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Capacity Markets

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Abstract - This work aims at studying an ideal capacity market model, a free-market competition model that allows all entities to commercialize power. The proposed capacity market differentiates itself from other market models mainly through implementing the possibility of any energy entity to participate. This new model allows a domestic consumer to become consumer and producer of capacity at the same time.
This work focuses on the limits of wind penetration in the power network and the creation of a capacity market that allows the commercialization of domestic capacity. It is also addressed the contribution of capacity market for the electrical system and its actors.

Keywords: Capacity markets, capacity, wind power, power network, smart grid, domestic capacity.

1. Introduction

With the increase of electricity consumption and a major concern for the environmental conditions, new conditions to improve the production and distribution of energy must be created. The increasing penetration of wind power on the electrical system brings a higher complexity level to the management and control of the network. This is caused by the intermittent and non predictable characteristics of wind resource.
The capacity market model presented in this paper is a market model largely participated, based on an optional contract model. This new model allows a domestic consumer who contracts a constant capacity from the utility to also become a capacity seller. The consumer can make offers to purchase/sell capacity in the market, this will be possible to accomplish with the creation of a smart-grid [1][2][3].

A. Iberian Peninsula wind distribution

One of the problems of increasing wind power penetration in electric power grid is that this energy cannot be dispatched. If the demand for energy is less than the energy that is being produced, then the energy from wind sources that is being produced in that instant must be used in other ways.
In 2007 about 9% of installed capacity in Portugal was produced from wind energy. In Spain this figure reached 12% [4].
The existing wind farms in the Iberian Peninsula are sparsely distributed (Figure 1).

Figure 1 - Wind farms distribution in the Iberian Peninsula (the red circles represent wind farms) [5].

Consider the case where it is being produced a high value of wind power capacity in a specific location of the system and in the following hour this value decreases significantly. What will the consequences be of this change on the network? The answer to this question depends on several factors: structural features of the system, distribution of wind power plants; fluctuation of produced power, i.e. whether this variation is significant (in the global system).
In a power network where wind farms are dispersed throughout the network, it is unlikely to have the same variation of wind at all wind farms. This picture is unlikely to happen in sparse networks, since the wind will not vary similarly in the various regions. The weather forecasting methods are a very important tool, for a growing integration of wind power [6][7].

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2. Capacity Markets - Proposed Model

This paper addresses the modeling of an ideal capacity market. A model of a market where there is a free competition. A market that is open to all holders of capacity.
This definition is particular important because it doesn't restrict the entry of potential new suppliers. In this situation it is possible for a domestic consumer to become a capacity supplier. With the creation of this market, the consumer/producer acquires an active role in the managing of the electric system. This market will allow a more efficient management of produced energy and aims to allow the decrease the traditional energy production and reduce the amount of fossil resources and CO_2 emissions.
If a domestic consumer should be able to sell the capacity available in his home, he will need to have a device that can control and regulate the capacity available in real time. This control is accomplished with a meter installed in the house. Using this device the consumer / producer can decide what to do with the capacity he has. He can use all the contracted capacity for the house or he can sell part of the capacity in the market.

A Structure of the proposed market

The capacity market structure is based on a Forward Capacity Market (by the NE ISO - New England Independent System Operator) [8][9]. Notice that this is a very recent market and that its results and importance remain yet to be tested.
The capacity market operates in an auction system. In the case of a free market, all entities can submit capacity bids on the market. This market has capacity auctions that aim to satisfy the capacity consumption for a defined year. To make this happen two or three auction may be needed, during that period. The auctions will be held with three years in advance for the chosen year. It allows potential producers/consumers to submit capacity bids for this year.

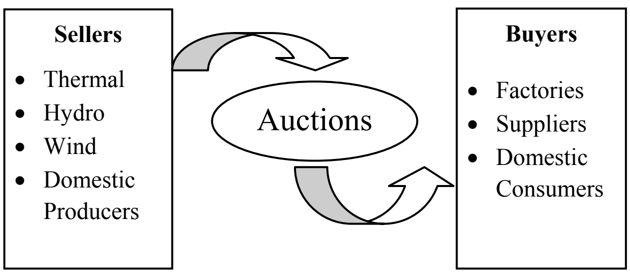

Figure 2 - Diagram of the proposed capacity market model.

B Wind and domestic consumers participation

The wind power and the domestic consumer's capacity are the mains concern of the presented work.
Considering all the wind farms on the network, we estimate the probability of no wind power produced.
To compute this probability we use formula (1.1).

$$P_{no\ wind} = \overline{P_1}.\overline{P_2}.\overline{P_3}\ldots.\overline{P_n} \quad (2.1)$$

Where:

$P_{no\ wind}$ represents the probability on no wind

$\overline{P_i}$ represents the probability of no wind produced for wind farm *i*

n represents the total number of wind farms

Since the value of this probability is very small, it means that some wind resources can be used as capacity resources. On the other hand if this value were significant it would mean that wind resources cannot guarantee capacity.

The proper operation of power networks depends on the proper management of the loads.
The simultaneity coefficients of loads (Table 1) are used to dimension the network.

Nº electric installations	Simultaneity coefficient
2 - 4	1,00
5 - 9	0,75
10 - 14	0,56
15 -19	0,48
20 - 24	0,43
25 - 29	0,40
30 - 34	0,38
35 - 39	0,37
40 - 49	0,36
>= 50	0,34

Table 1 - Simultaneity coefficient.

We defined two types of capacity: the commercialized capacity and the real capacity. The commercialized capacity represents the capacity commercialized in the market. The real capacity represents the capacity available if the simultaneity coefficient had the value 1.

Formula (2.2) represents the maximum capacity value contracted for domestic consumers. Formula (2.3) represents the maximum capacity value of the part of network that feeds the domestic consumers.
Formula (2.4) represents the difference in percentage between the total capacity contracted for domestic consumers and total power value of the power line that feeds the domestic consumers.

$$S_C = \sum_{i=1}^{N} S_i \quad (2.2)$$

$$S_T = \sum_{i=1}^{N} S_i.Cs_i \quad (2.3)$$

$$S_S = S_C.-.S_i \quad (2.4)$$

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- Cs_i - Simultaneity coefficient;
- S_i – Power of the installation *i*;
- S_T – Total power value of the power line that feeds the building.
- S_C - Total power value contracted for domestic consumers.

3. Case studies

Case study 1

Consider wind power as a negative power demand.
This case study consists in considering one chosen point of each demand and wind production curve (Figure 2, Figure 3). The point that is analyzed in all the graphs is the point corresponding to hour 21:30.

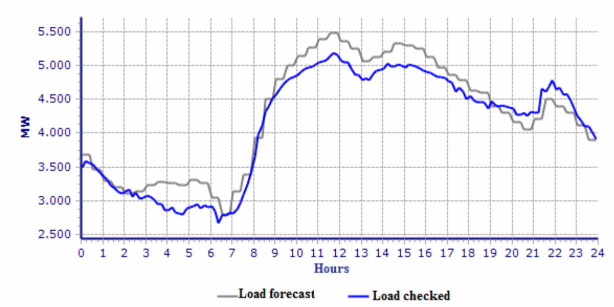

Figure 3 - Forecast load (gray) and actual load (blue) for the 7th of July 2009 [1].

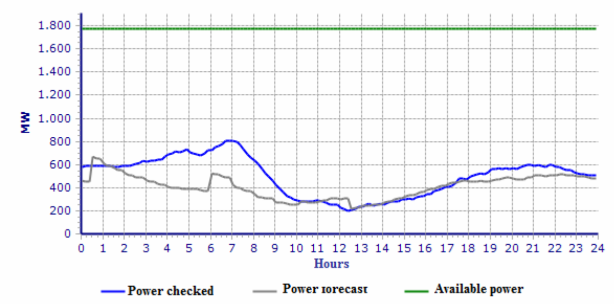

Figure 4 – Forecast wind power (gray) and actual wind power (blue) for the 7th of July 2009 [1].

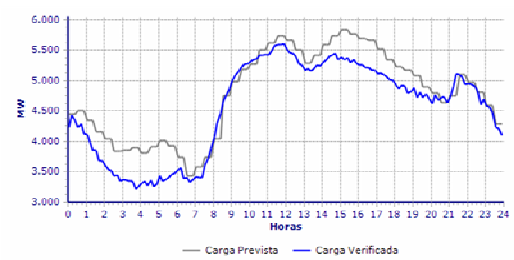

Figure 5 - Forecast load (gray) and actual load (blue) for the 24th of July 2009 [1].

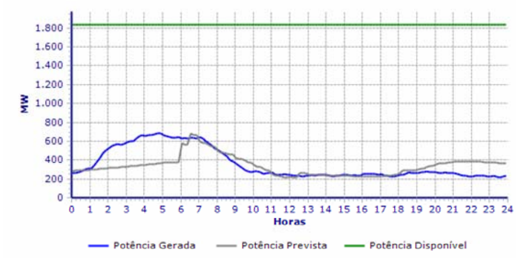

Figure 5 – Forecast wind power (gray) and actual wind power (blue) for the 24th of July 2009 [1].

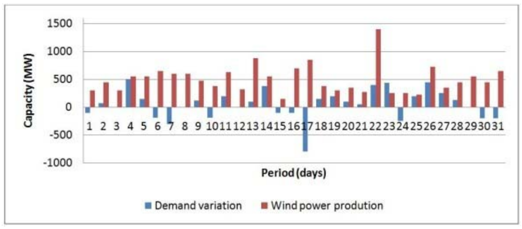

Figure 6 - Variation between forecast load and actual load, wind power capacity produced (July 2009).

Figure 6 presents the variation between forecast load and actual load of wind power capacity produced in July 2009

The blue color bars for "Demand variation" are the differences between the value of the expected load and the effective load value, to the point corresponding to hour 21:30.

The red color bars represent the wind power in July 2009 estimated from figures 2, 3,4 and 5 and similar figures obtained for the other days of July in a similar manner.

The same kind o f study was performed for the months of August and September as we present in figures 7 to 16.

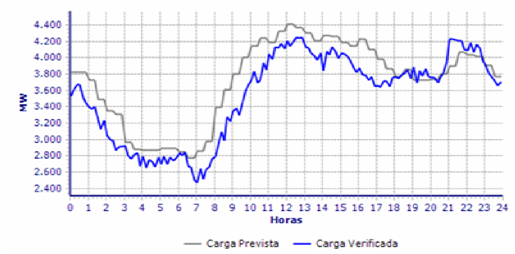

Figure 7 - Forecast load (gray) and actual load (blue) for the 8th of August 2009 [1].

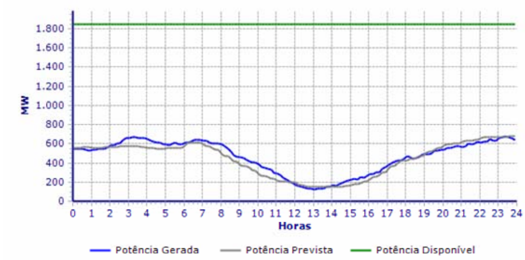

Figure 8 – Forecast wind power (gray) and actual wind power (blue) for the 8th of August 2009 [1].

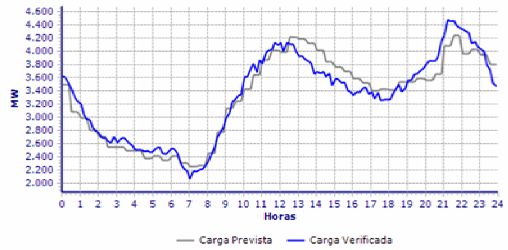

Figure 9 - Forecast load (gray) and actual load (blue) for the 9th of August 2009 [1].

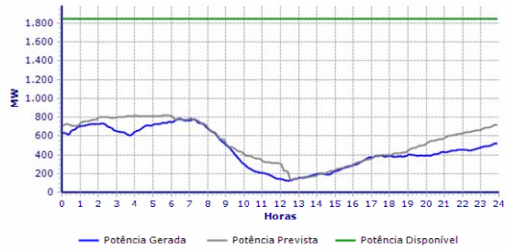

Figure 10 – Forecast wind power (gray) and actual wind power (blue) for the 9th of August 2009 [1].

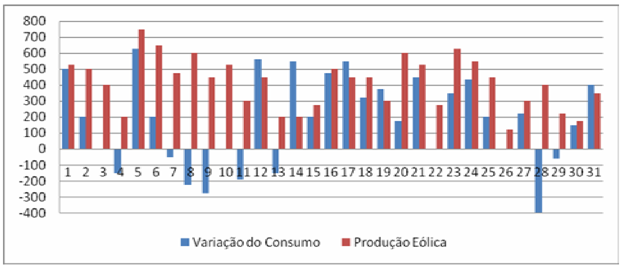

Figure 11 - Variation between forecast load and actual load, wind power capacity produced (August 2009).

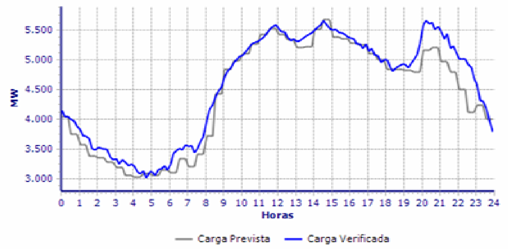

Figure 12 - Forecast load (gray) and actual load (blue) for the 14th of Sepember 2009 [1].

Figure 13 – Forecast wind power (gray) and actual wind power (blue) for the 14th of September 2009 [1].

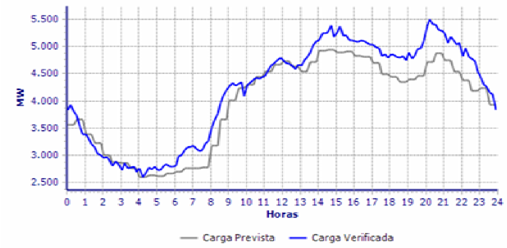

Figure 14 - Forecast load (gray) and actual load (blue) for the 24th of September 2009 [1].

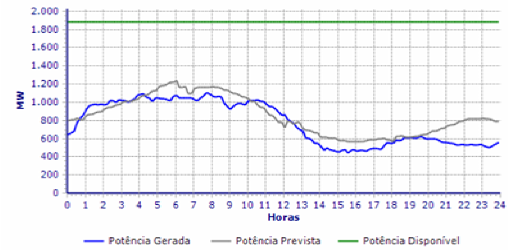

Figure 15 – Forecast wind power (gray) and actual wind power (blue) for the 24th of September 2009 [1].

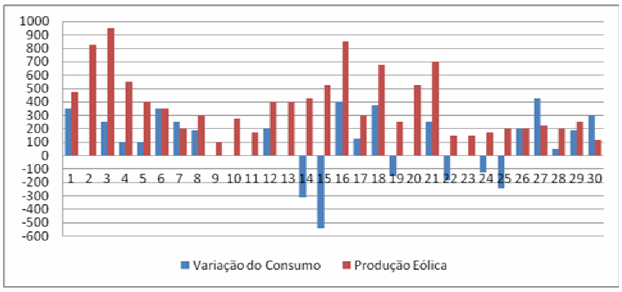

Figure 16 - Variation between forecast load and actual load, wind power capacity produced (September 2009).

Our results show the possibility of increasing the number of wind farms and thus to increase the wind capacity.

Case study 2

The following figures (figures 17 to 19) present a chosen typical case of the annual wind velocity frequency.
These figures are used as examples to allow the computation of the variation of wind production in a case study power networks.
It is assumed that there are only 3 wind profiles, defined as: low wind, moderate wind and high wind.

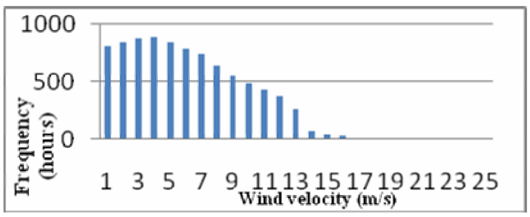

Figure 17 – Wind velocity frequency (low wind)

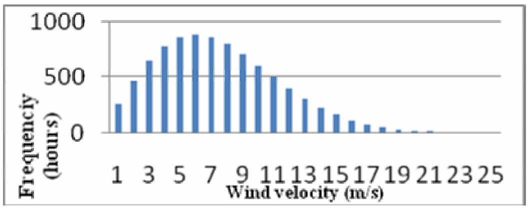

Figure 18 - Wind velocity frequency (moderate wind)

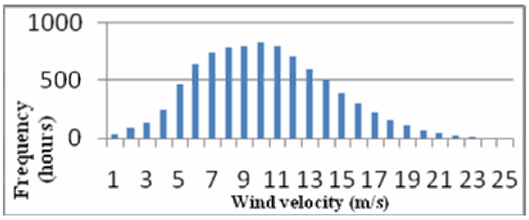

Figure 19 - Wind velocity frequency (high wind)

Consider that in each wind farm the wind turbines are all similar. As an example consider wind turbines of 2 MW (Enercon turbines), in all wind farms represented in Figure 1. The values in Table 1 are computed using the turbine power curve[ ] and represent the annual use of wind for each turbine.

	Annual use of wind producing
Low winds	71,15%
Moderate winds	84,30%
High winds	96,93%

Table 2 – Annual wind percentages used for production

Consider the following wind profiles:

- Wind Farm 1 – High wind
- Wind Farm 2 – High wind
- Wind Farm 3 – High wind
- Wind Farm 4 – Moderate wind
- Wind Farm 5 – Moderate wind
- Wind Farm 6 – Low wind

We are interested in computing the probability of not producing any wind energy in this network for a year.

Considering the values presented in Table 2 and using the formula (2.1) the result is 0,0018%. This result is almost near to zero (represent 9 minutes in the year), so we can conclude that in this case study there is always wind available to produce energy.

Case study 3

With the implementation of the smart grids, we can use the domestic capacity and later on use the capacity stored in the electric vehicles [1][2][3]. Table 3 presents the capacity that could be saved due to the commercialization of domestic capacity. The data used in this analysis are from the Portuguese electric system.
In order to demonstrate this matter, an example is used. It is assumed that all houses have contracted 6.9 kVA and that this network analyses occurs in the maximum demand period.

Table 3 presents: total capacity; the capacity that could be commercialized ("Savings capacity"). The full domestic capacity presented in Table 2 is higher than all capacity installed in Portugal, which means that it is being commercialized more capacity than that really exists.

Nº domestic consumers	Contracted power (kVA)	Total capacity (MW)
5.966.998	6,9	41.172,28

Capacity used per consumer (%)	Maximum value used per consumer (kVA)	Saving capacity (MW)
90	6,21	4.117,23
80	5,52	8.234,46
70	4,83	12.351,69
60	4,14	16.468,91
50	3,45	20.586,14

Table 3 - Saving expectations of domestic consumption

Hence we just count the contribution of power traded among domestic consumers and the network, we neglected the common services of the building (the common services of the building has always the maximum value).
It is analyzed a building where there are five independent apartments, in this situation the simultaneity coefficient is 0,75 (Table 1).

Figure 20 illustrates the maximum theoretical value of total domestic capacity (blue -maximum theoretical capacity value of the building); the maximum capacity allowed by the power line that feeds the building (red); the maximum theoretical capacity in the building after the sale of a percentage of contracted capacity (green).

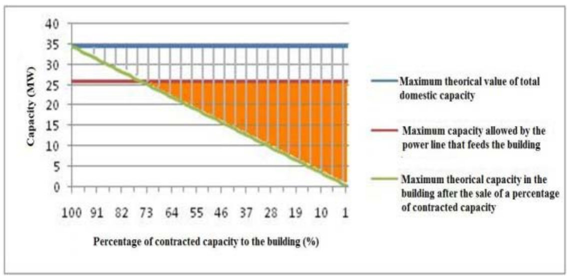

Figure 20 – Five houses building.

The results show that the total contracted power for the building is 34.5 kVA (formula (2.2). The problem is that the power line was designed to support a maximum of 25.88 kVA, calculated according to (2.3). Meaning that in the limit each domestic consumer uses a maximum of 5,18 kVA (75% of the maximum contract value) simultaneously.
For sales value less than 25% of the contracted capacity, there are not physical transfer of power. This happens

because the power line that feeds the building cannot support that capacity value.

In Figure 8 it is represented the capacity that can be commercialized by the building. This capacity is represented by gray lines above the diagonal green line. The orange zone represents the value of capacity that actually is transferred from the building to the power network.

The final version of this paper will include a second example in witch we consider a case study with a low simultaneity coefficient. It will be shown that the difference between S_C and S_T will be significant in this case.

4. Conclusions

Today's use of wind power is minute compared with the wind potential available on earth. The use of global wind resources would be sufficient for the needs of global energy consumption [11]. Another problem studied in this work relates to the existence of a penetration limit of renewable power plants in the electric power grid. The market structure analyzed in this paper is based on the structure of an options market, based in the New England Forward Capacity Market [8][9]. The model analyzed here adds more complexity to the market, since it allows the entry of all entities wishing to transact capacity.
In conclusion, in the near future it is possible to connect more wind power plants into the power grid. The penetration limit of wind resources is not possible to determine, it depends on the topology of the network.
It is unattractive to electric companies to buy all domestic capacity. It only becomes attractive to buy domestic power from a certain amount of power.
The implementation of smart grids is fundamental to enable a more efficient capacity management [1][2][3].
The implementation of smart grids would help to enable the use of electric vehicles in the power grid.

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