Wind-Hydro Integration: Pumped Storage to Support Wind

By Fernando Perán Montero and Juan J. Pérez

Public awareness continues to increase regarding the environmental effects of greenhouse gas emissions. As a result of this increasing awareness, over the past 15 years there has been substantial development throughout the world of new electricity generating technologies that produce fewer greenhouse gas emissions.

Wind power is now included in the electricity systems of many developed countries. In Spain, more than 13,800 MW of wind power is installed, providing about 10 percent of the country's electricity production.

While wind power can offer significant financial and environmental returns, this resource does pose many challenges. Among these is the fact that wind is an idiosyncratic "fuel," due to its stochastic nature and to the fact that it is impossible to store. This idiosyncrasy poses difficulty for managing energy systems, with a significant increase in the resources required to establish a real-time balance between generation and demand.

There are several existing generation technologies available to firm the variability of wind capacity. At Iberdrola, we believe the best operational option is pumped storage, which is always available and provides significant flexibility with regard to start ups and shutdowns. Iberdrola is building the 852-MW La Muela 2 pumped-storage plant for this purpose and is investigating construction of three additional pumped-storage plants with a total capacity of 1,640 MW.

Iberdrola's wind resources

Iberdrola is the largest producer of wind energy in the world. At the end of 2008, the company had an installed wind capacity of 9,302 MW around the world, including 4,526 MW in Spain, 665 MW in the United Kingdom, and 2,876 MW in the United States. These plants produce nearly 17,000 gigawatt-hours of electricity each year. In addition, Iberdrola is investigating potential new wind plants around the world with a total capacity of more than 54,000 MW.

By comparison, worldwide wind capacity at the end of 2008 was nearly 121,200 MW, with production of 260 terawatt-hours of electricity each year, according to the World Wind Energy Association. More than 27,200 MW of this capacity was added in 2008, the association reports.

Challenges with wind in an electricity system

Wind is limited in quantity and cannot be stored. Therefore, it is important to forecast wind speed in order to estimate future production. However, because wind is highly variable, this production forecast has a large margin of error.

Wind imposes special requirements on the electricity system, both in the long and short term.

Long term

Over the long term, the challenge arises from the fact that there are periods of time during which high demand coincides with a low level of wind power generation, and vice versa. For example, for wind production by the Spanish mainland power system, the average load level between 2005 and 2007 was about 21 percent. During this same time period, the load factor — the ratio between the net amount of electricity generated and net output capacity — varied significantly, with values of 2.5 percent to 70 percent. Thus, wind power stations may not be available at those times in which they are most needed for the electricity system. This requires the installation of additional power based on other technologies, which replaces wind during periods of low wind electricity production.

Short term

Over the short term, the effect of wind power production on the balance between the market and electricity system is clear. The time horizons of interest include weekly, daily, and real time.

The 635-MW La Muela pumped-storage plant in Spain is being expanded with the addition of a second powerhouse, 852-MW La Muela 2. Iberdrola anticipates that this plant will begin operating in 2012 to help firm the variability of the utility's extensive wind capacity.

Due to the difference in demand between work days and holidays, each generating company produces a weekly operation schedule that plans the start up and shutdown time for each plant (called the "unit commitment"). Thermal stations have a high cost associated with start ups and shutdowns, so utilities make use of their most flexible plants, such as conventional hydro plants and pumped-storage facilities. In this context, the presence of substantial wind power production has an important effect on the weekly operation schedule. Because of the stochastic nature of wind speed, the uncertainty involved in weekly planning is ±25 percent of installed capacity, with a confidence level of 70 percent.[1] With wind power in Spain of 13,836 MW, the uncertainty level on a one-week horizon is ±3,460 MW. To absorb this uncertainty would require shutting down or starting up about nine 400-MW single-shaft, combined-cycle plants.

On the daily horizon, auctioning of production and demand of most of the system's energy occurs one day ahead. Predictive uncertainty in wind power production one day in advance is ± 15 percent.1 Using the 13,836 MW of wind power in Spain as an example, this uncertainty represents about 2,075 MW. This is equivalent to starting up or shutting down five 400-MW single-shaft, combined-cycle plants.

A substantial portion of the work to correct this imbalance may be performed in markets organized less than one day ahead (typically three to 24 hours). However, the remaining imbalance has to be managed in real time by other groups of the system, which requires an increase in the services dedicated to this objective. Using the Spanish mainland power system as an example, there are two principal mechanisms to solve these imbalances:

- A secondary reserve system, in which plants offer a range to increase and/or decrease generation, which is governed in real time by the system operator's secondary power/frequency regulation loop; and
- A tertiary reserve mechanism, which consists of the start up/shutdown of a series of plants that receive remuneration for varying the load over a maximum time of 10 minutes.

The role hydro can play in these two mechanisms is discussed below.

Why pumped storage is the best option

There are several types of electricity generation technologies that can be used to help firm the variability of wind capacity. These include conventional hydro, pumped storage, conventional thermal, gas, and combined cycle. To analyze the regulation capacity of these technologies, Iberdrola considered:

- Start-up and shutdown capacity;
- Regulation velocity (in percent load per minute); and
- Technical minimum load (in percent of maximum load).

Conventional hydro

Hydro plants have several advantages. First, they are the most flexible of the technologies in performing continuous start ups and shutdowns without a significant detrimental effect on the equipment's service life. Second, their load variation speed is high. For example, it is possible to vary the power by about 100 percent per minute. Third, the minimum load is low, often less than 10 percent of the installed power. Fourth, their fuel cost is zero. And last, they do not produce any emissions of greenhouse gases.

The only limitation of this type of technology is its connection to the hydraulic management of rivers. This is mainly conditioned by the storage capacity of the reservoirs in the basin in which each plant is located. During dry years, the reservoir level can decrease significantly, limiting the hydraulic power available.

Construction is under way on the 852-MW La Muela 2 pumped-storage project in Spain and is scheduled to be complete in 2012. In addition, Iberdrola plans to begin construction of two other pumped-storage plants in Portugal in 2010.

Conventional hydro is the most attractive option for firming the variability of wind capacity, for two main reasons. It is the lowest cost technology and the cleanest one, as its greenhouse gas emission level is zero. However, in developed systems, almost all the hydroelectric potential is harnessed. This makes it difficult to increase power to supply regulation services. Therefore, other technologies are needed to provide balancing services.

Pumped storage

From the technical point of view, pumping stations have the same characteristics as conventional hydro plants. Additionally, their operation is not limited by exploitation of the basin in which they are located. Thus, their power is always available, even during dry periods when conventional hydro is limited.

A disadvantage of pumped storage, when compared to conventional hydro, is that it is necessary to pump the water to the upper reservoir to produce electricity. This cost of this process is the price of the electricity divided by the efficiency of the cycle (about 75 percent).

From the environmental point of view, these stations permit a significant reduction in electricity system emissions by producing low-emissions electricity during off-peak periods and replacing more contaminating technologies (such as fossil-fueled plants) during periods of peak electricity demand.

After conventional hydro, pumped-storage plants are the best choice to firm the variability of wind. Power from these plants is available without the restrictions inherent in conventional hydro plants. A disadvantage of this technology is its “fuel cost.” However, in systems with a significant quantity of thermal generation, this risk is quite limited because off-peak prices usually drop considerably due to the fact that these stations cannot perform start ups and shutdowns on a daily basis.

Conventional thermal

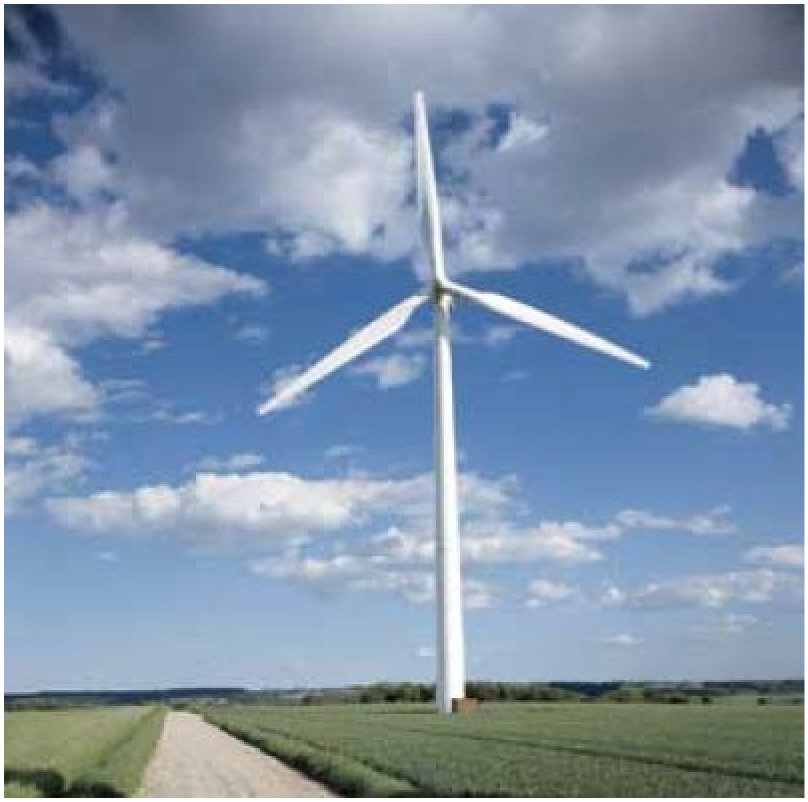
The start-up and shutdown capacity of a conventional thermal plant is limited, for two reasons. First, its start-up process requires a substantial amount of energy, which involves a substantial cost. Second, performing continuous start ups and shutdowns significantly reduces the service life of the plant.

The regulation velocity of conventional thermal stations is limited to about 1 percent per minute, due to their high thermal inertia. However, their control range is acceptable, given that the technical minimum lies at about 45 percent of maximum power.

Open cycle gas

This type of technology involves significant flexibility for continuous start ups and shutdowns. In addition, it allows relatively rapid power variations, with a change velocity of about 4 percent per minute.

On the other hand, the minimum power of these plants usually is about 60 percent of full load, which limits their regulation capacity to 40 percent of rated power.



Wind turbines provided about 10 percent of the electricity production in Spain. Spanish utility Iberdrola, the largest producer of wind energy in the world, had installed wind capacity worldwide of 9,302 MW. The utility is building pumped-storage facilities to help firm the variability of its wind capacity.

Despite the technical advantages of this type of plant, the main disadvantage is their high fuel cost (40 percent greater than those of combined cycle plants).

Combined cycle

From the flexibility point of view, these are between conventional thermal stations and open cycle turbines. Thus, with respect to conventional thermal stations, they are more robust to perform continuous start ups and shutdowns, due to the greater flexibility provided by the gas turbine.

With regard to the regulation velocity, it is about 2.5 percent per minute, slightly lower than open cycle turbines, because of the higher thermal inertia of the combined cycle's conventional part.

Lastly, the minimum power of these plants is nearly 50 percent of the power at full load.

After conventional hydro and pumped storage, combined cycle plants are the next most likely option to firm the variability of wind. These plants can render regulation services at a moderate variable cost, although qualitatively higher than conventional hydro or pumped storage.

In the case of systems with low levels of hydro generation, a mixture of open cycle and combined cycle power plants is the most viable alternative to firm the variability of wind.

Iberdrola's pumped storage development activity

Iberdrola has always sought to develop technologies that provide low greenhouse emissions. In fact, the company has about 10,000 MW of hydro capacity worldwide, including more than 8,800 MW in Spain. Of this 8,800 MW, more than 2,300 MW is pumped storage. Ibderdrola's plants represent 47 percent of the installed hydro capacity in Spain. This large portfolio of hydropower plants has allowed Iberdrola to maximize the profitability of its wind turbine installations from the moment of their construction.

Because of its rapid development of new wind turbine installations, Iberdrola is continuously seeking to broaden its portfolio of pumped-storage stations. It can be difficult to find suitable sites that permit the construction of pumped-storage stations at a moderate investment cost. Even in systems where suitable sites are available, the investment cost of this type of station is very high, which obliges developers to assume a very high risk during the long periods of amortization required.

Iberdrola's most recent activity to add to its pumped-storage portfolio involves expansion of the existing 635-MW La Muela plant with the installation of a second powerhouse. La Muela began operating in 1989. Construction of 852-MW La Muela 2 began in 2006 and is expected to be complete in 2012. The new powerhouse will contain four sets of generators (supplied by Alstom) and pump-turbines (supplied by Voith Hydro). Fomento de Construcciones y Contratas, S.A. (FCC) of Spain is the civil contractor for La Muela 2, and a consortium of Alstom, Sacyr Vallehermoso, and Cavosa is supplying the penstock. Ingenieria y Construccion S.A.U. (Iberinco) is performing the engineering work for La Muela 2.

In addition to this plant currently under construction, Iberdrola plans to develop the Alto Tomega hydroelectric complex in Portugal. Construction of the 1,200-MW complex involves building four dams and four power stations, two of which will be pumped-storage facilities. The two pumped-storage plants will be 779-MW Gouvaes and the 112-MW Pradoselos. Construction on this complex is proposed to begin in 2010 and be completed in 2018.

Finally, Iberdrola is considering several other locations for pumped-storage facilities. Among these is the 750-MW Santa Cristina plant in Spain.

Summary

Wind power is a generating technology that is included in many countries' electrical systems and permits a substantial reduction in emissions of greenhouse gases. However, the increasing penetration of this technology in current electricity systems requires a substantial increase in the resources required to balance generation and demand, as well as additional investments to guarantee the continuity of electricity supply when wind intensity is low.

Of all of the available technologies in current electricity systems, pumped-storage plants constitute the most attractive option for firming the variability of wind. Accordingly, Iberdrola is involved in the development of several of these plants. When completed 2018, they will provide nearly 1,750 MW of capacity to the electrical system in Spain and Portugal.

Note

[1]Nielsen, Henrik Aalborg, et al, et al. "From Wind Ensembles to Probabilistic Information about Future Wind Power Production – Results from an Actual Application," 9th International Conference on Probabilistic Methods Applied to Power Systems, Royal Institute of Technology, Stockholm, Sweden, 2006.

Reference

Carlsson, Frederik, and Viktoria Neimane, "A Massive Introduction of Wind Power. Changed Market Conditions?" Elforsk Report, Elforsk, Sweden, June 2008.

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