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Real Time Pricing Approaches to Deal With Unexpected Wind Power Variations

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Abstract

The use of renewables have been increased I several countries around the world, namely in Europe. The wind power is generally the larger renewable resource with very specific characteristics in what concerns its variability and the inherent impacts in the power systems and electricity markets operation. This paper focuses on the Portuguese context of renewables use, including wind power. The work here presented includes the use of a real time pricing methodology developed by the authors aiming the reduction of electricity consumption in the moments of unexpected low wind power. A more specific example of application of real time pricing is demonstrated for the minimization of the operation costs in a distribution network. 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.

Keywords: Demand response, Real time pricing, Renewable energy resources, Wind power.

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1. Introduction

Several countries in Europe have increased the electricity generation based on wind power and other renewables in order to meet European Union energy policy goals [1]. As can be seen in Figure 1, Portugal is the third European country with higher renewables use.

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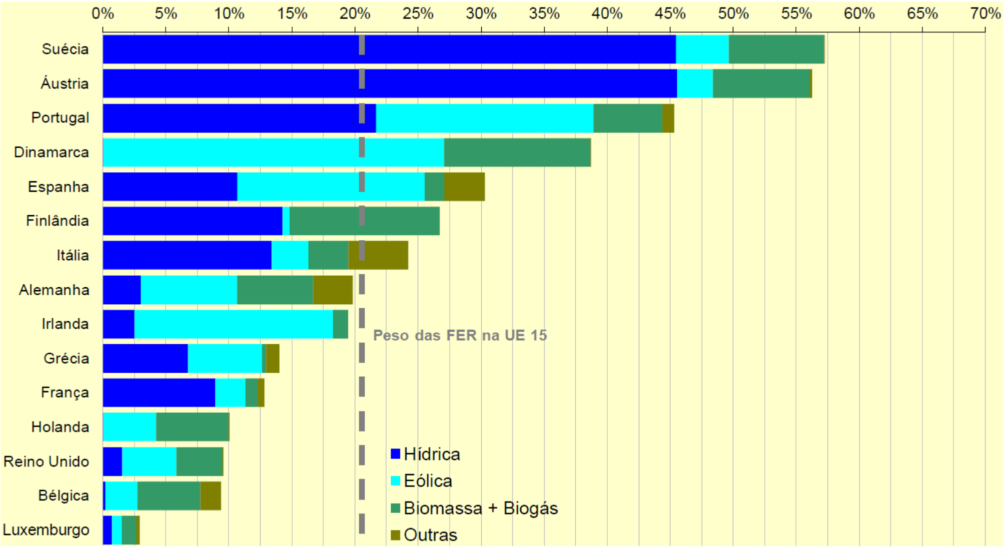

Fig. 1. Renewables use by country in 2011 [2]

Following the European Union tendencies and directives, Portugal is currently one of the countries with higher wind energy penetration (percentage of demand covered by wind energy). The evolution of wind power generation, from 2003 to 2011, in Portugal is presented in Figure 2 [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].

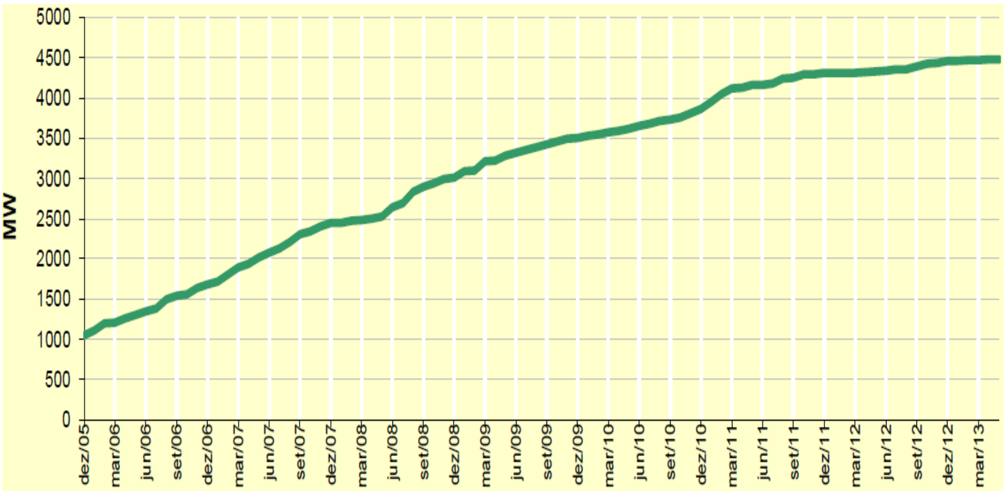

Fig. 2. Wind energy use in Portugal [2]

Focusing on distribution power grids, and on electric power systems in general, one can also note that the increasing 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]. The 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 related to wind power generation is the large variability of wind power and the lack of accuracy in day ahead wind forecast. Demand response can be efficiently used to address this problem [7-10]. Adequate concerns must be given to the provision of reserve in order to maintain adequate levels of security in the power systems' operation [11].

Real Time Pricing (RTP) can be used in order to give signals to the consumers aiming a desired consumption increase or reduction. The methodology presented in this paper uses RTP to address the problem of unexpected low wind power situations.

After the introductory section, Section 2 presents some facts concerning the unexpected low wind power situations in Portugal. Then, in Section 3 the methodology is explained. A case study based on a real scenario adapted to a distribution network is presented in Section 4. Finally, Section 5 presents the main conclusions of the paper.

2. Wind power and renewables in Portugal

The present section includes some facts concerning renewables use (sub-section 2.1) and low wind power situations (sub-section 2.2) in Portugal.

2.1. Renewables in Portugal

In order to illustrate these resources amount in the past years, Figure 3 shows the renewable-based installed power and the generated energy per year since 1995, whereas Figure 4 focuses on the wind generation since 2009.

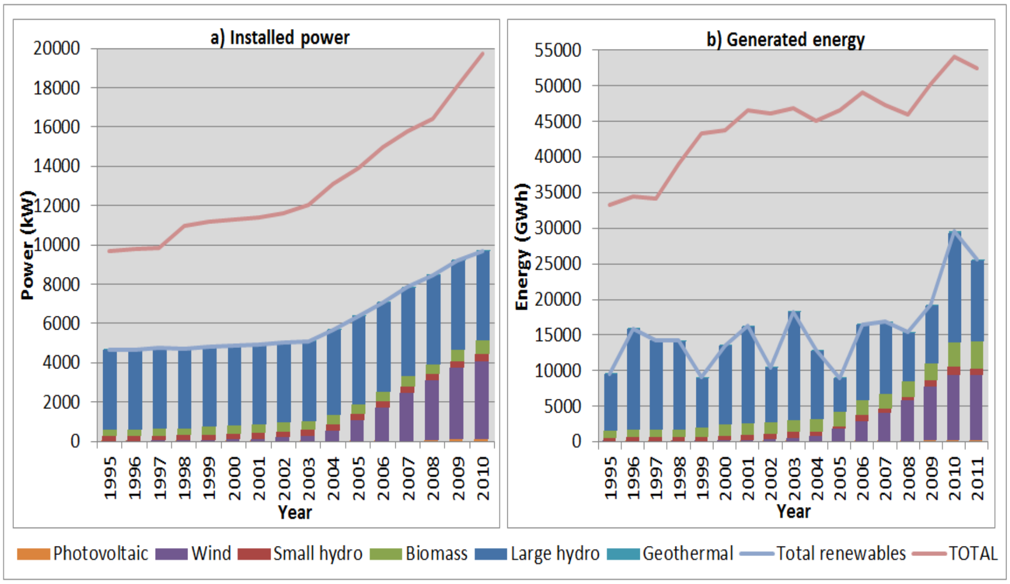

Fig. 3. Renewables installed power (a)) and generated energy (b)) in Portugal in past years [12].

In what concerns the renewables integration and contribution in the Portuguese power system, it can be seen that renewables are very significant. The large hydro power plants, which have been installed even before the recent year's environmental concerns and policies, are the most significant resources. 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 in Figure 4 one can see that winter months are generally the ones with higher generation. Note that in April 2013 there was a huge generation when compared with the values in the same month of other years.

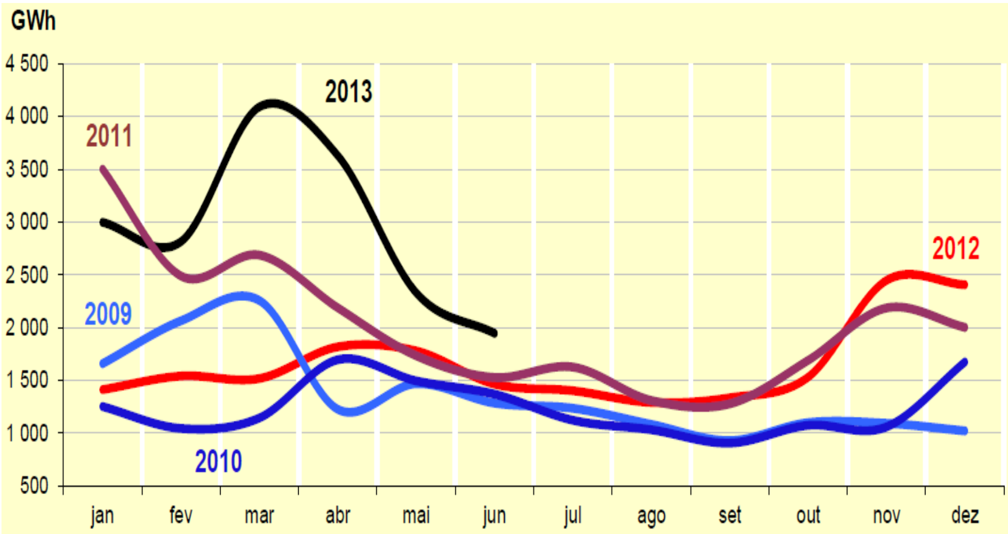

Fig. 4. Wind generation in Portugal since 2008 [2]

Concerning the generation mix in October 2012, the total amount of electricity generation was 3155 GWh. The installed power was 12053 MW [13]. Portugal has exported 40 GWh of energy to Spain, while Spain has exported 852 GWh to Portugal, during October 2012.

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.

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. The three specific examples belong to a) April 29th 2013; b) March 23rd 2013; c) March 28th 2013. 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.

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.

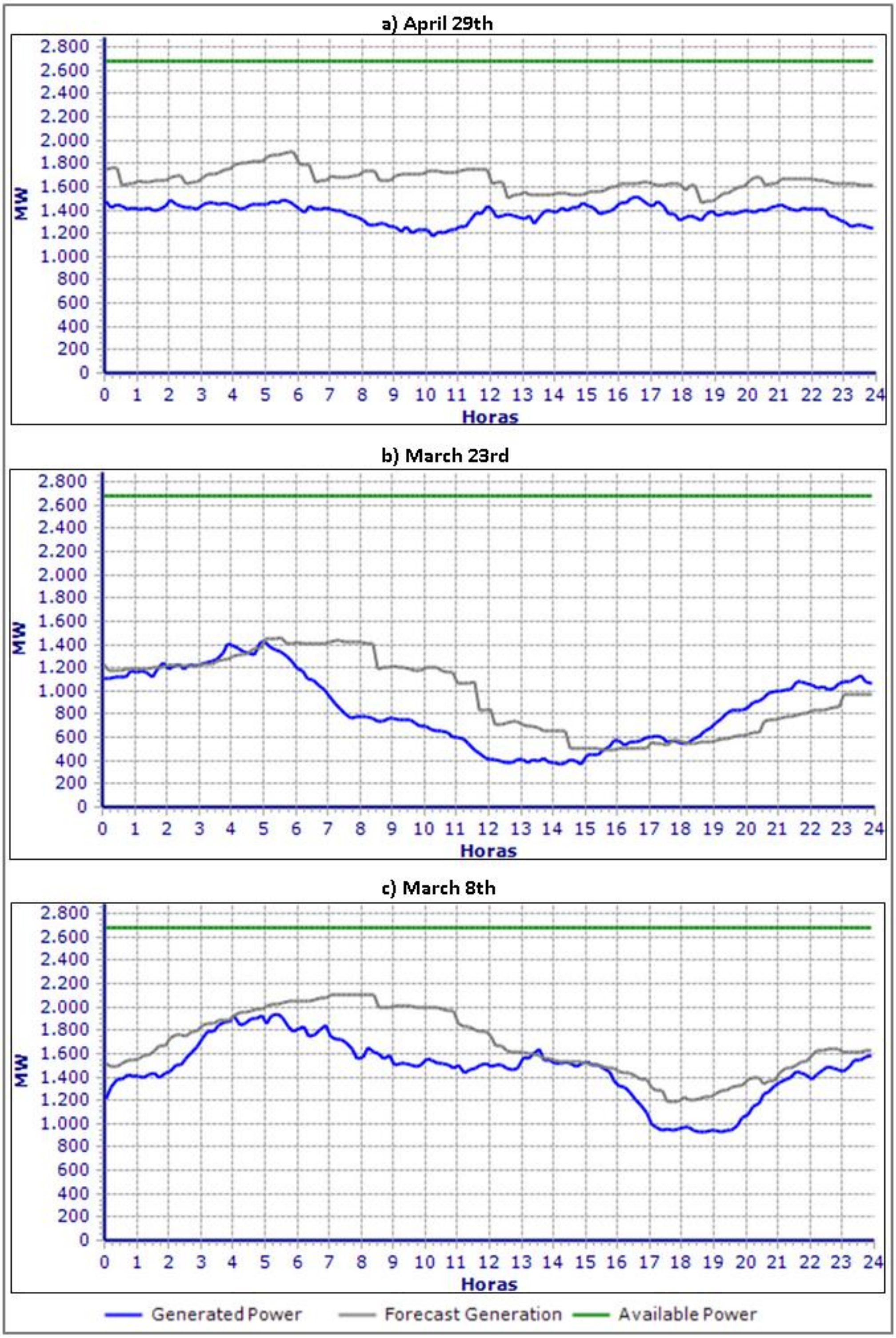

Fig. 5. Examples of wind power generation forecast and actual values in 2013

3. Resources scheduling model

The present section explains the developed demand response methodology, which is based on real time pricing. It aims to reduce the unexpected low wind power generation impacts. Figure 6 presents the conceptual design of the methodology. As the wind generation and other natural sources based generation are wasted if not used, and their generation is anyway paid, and, moreover, its amount is lower than the envisaged load demand, the real time pricing application envisages making the demand equal to actual values of generation.

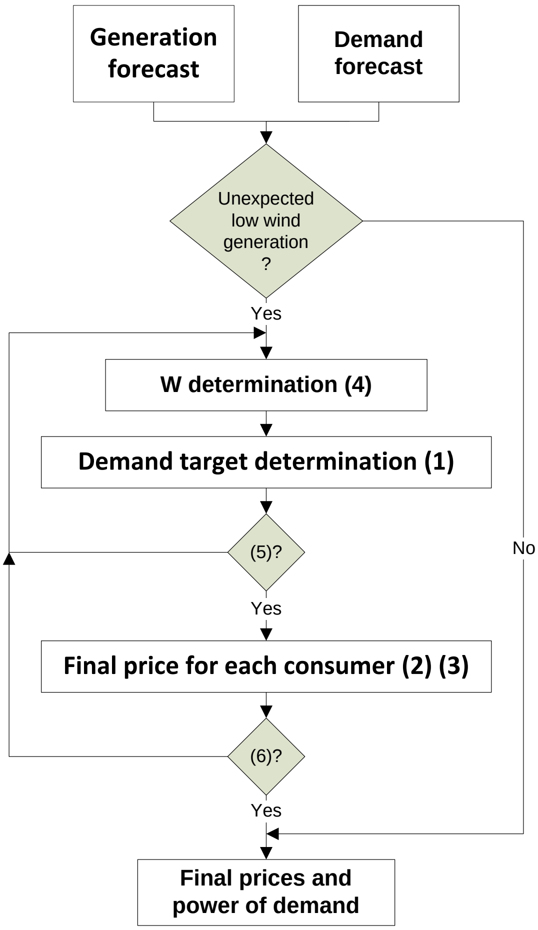

Fig.6. Proposed methodology diagram

In the day-ahead planning of the operation of the system, the forecast of both demand and generation are performed. For the periods in which the wind power generation is, in the hour-ahead operation planning, lower than the day-ahead wind power forecasted generation, an increase in the price of electricity is calculated in order to induce a reduction in the consumption. The consumer response to the changes in the electricity price is performed using the concept of price elasticity of demand.

The first step to calculate the variation in the electricity price (i.e. the final price), considered equal in this methodology for the consumers of each consumer type, is to determine the weight (W) of each consumer type in the load diagram. After this, using the expression (1), it is possible to determine the demand variation (*reduction*) target for each consumer type. It is important to verify if the determined demand variation targets respect the maximum permitted variation for each consumer type (5). This value is based on the impossibility of consumers largely reduce the demand. If some violation is verified, the consumer types weights (*W*) are updated.

$$Demand_{Var(Type)}^{Target} = \left(PRE - Demand_{Initial}^{Total}\right) \times W_{(Type)}, \forall Type \quad . \tag{1}$$

$$Price_{Var(Type)} = \frac{Demand_{Var(Type)}^{Target}}{Demand_{Initial(Type)} \times Elasticity_{(Type)}}, \forall Type \quad . \tag{2}$$

$$Price_{Final(Type)} = Price_{Initial(Type)} + Price_{Var(Type)}, \forall Type \quad . \tag{3}$$

$$\sum_{Type=1}^{NType} W_{(Type)} = 1 \; . \tag{4}$$

$$Demand_{Var(Type)}^{Target} \le Demand_{Var(Type)}^{Max}, \forall Type \; . \tag{5}$$

$$Price_{Var(Type)} \le Price_{Var(Type)}^{Max}, \forall Type \; . \tag{6}$$

where,

$Demand_{Var(Type)}^{Target}$	Demand variation target for each consumer type [MW]
PRE	Power available from special PRE generators [MW]
$Demand_{Initial}^{Total}$	Total initial demand for all the consumers types [MW]
$W_{(Type)}$	Weight of each consumer type in the load diagram
$Type$	Each one of consumer types
$NType$	Total number of consumer types
$Price_{Var(Type)}$	Electricity price variation for each consumer type [€/MWh]
$Demand_{Initial(Type)}$	Initial value of demand for each consumer type [MW]
$Elasticity_{(Type)}$	Price elasticity of demand in each consumer type
$Price_{Final(Type)}$	Final value of electricity price, for each consumer type [€/MWh]
$Price_{Initial(Type)}$	Initial value of electricity price, for each consumer type [€/MWh]
$Price_{Var(Type)}^{Max}$	Maximum permitted electricity price variation, for each consumer type [€/MWh]
$Demand_{Var(Type)}^{Max}$	Maximum permitted demand variation for each consumer type [MW]

After determining the demand variation target for each consumer type, it is possible to determine the price variation (*increase*) to be applied to each consumer type, using expression (2) that considers the referred concept of price elasticity of demand. As the price of electricity can't be largely increased, it is necessary to verify if the determined price variations respect the maximum established price variation values (6). If some violation is verified, the consumer types weights (*W*) are again updated. The results of the application of the model are the final electricity prices and the update demand forecast, for each consumer type.

The authors have also developed an improved model already presented in [14]. It aims to reduce the impacts of wind generation largely lower than the forecasted value, optimizing the operation of a VPP. Figure 7 presents a scheme that represents the use of each resource.

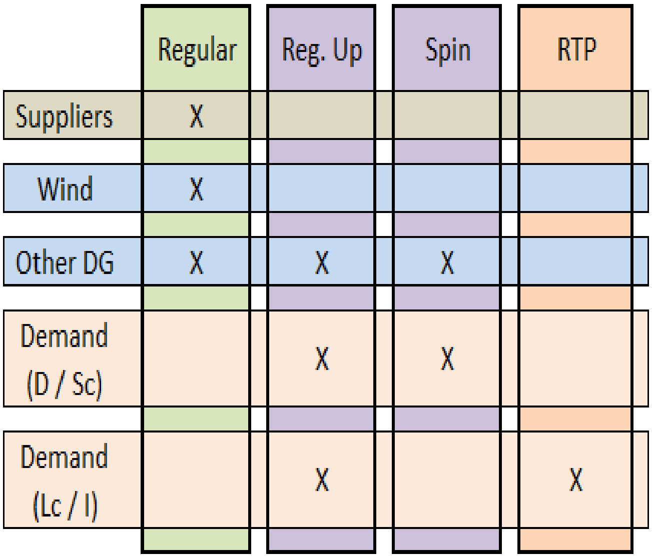

Fig. 7. Proposed resources use methodology diagram [14]

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.

The objective function of the proposed Mixed Integer Non Linear problem aims at the minimization of the Operation Costs (OC). It considers the values of both generation and demand (consumers divided in Domestic (D), Small commerce (Sc), Large commerce (Lc), and Industrial (I)) resources.

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 in which the authors have implemented a scenario that corresponds to the real conditions of a certain day in Portugal (sub-section 4.1). The results of the case-study are presented in sub-section 4.2.

4.1. Scenario

The defined scenario is based on a 33 bus distribution network, also used in [15] by the authors of this paper. 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.

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.

Table 1. Demand parameters for each consumer type

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

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.

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. The values of wind forecast are also shown in figure 8.

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 characteristics of the selected day of the Portuguese power system, namely in what concerns the PRE generation and demand, are presented in Figure 8.

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 8) 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.

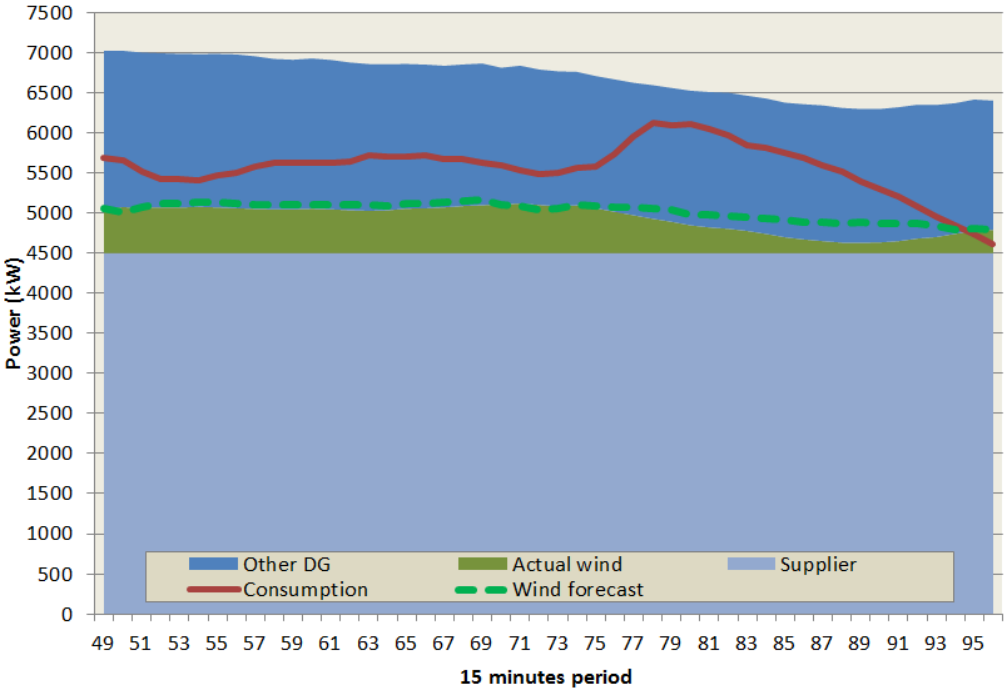

Figure 8: Resources availability values

4.2. Results

The present sub-section shows the obtained results. Figure 9 presents the resources' use after applying the proposed methodology. 15 minutes is the elementary period; the 48 periods in Figure 9 belong to the second half of the day.

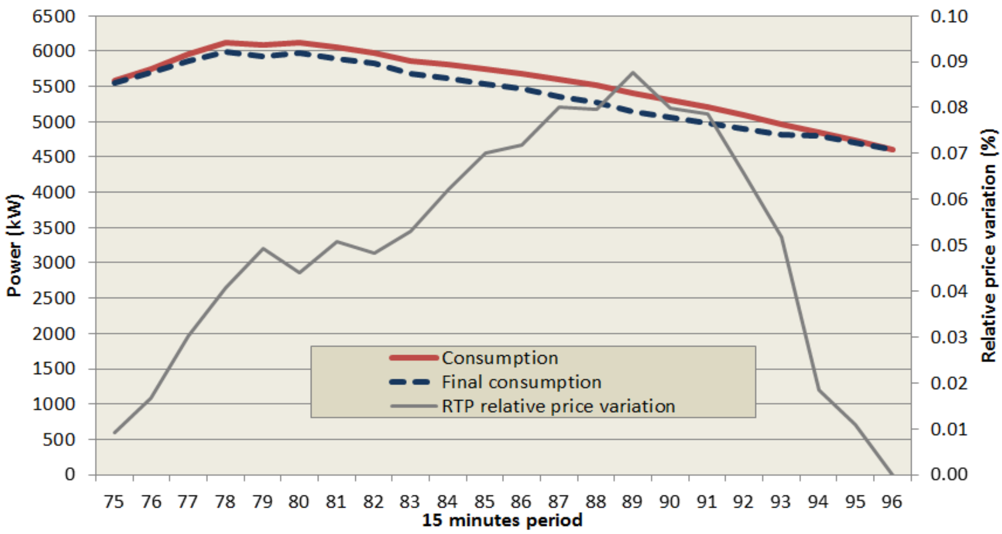

Figure 9: RTP use results between periods 73 and 94

Real time pricing is used 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 resources, are also used in distinct wind forecast errors amounts.

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 10 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.

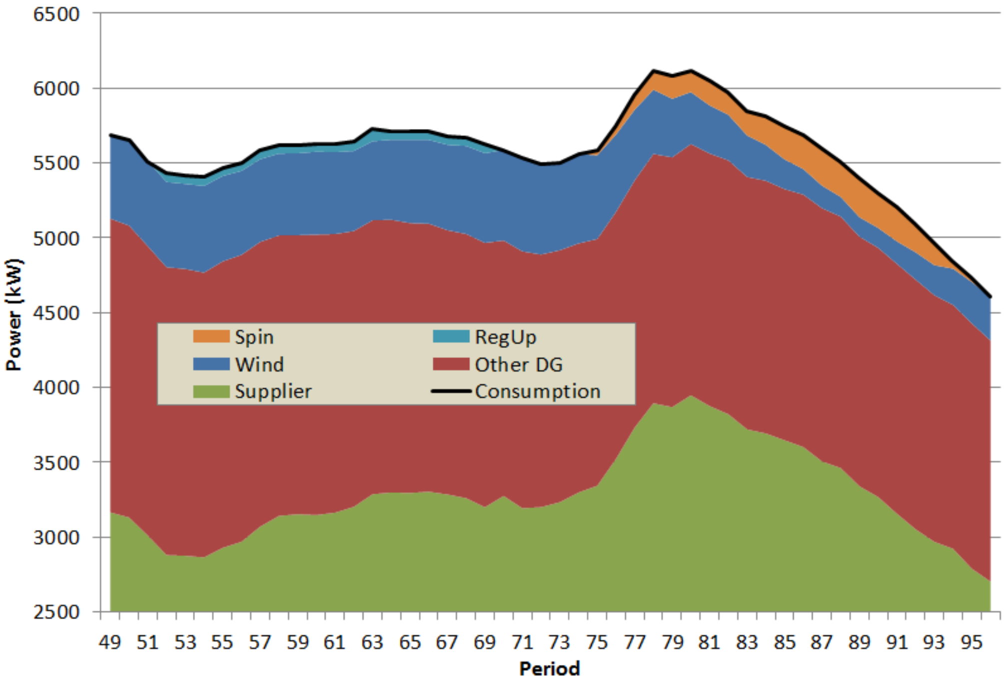

Fig. 10: Generation and demand results

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.

5. Conclusions

The present exposed some facts concerning renewables, namely wind power and low wind power situations. Special focus is given to the Portuguese scenario. The work presented in the paper proposes a DR-based methodology to face situations of wind generation largely lower than the forecasted value. The energy resources use is optimized in order to minimize the operation costs.

The proposed model is especially useful when actual and day-ahead wind forecast differ significantly.

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