Abstract.- Due to market rules, wind energy can be forced to stay off the network for some periods of the year for security or other reasons. This circumstance should be avoided in a country with heavy energy dependency, such as Spain. In this paper, we attempt to assess the possibility of storing excess wind energy by means of hydro pumping stations, taking into account the fact that wind energy use will continue to grow over coming years. The proposal in this paper is to analyze the use of installed pumping capacity for storing energy excess from renewables, especially from wind, due to its potential as a source in the region.

INTRODUCTION
Operating rules of the Spanish electricity market make it necessary to predict wind energy in order to sell it, for which specific tools have been developed in recent years [1]. This is especially true when the installed wind power increases, such as in Spain, particularly in the northwestern autonomous community of Galicia.

Spain imports large amounts of fossil fuels to meet its energy demand, although the production of hydro and wind energy is not negligible [2].

There are more than 3,036 MW of installed wind power in Galicia. The distribution of wind energy areas is information that can be found in documentation made by INEGA, the Galician energy institute (Instituto Enerxético de Galicia) and is shown in Fig. 1 [3]. Observation of such figures allows us to deduce that wind parks have been installed on a large surface of the community. It represents 18.79% of the total installed power in Spain. Wind power has a great impact on the Galician generating system.

Given the market rules and the growth of installed wind power, it can happen that during some time intervals throughout the year, some of this wind energy has to be disconnected from the electrical network for security or other reasons. This circumstance is undesirable given our energy dependency [4].

In this paper, we attempt to evaluate the possible recovery of excess wind energy with help of hydraulic storage. We present information extracted from an event that occurred on Nov. 2nd 2008 in the Spanish electrical network, and assume that this can be a common situation in the future. Some MW of installed wind power had to be disconnected, as will be explained, and the discussion that emerged is whether this situation could be avoidable with different market rules relating energy storage by means of pumping systems.

Let us remember that hydro pumping stations began to operate years ago for storing energy margins proceeding from thermal power stations. Later, when the market was restructured, some companies
began to use them to make profits, as they could buy energy to resell at a higher price, making use of the different prices in the market at different hours.

Our proposal here is to use the installed pumping capacity to store excess of energy from renewable sources, especially wind, given its potential in the region. This is because there are several pumping stations in Galicia, mainly in the area known as the River Sil basin, exploited by the company Iberdrola.

In recent years, the installation of wind power connected to the generation system has grown very rapidly in Spain, with Galicia becoming the third autonomous community there in installed power. 6,500 MW of wind energy are intended to be installed by 2012, according to the Law 8/2009, of December 22nd 2009 [5], which will represent between 25 and 30% of installed wind power in Spain.

Several agents have been developing some research over the recent years in Spain, covering aspects such as:

- Tools for predicting wind speeds.
- Connection requirements for wind farms.
- Monitoring and control of wind energy.

The main problem with wind power is its integration under secure conditions for the system. Such conditions are generally established as a function of stability, system failures and the need to match generation and consumption (market operating conditions).

Depending on different possible events, such as sudden wind speed ramps, the need can appear to disconnect wind energy production from the electrical network for security reasons. An event like this has been previously mentioned and will be described below to illustrate this situation.

### EVENT DESCRIPTION

The event that occurred on November 2nd 2008 can be considered the cause for the disconnection of some 2,800 MW of wind energy from the electrical network during 2 hours. According to data published by the Spanish Transmission System Operator Red Eléctrica de España (REE) on its web page [6], wind energy generation between 22:00 and 9:30 a.m. presented the profile shown in Fig. 2.

A possible interpretation of this curve is as follows:

1. There is an abnormally and rapidly growing ramp of wind energy between 22:00 and 7:20 a.m. At 7:20 a.m. there are 7,500 MW of wind energy being injected in the network.
2. Then, in a very short time interval, 2,800 MW disappear from the system. During approximately 2 hours the system does not accept this 2,800 MW input.
3. At approximately 10:20 a.m., the system returns to a state where almost 7,500 MW are being injected.

There are two possible interpretations for this event. One of them is that wind speed decreased from 7:20 to 9:30 a.m. and then returned to its previous value. The other one is that wind speeds remained at their values during that period of time and the system could not accept all this wind energy. If this last hypothesis is right, then we have to think that a better option would be to store all this energy, for which pumping hydro systems could be a very good choice.

Now we are going to assume this energy is recovered by means of pumping systems and present some figures for alternative scenarios. We will try to extend our conclusions to a case in which similar events occur more often.
ECONOMIC SURVEY

A. Particular case

Returning to the described event, let us remember that, between 7:20 and 9:30 a.m. of Nov. 2\textsuperscript{nd}, 2,800 MW of wind energy were disconnected from the electrical network. As two hours later the level of wind production was the same, we are assuming that this 2,800 MW could be used in an alternative constant operation for the two hours. That is, a total of 5,600 MWh of wind energy priced in 2008 at 10 c€/kWh, which comes to €560,000. A summary of these figures can be seen in Table I.

Table I: Energy losses

<table>
<thead>
<tr>
<th>Power (MW)</th>
<th>Time (h)</th>
<th>Energy (MWh)</th>
<th>Price (c€/kWh)</th>
<th>Money (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,800</td>
<td>2</td>
<td>5,600</td>
<td>10.089</td>
<td>560,000</td>
</tr>
</tbody>
</table>

If we put that energy into a pumping system, assuming an efficiency of 77%, a total amount of 4,312 MWh would be recoverable. Hydroelectric energy was paid at 9.67 c€/kWh in 2008, which would mean €416,970. This has been summarized in Table II.

Table II: Energy recovered in pumping hydro stations

<table>
<thead>
<tr>
<th>Power (MW)</th>
<th>Efficiency (%)</th>
<th>Energy (MWh)</th>
<th>Price (c€/kWh)</th>
<th>Money (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,600</td>
<td>77</td>
<td>4,312</td>
<td>9.67</td>
<td>416,970</td>
</tr>
</tbody>
</table>

As a conclusion, assuming that the wind energy were stored instead of rejected from the electrical system, a total amount of 4,312 MWh would be saved, which would mean a total of €416,970.

B. General case

Let us assume a forecasting error of 8%. A previous explanation of this is the following: according to current market rules, wind energy producers can renounce offering part of their energy to avoid penalties due to error forecasting. This can mean approximately 8% of the energy really being produced. Maybe, with different rules, the use of this energy by means of storage could be contemplated.

CONCLUSIONS

In this paper some discussion and results have been presented regarding the possibility of using pumping systems for energy storage from renewables, especially wind energy.

The main conclusion is that in Spain and, in particular in its most northwestern autonomous community, Galicia, pumping systems have the potential to be used in a more efficient way in combination with wind energy, in order to improve energy efficiency and reduce energy dependency.

ACKNOWLEDGMENT

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REFERENCES


Fig. 2: Wind energy generation on Nov. 2nd 2008 between 22:00 and 9:30.

Fig. 3. Economic Survey General Case.