of the porposed methodology to the real conditions of power systems, a special day in the portuguese power system, has been selected. The selected day is 17th October 2012, a wednesday. Its special characteristics are exposed in the present sub-section.

The characteristics of the selected day of the Portuguese power system, namely in what concerns the PRE generation and demand, are presented in Figure 7.

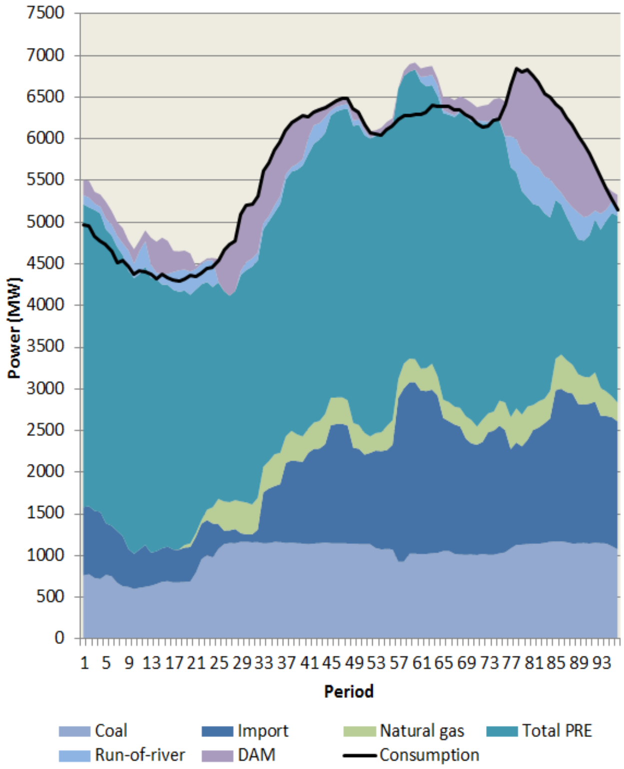

Figure 9: Energy resources use in the selected day [16].

In what concerns the detail of PRE resources use, the values are the ones presented in Figure 10.

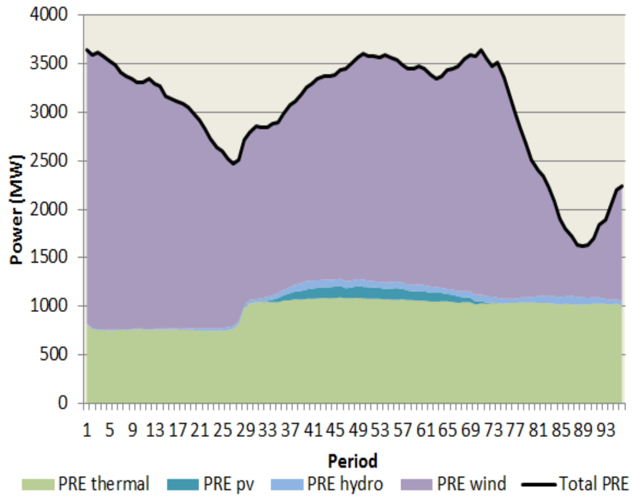

Figure 10: Detailed PRE resources use.

The used energy resources includes, in addition to PRE, imports, coal, natural gas, and other renewables. In the periods in which the generation in Figure 9) is higher then demand, that exceeding generation was used for pumping in order to restore water in dams and use that resource in other periods.

This scenario ilustrates the conditions in which is possible to apply the proposed methodology. In the specific periods of wind power generation lower thatn the forecas, the distribution network operator (which is, in the present approach, a Virtual Power Player – VPP) becomes able to make use the proposed methodology.

4.3. Results

The present sub-section shows the results obtained with the application of the proposed methodology to the scenario presented above.

A virtual power player operating the network uses real time pricing in periods of reduced wind power, increasing the electricity price, and expecting a reduction in the demand value. Regulation up and spinning reserve services provided by several available resources, as explained in Section 3, are also used by the VPP, in distinct wind forecast errors amounts.

Figure 11 presents the use of the available resources, after applying the proposed methodology. The elementary period is of 15 minutes; so, the 48 periods in Figure 8 correspond to the second half of the day.

There are two main period sets of wind power lower than the forecast. The first occurs between periods 52 and 68 of the day. The second one corresponds to the period between periods 73 and 94. In the first periods set (between periods 52 and 68), the one with lower difference between the forecast and the actual values of wind power generation, regulation up was used, whereas in the second period it was used the spinning reserve.

Figure 12 shows the values concerning the real time pricing application. It includes the obtained demand after the application of RTP (represented by the dashed black line) in the secound identified period (between periods 73 and 94) instead of using spining reserve to increase generation.

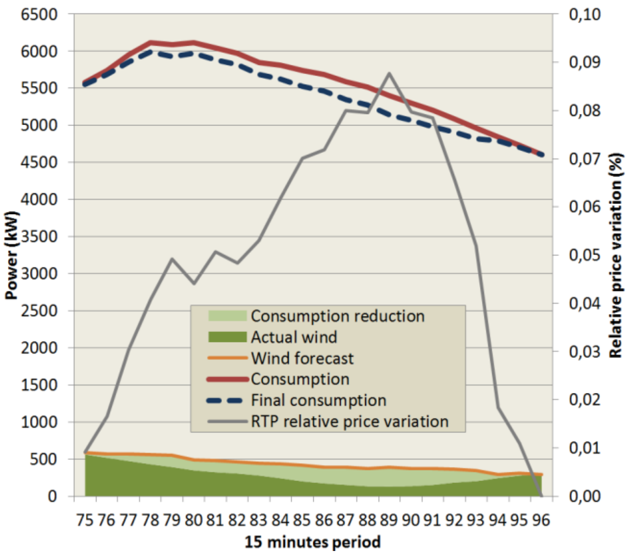

Figure 12: RTP use results between periods 73 and 94.

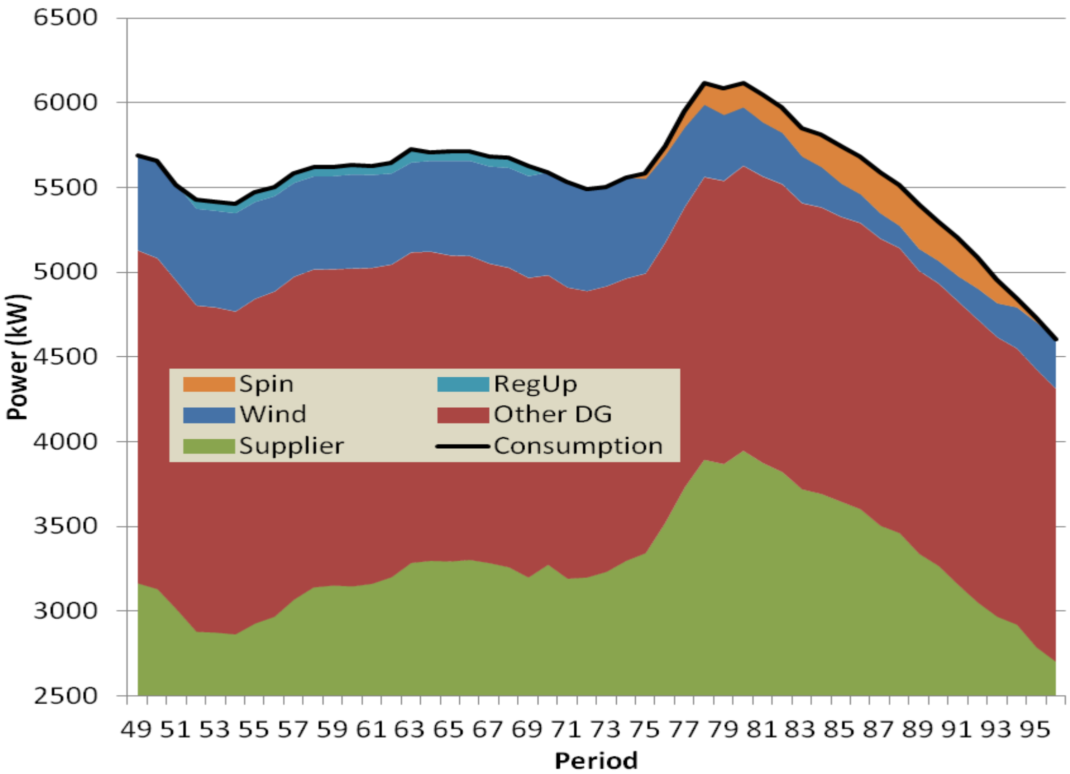

Figure 11: Generation and demand results.

The same price elasticity of demand was considered for the consumers of a certain type. However, since the initial consumption of each consumer is distinct, distinct demand increase is verified in each consumer.

The results of the consumers' response to real-time pricing are presented in Figure 12, for the case of the period 90, selected as an example.

A certain price variation is applied to the consumers' original prices, which are dependent on the type of consumer and contractual tariffs. The same price increase has been applied to the consumers of the same type, for each one of the two considered participating types of consumer, since it was decided to apply the same price to the consumers of the same type.

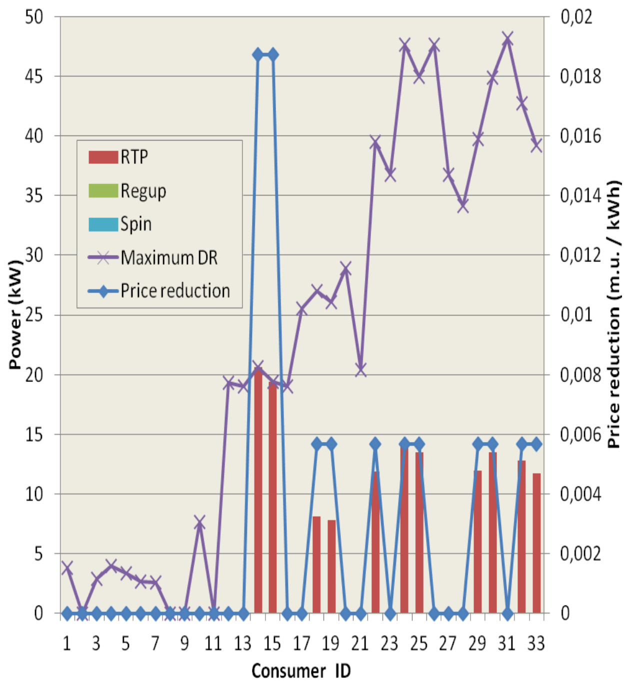

Figure 13: Consumers' response to the RTP.

The higher demand reduction values are verified for indutrial consumers due to their higher consumption reduction capacity, but also due to the higher values of price elasticity of demand of these consumers.

5. Conclusions

The present paper proposed a DR-based methodology to face situations of wind generation largely lower than the forecasted value. A VPP operating a distribution network optimizes the energy resources use, minimizing the operation costs in a smart grid context.

The proposed model is especially useful when actual and day-ahead wind forecast differ significantly. Its application was illustrated in this work using a 33 bus distribution network with 32 consumers and 66 DG units. The scenario reflects a special wind availability reduction day in Portugal, which corresponds to October 17th 2012.

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