

A real time pricing approach to deal with excessive wind power situations

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Abstract

The introduction of wind power generation in several countries around the world, including in European countries, where energy policy directives have encouraged the use of renewables, led to several changes in market and power systems operation. The intensive integration of these sources has led to situations in which the demand is lower than the available renewable resources. In these situations a part of the available generation is wasted if not used for storage or to supply additional demand.

This paper proposes a real time demand response methodology based on changing the electricity price for the consumers expecting an increase in the demand in the periods in which that demand is lower than the available renewable generation. The consumers response to the changes in electricity price is characterized by their price elasticity of demand considered distinct for each consumer type.

The proposed methodology is applied to the Portuguese power system, in the context of the Iberian electricity market (MIBEL). The renewable-based producers are considered as special producers, with special tariffs, and so it is important to use the energy available as it will be paid anyway. In this context, consumers are entities actively participating in the operation of the market.

1. Introduction

Several European countries have significantly increased their wind power generation over the past years, in order to meet the European Union energy policy goals [1]. Presently some of these countries have a relevant wind energy penetration. One measure that can be used to express the wind energy penetration is the percentage of demand covered by wind energy in a certain region, normally on an annual basis. The values for European countries in 2010 are presented in Figure 1.

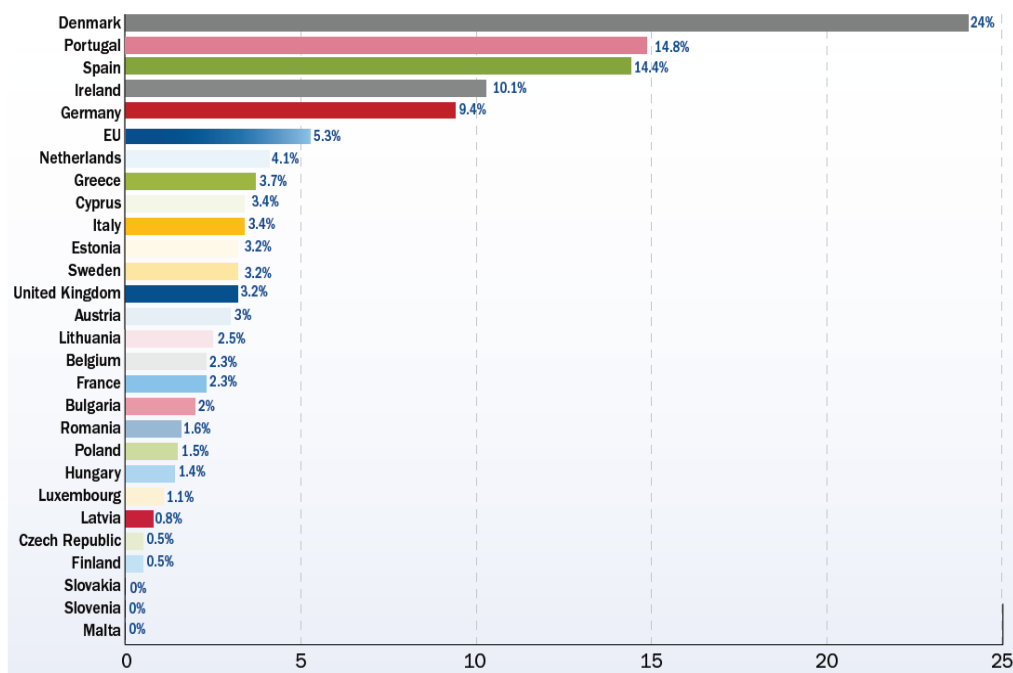


Figure 1: Wind energy penetration in European countries in 2010 [2]

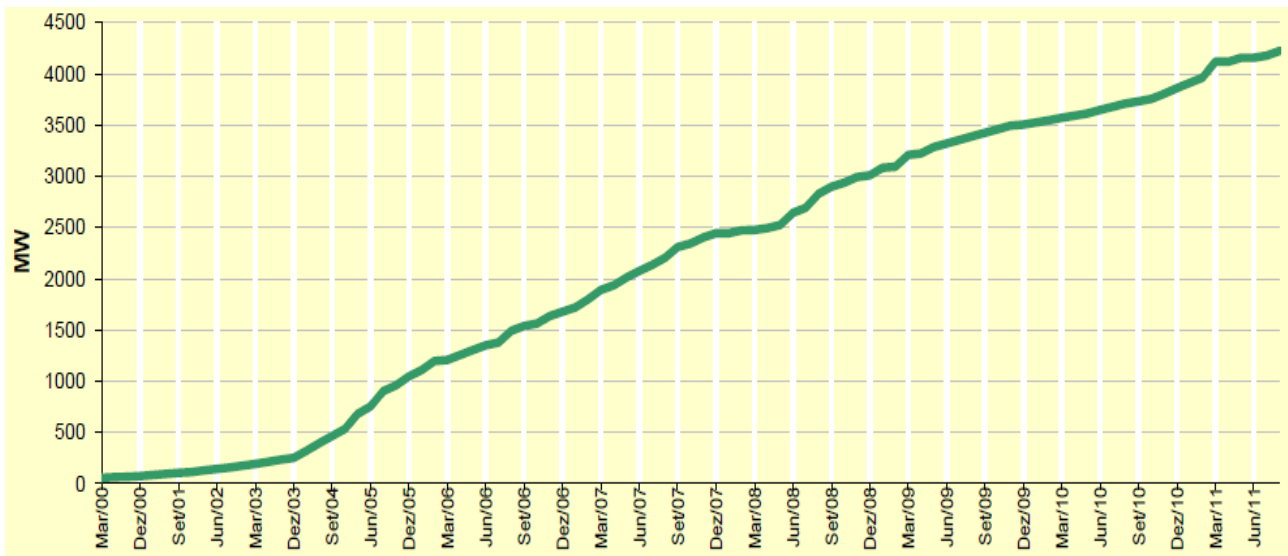


Figure 2: Wind energy use in Portugal [4]

The country with the highest value of wind energy penetration is Denmark with 24%. The second and third positions are occupied by Portugal and Spain with similar values of wind energy penetration (around 14.5%). This paper will focus on the Portuguese case.

Portugal has followed the European Union tendencies and directives. The evolution of wind power generation, from 2003 to 2010, in Portugal is presented in Figure 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].

An important issue regarding the wind power generation is the wind curtailment. Apart from technical reasons, wind curtailment may occur due to a reduced value of electricity consumption when compared with the wind generation availability over a certain period.

[5] presents several examples of wind energy curtailment practices. The trigger for the wind curtailment includes the economic schedule, network congestions, situations of reduced demand, technical limitations on system reserve response, and system reliability. The curtailed capacity may lead, in some cases, to some compensation for wind generators owners, namely because wind farm contracts are established on a must take basis. The most common case is the payment of the energy generation that would be expected if the units were not scheduled to be turned off. This compensation may be based on the guaranteed price for wind generator or on the electricity market price.

Wind curtailment situations result in inefficient resource use and often cause abnormal market clearing prices, in face of the actual demand and generation bids. Demand response can be efficiently used to address this problem [6]. Real time pricing is adequate to achieve a more efficient power system operation, including the reduction of wind curtailment [7-9].

This paper proposes a real time pricing methodology to reduce wind generation curtailment and its impacts. This method is based on day-ahead forecasting of the

available generation resources and demand. The method considers the sum of the forecasted generation for hydro run-of-river, wave power, and thermal power generation plants, and wind farms with must take contracts. As these generation resources are wasted if not used, real time pricing application envisages making the demand at least equal to their forecasted generation. For this purpose, the required price variation is calculated for each time period for which the demand should be increased. In this case, the price variation corresponds to a price decrease, aiming to obtain a load increase.

After this introductory section, the outline of the paper is as follows: Section 2 briefly presents the resources available in Iberian electricity market (MIBEL), which includes the participation of both Portugal and Spain. Then, in Section 3 the conceptual design and the mathematical formulation of the proposed methodology are explained. A case study regarding the application of the proposed methodology is shown in Section 4. Section 5 presents the main conclusions of the developed work and of the present paper.

2. Iberian electricity market

The present section includes some information regarding the Iberian electricity market (MIBEL). The presented information regards the situation in September 2011 [10].

The total amount of electricity generation was 21308 GWh in Spain and 3642 GWh in Portugal. The installed power was 62590 MW in Spain and 11204 MW in Portugal. Portugal has exported 65147 MWh of energy to Spain, while Spain has exported 507978 MWh to Portugal, during September 2011.

The mix of generation by generation technology, in each country, is presented in Figure 3 (a) Portugal and b) Spain). In the legends of Figure 3, CCGT stands for combined-cycle gas turbine; CoGen stands for combined heat and power; and PRE represents the special

producers. Those special producers (denominated in the paper, like in Portuguese, as PRE) are producers based on generation technologies that are usually renewable and 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 % in each country). As PRE producers are benefiting from special tariffs, it is important to take the most possible advantage of the energy available in these producers must take contracts.

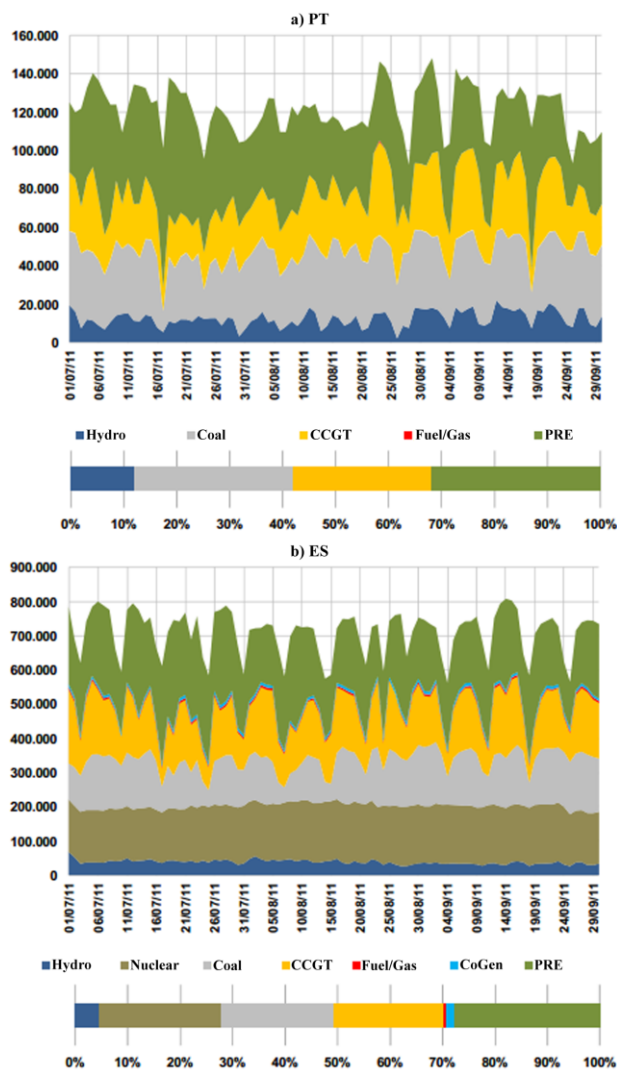


Figure 3: Generation mix [10] – a) in Portugal and b) in Spain

The work presented in this paper has been developed in order to make use of all the PRE energy from the point of view of Portugal in order to increase the competition in the electricity market, aiming to decrease the electricity price. In this way, for a more comprehensive explanation of the characterization of the Portuguese power system, Figure 4 shows the distribution of the PRE energy by type of generation. As it can be seen, almost half of the PRE energy in Portugal regards the wind generation; the developed methodology

is designed to make use of all of the PRE energy to supply the demand, mainly to increase the demand in the periods in which the demand is lower than the available PRE power.

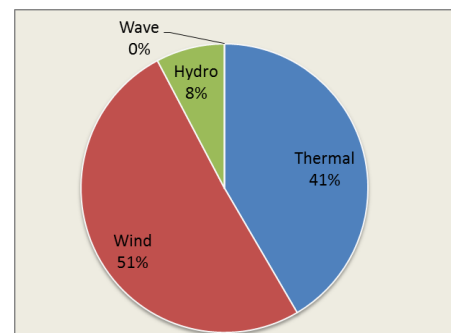


Figure 4: PRE generation in Portugal [11]

3. Demand response model

The present section explains the developed demand response methodology, which is based on real time pricing. It aims to reduce the wind generation curtailment and its impacts, in periods in which the demand is lower than the available power. Figure 5 presents the conceptual design of the methodology.

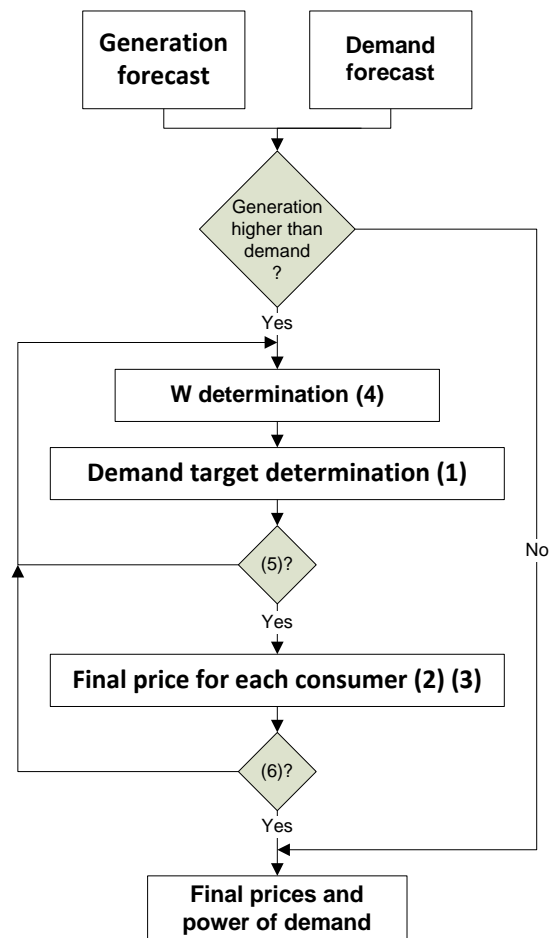


Figure 5: Proposed methodology diagram

As the envisaged generation resources (PRE) are wasted if not used, and their generation is anyway paid, the real time pricing application envisages making the demand at least equal to the forecasted generation. 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 generation is higher than the demand, a decrease in the price of electricity is calculated in order to increase the consumption and use all the available PRE energy. The consumer response to the changes in the electricity price is performed using the concept of price elasticity of demand [6, 9].

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 (increase) 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 increase the demand. If some violation is verified, the consumer types weights (W) are updated.

After determining the demand variation target for each consumer type, it is possible to the price variation (decrease) 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 decreased, 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.

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

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

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

$$\sum_{Type=1}^{N_{Type}} W_{(Type)} = 1 \quad (4)$$

$$Demand_{Var(Type)}^{Target} \leq Demand_{Var(Type)}^{Max}, \forall Type \quad (5)$$

$$Price_{Var(Type)} \leq Price_{Var(Type)}^{Max}, \forall Type \quad (6)$$

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
N_{Type}	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]

The results of the application of the model are the final electricity prices and the update demand forecast, for each consumer type.

4. Case study

This section presents the application of the proposed methodology to the MIBEL scenario in 13th November 2011, which has been an especially windy day, in the Portuguese power system.

The system operator will make use of real time pricing in periods in which the demand is lower than the available power. Decreasing the flat rate tariff electricity price, the consumers are expected to increase the demand value and, therefore, use the available wind power.

In subsection 4.1 are presented the system and market characteristics for the considered day; subsection 4.2 shows the results of the application of the proposed methodology.

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.

	Initial price (€/MWh)	Elasticity	Initial consumption (%)
VHV	60	0,53	10
HV	70	0,45	20
MV	80	0,41	20
SLV	90	0,37	15
NLV-2	100	0,33	15
NLV-1	130	0,27	20

Table 1: Demand parameters for each consumer type

The consumer types are: VHV – Very High Voltage; HV – High Voltage; MV – Medium Voltage; SLV – Special Low Voltage; NLV-2 – Normal Low Voltage group 2; and NLV-1 – Normal Low Voltage group 1. The two NLV consumer types corresponds to the consumers registered in the double tariff (NLV-2), which have two different electricity price periods, and in the single tariff (NLV-1).

4.1. 13th November 2011

This case corresponds to the 13th November 2011 which has been an especially windy day. Being a Sunday, the total demand was relatively low, requiring a very particular resource management from the Portuguese transmission system operator.

Figure 6 presents the forecasted (in light grey) and actual (in blue) values of the wind power generation for the considered day. As it can be concluded from the analysis of this figure, the forecasted wind generation is

sufficiently accurate to make the management of the available generation resources able to be approached in day-ahead basis. This way, the proposed methodology can be applied the day before and real time pricing application periods can be advertised in advance.

Figure 7 shows the electricity market prices for the considered day. It is evident that the huge wind power generation during a relatively low load period led to unusual low market prices (see hours 3 to 10).

The analysis of the aggregated supply and demand curves is important for understanding why the prices have been kept relatively high for the Portuguese system in periods 4 to 6. This is due to complex bids that must be respected, leading the marginal price to be higher than the price value corresponding to the matching of the sale and purchase offers. This can be clearly seen in Figure 8, which shows these curves for hour 4 of the considered day for Portugal. Figure 9 presents the corresponding curves for Spain.

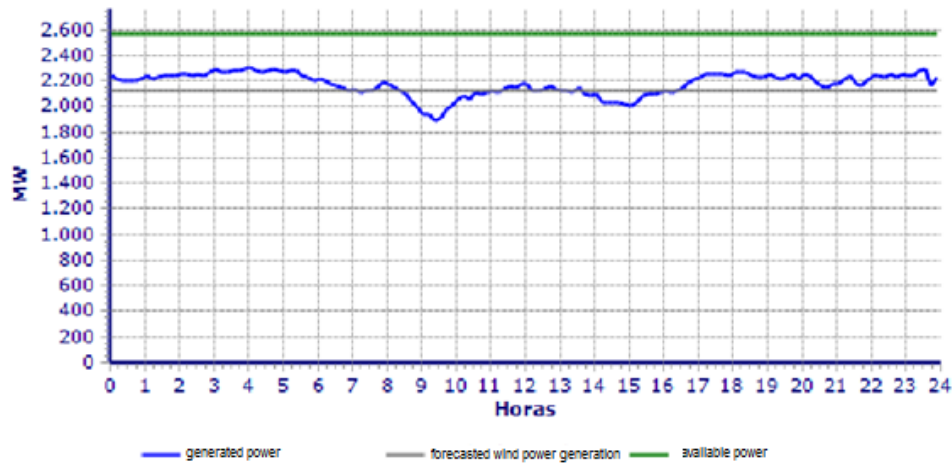


Figure 6: Wind generation: actual and forecasted values for the 13th November 2011

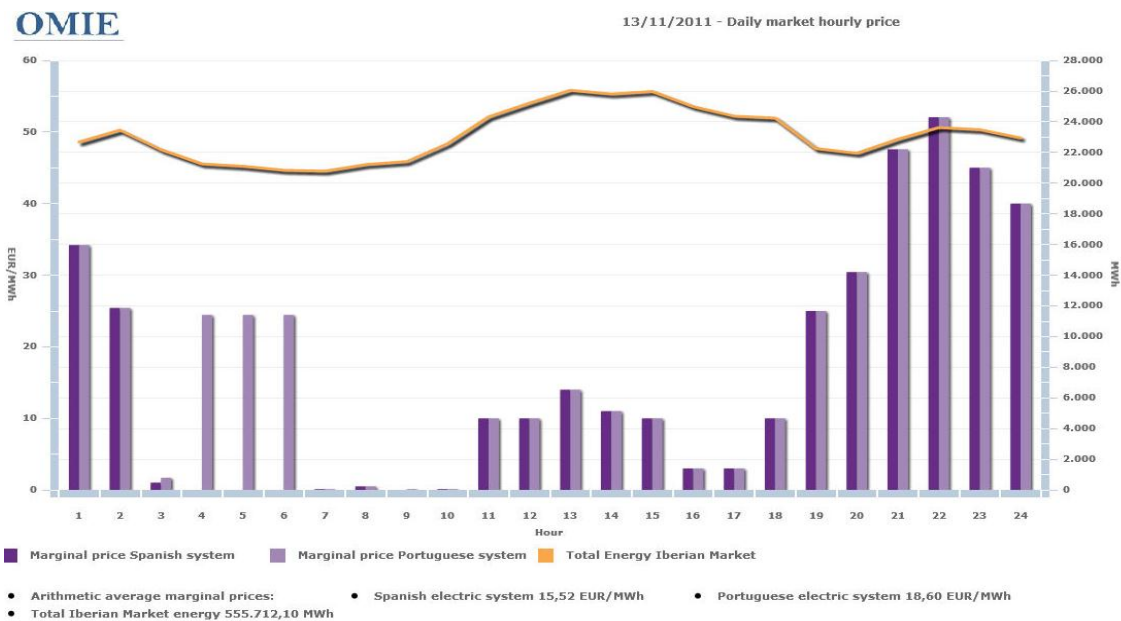


Figure 7: Electricity market prices

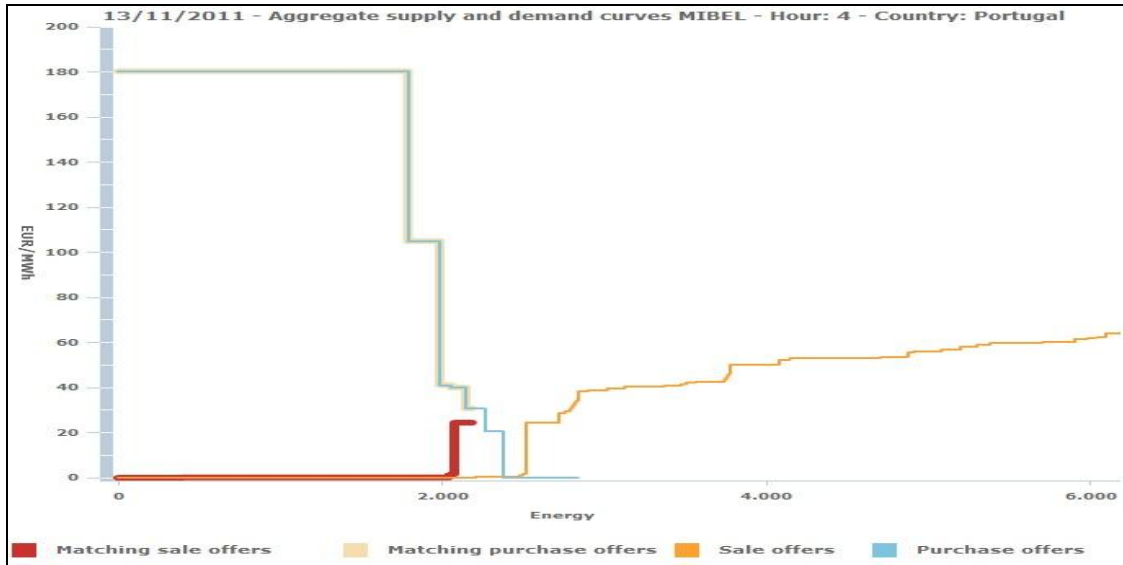


Figure 8 – Matching of the sale and purchase offers, four hour 4, in Portugal

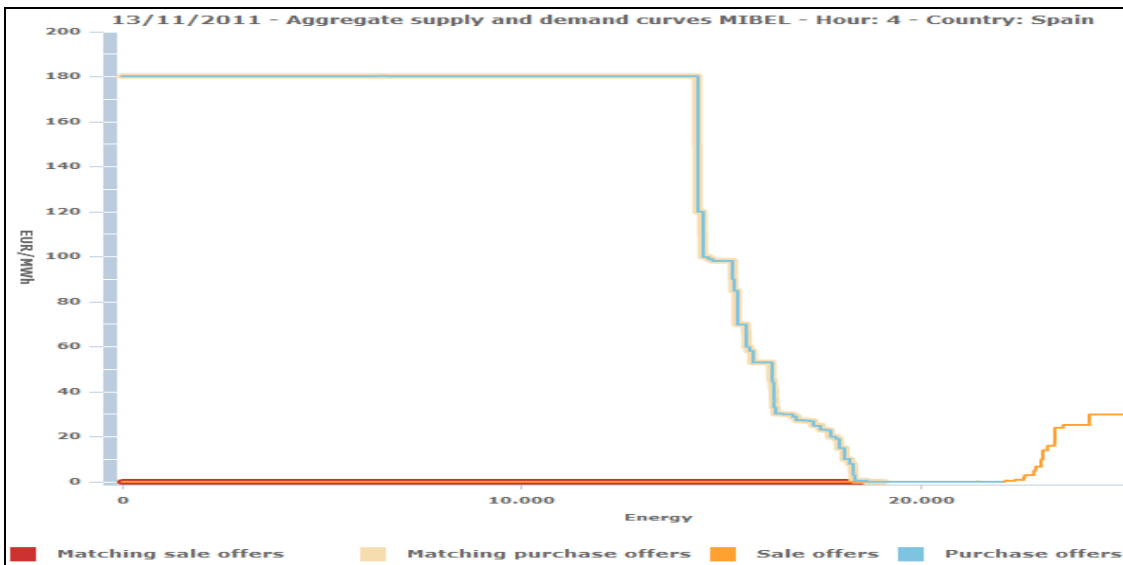


Figure 9 –Matching of the sale and purchase offers, four hour 4, in Spain

4.2. Results

This subsection presents the results of the application of the proposed methodology to the selected case study. Figure 10 presents the detail of PRE based power generation, per generation technology, in the periods of application of the proposed real time pricing model. It is important to note the relative large contribution of the wind power generation for the total amount of power generated by the available technologies.

Figure 11 presents the available PRE based generation (including wind, waves, thermal, and hydro power generation), in green, the ordinary run-of-river hydro generation (not considered PRE but also wasted if not used), in blue, and the total demand, in red.

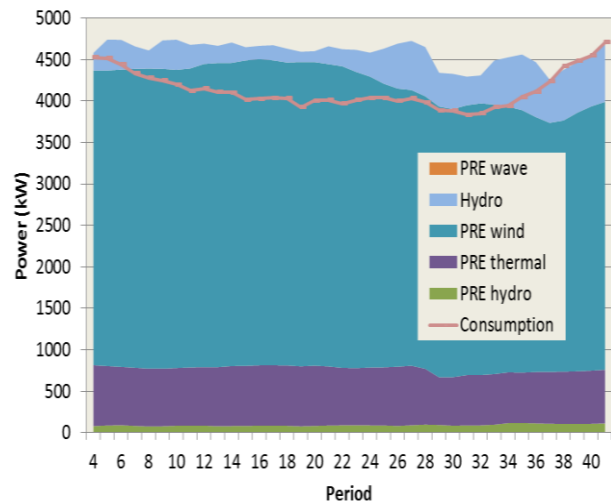


Figure 10 – PRE based power generation per type

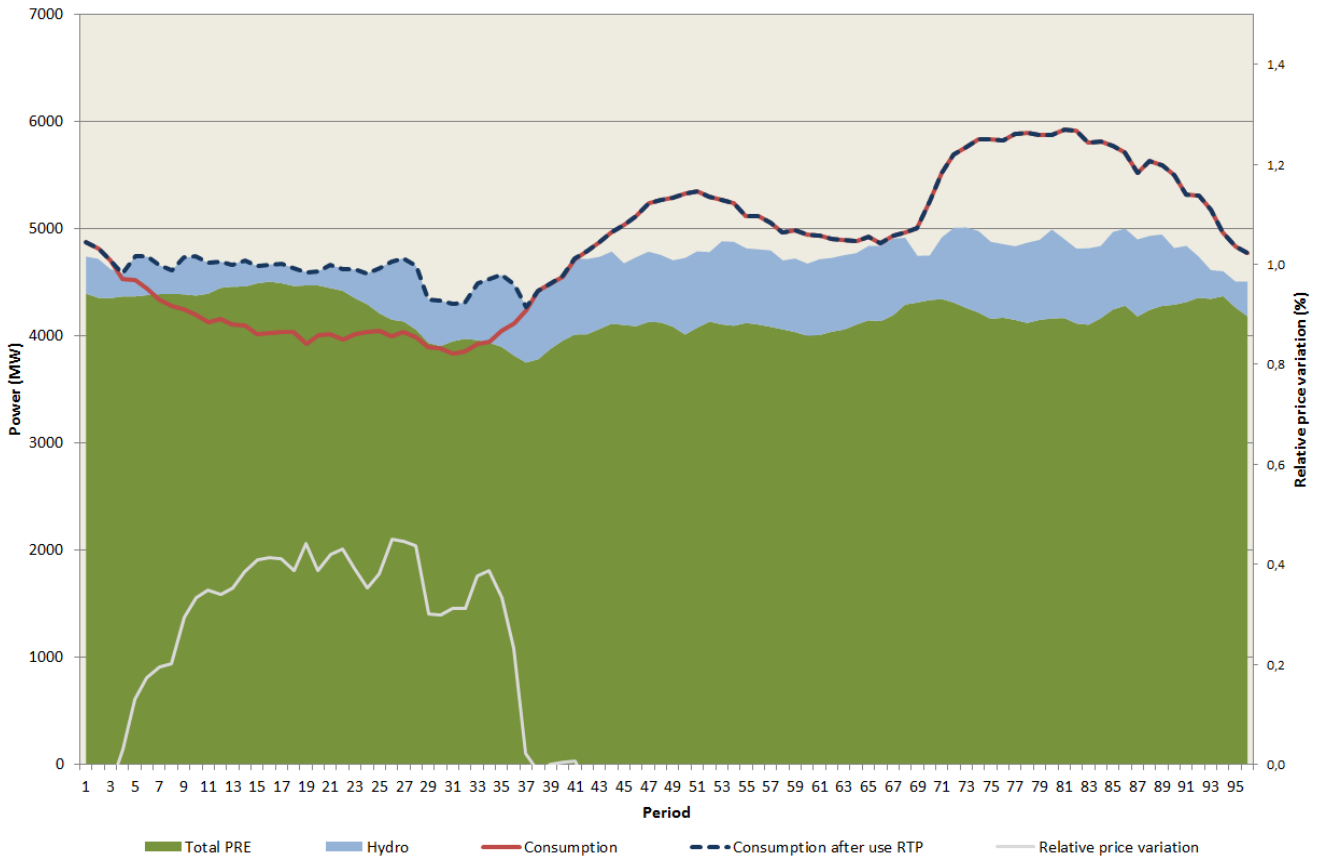


Figure 11 – Generation and demand on the 13th November 2011

Figure 11 also shows the obtained demand after the application of the proposed methodology (represented by the dashed black line) for the period when the demand is originally lower than the sum of the available run-of-river hydro and PRE power generation, i.e. from 0:45 to 10:15 a.m., with the exception of the period from 09:15 to 09:30 a.m. The white line shows the relative price variation determined by the proposed methodology, in order to attain the previously referred goal.

For this case study, the relative price variation has been considered as equal for all types of consumers. The obtained result for the price variation maximum value is equal to 74.02% and it is referring to the period from 06:15 to 06:30 a.m. The obtained percentage price variation is applied to the consumers' original prices, which are dependent on the consumer type and contractual tariffs.

In order to understand the impact of the application of the proposed methodology, it is also important to analyze the MIBEL performance during the considered day, especially in the most relevant period (from 00:45 to 10:15 a.m.).

The model uses the value of the price elasticity of demand to determine the price to be applied to each consumer type in order to reach the required demand variation (increase). The price elasticity of demand is a very important parameter due to the fact that it is the way the network operator knows the consumers, but also because small uncertainties in this value cause large

mistakes in the demand change forecast. The sensitivity analysis of the proposed methodology to the value of the price elasticity of demand is presented in Figure 12.

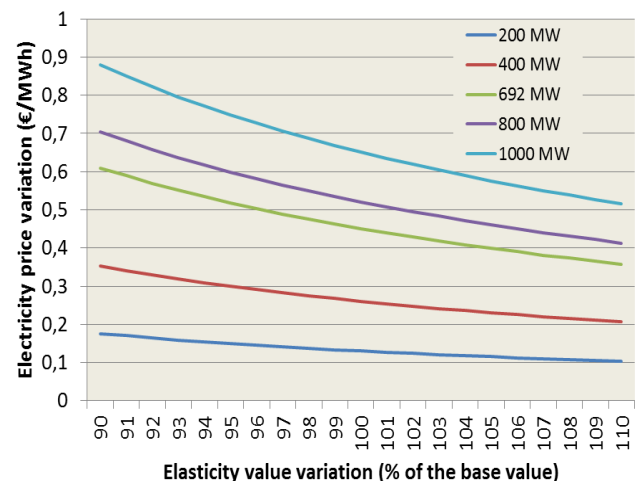


Figure 12 – Sensitivity analysis of elasticity

In light green, in Figure 12, it can be seen the influence of elasticity in the final electricity price caused by small reductions and increases in the value of elasticity, for the maximum required demand variation target (692 MW). It is shown that lower values of elasticity cause a larger value in the final price of electricity. Figure 12 also shows the influence of the

required demand variation target in the final price of electricity for the consumers.

In a global analysis of the present case study, one can verify that the application of the proposed methodology enables the transmission system operator to undertake the resources management making use of the capacity that, otherwise, would be wasted. Moreover, a part of the benefits resulting from the application of the proposed methodology is given to the consumers. This is a very relevant point as the presently existing models show difficulties in involving consumers in this process.

5. Conclusions

The increasing penetration of wind power generation in several countries in Europe and around the world, regarding the accomplishment of energy policy directives, is changing the way that both power systems and electricity markets are operated.

The work presented in this paper proposes a methodology designed to increase the demand consumption in the periods that renewable energy generation, with must take contracts, as the case of wind, is higher than the demand. The developed methodology enables the transmission system operator to undertake a much easier management of the available resources. Moreover, it can also bring relevant advantage in what concerns the distribution of the benefits that can be obtained by the existence of huge wind power generation. In fact, applying the proposed methodology corresponds to giving directly a part of these benefits to electricity consumers, which are players that usually are not involved in the scheduling process.

The importance of an adequate price elasticity of demand characterization to be used in consumers' response studies has also been demonstrated.

Acknowledgements

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