MANAGING THE WIND

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Managing the wind

By Russel Snyder
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In west Texas, wind has often been the theme of country ballads, now it’s a source of something more practical: electricity.

As more and more power generated from the wind is being employed in the United States, new solutions are needed to make sure the power grid remains stable. Wärtsilä’s flexible power plants fulfill the necessary criteria - they are able to provide 25% of full power in two minutes and can achieve full output in just eight minutes. They also have the highest levels of simple-cycle efficiency available in the industry and offer consistent performance under varying ambient conditions, low lifecycle costs, small unit sizes and rapid response to varying grid conditions.

“Analysis of the different options showed Wärtsilä to be the clear winner in both environmental and economic terms, and in this project’s ability to meet rapidly changing market conditions,” says Michael Packard, General Manager of South Texas Electric Cooperative (STEC). The subject of Packard’s comments is the more than EUR 100 million contract awarded to Wärtsilä by this non-profit generation and transmission cooperative.

203 MW of flexible capacity

STEC’s order is for a power plant consisting of 24 Wärtsilä 20V34SG gas engines, chosen for their low heat rate, low level of emissions and high efficiency. They are scheduled to be installed at Pearsall, fifty miles southwest of the town of San Antonio by 2010. Each engine will provide 8.4 MW, allowing STEC to use only the number of engines required to meet the demands of the cooperative’s members. The plant’s total capacity will be 203 MW.

The plant in Pearsall will be connected to the ERCOT grid, supplying power and ancillary services to STEC’s eight members, helping to service their peak load of 750 MW. It is expected to run for about 4000 hours each year. “This flexible facility will efficiently provide the electricity needed for the region’s rapid growth, as well as the grid stability required to cope with the increasing proportion of wind-generated electricity,” says Frank Donnelly, President of Wärtsilä in North America.

In 2007, some 5300 MW of wind power generating capacity was commissioned in the United States, in 2006 the amount was 3000 MW. That’s more than any other type of energy source, including coal, oil and gas. And for the third consecutive year, Texas was the US leader in terms of additions to windpower generating capacity. It now has 4356 MW of the 16,818 MW currently installed. The demand for ancillary services is therefore increasing.

New markets result from new requirements

Some years ago, a major change took place in the US energy market. Before this, utilities controlled both power generation and transmission - the grid. After power generation and the grid became separate entities, grid stability became a grey area. Usually, such stability is provided by thermal power plants, which provide sufficient reserve capacity to ramp up power generation very quickly if output from an operating power source falls.

The United States has several independent power producers who, under contract, simply supplied power to the grid with no responsibility to keep it stable. That meant that the utilities incurred substantial costs to maintain this stability by having to keep some of their plants on partial load, able to ramp up their output rapidly if anything went wrong. This in turn helped create a new market in ancillary services, in which capabilities are traded rather than electricity. Tradable capabilities include load changes or rapid start-up and are traded on a daily or hourly basis.

The US opportunity

The capabilities market runs parallel to the electricity market. As an increasing quantity of wind-generated power sources are connected to the grid, this market becomes increasingly important. “In the past, when many factories operated on a 24-hour basis, load levels were relatively easy to predict,” says Jussi Heikkinen, Director, Business Development, Wärtsilä Power Plants.

“That, as the number of offices increased and the number of factories fell, these predictions became more difficult. However, it was still possible to make adjustments for the fluctuations and let your electricity suppliers know: ‘At 06:30 the load will pick up so I want No.1 to be online at that time. No.2 should come online at 07:00, and go offline by 22:00.’ But the inherent variability of wind power makes such predictions very challenging. In fact, once wind power is supplying more than 5% of the load, it’s only possible to make forecasts for the next couple hours, and the situation has to be monitored on a second-by-second basis.”

According to Heikkinen, Wärtsilä has exactly the right set of power plant solutions to meet these challenges. While STEC has given Wärtsilä its biggest order in the United States to date, he sees even bigger orders in the pipeline. New business opportunities are blowing in the wind.
Reliable power from renewables with assistance from reciprocating engines

By Jacob Klimstra, Senior Energy and Engine Expert, Wärtsilä Power Plants in The Netherlands
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The need to cut greenhouse emissions is driving the move to renewable energy sources. Wind and solar power are frequently mentioned as natural alternatives to fuel-based electricity generation, but both depend upon weather conditions. Reliable reserve power capability is, therefore, necessary to ensure electricity supply.

Rising fossil fuel prices, decreasing security of fuel supply as well as the desire to limit greenhouse gas emissions are reasons why the EU has decided to stimulate an increase in the use of renewable energy sources in Europe. The European Commission has recently decided that Europe has to derive 20% of its energy needs from renewable sources by the year 2020. Part of this will be achieved in the transport sector, where 10% of the fuel demand will be covered by renewables such as ethanol or methanol. The bulk of the renewable energy will be used for electricity generation and high hopes are put in wind power and photovoltaics. However, electricity generation based on wind power and solar radiation lacks the easy controllability of power output from fuel-based power generation, resulting in difficulties in matching electricity production with demand.

Matching demand pattern and production
The use of electricity and human activities are closely connected. Electricity is a very versatile energy source used for example for artificial lighting, to power production lines and public transport systems. During the night, the demand for electricity falls to a minimum, but from 7 am on weekdays many activities start up again, resulting in a sharp rise in power demand, which can be up to 180% of the minimum demand. In hotter countries, air conditioning causes a peak in demand at noon. In colder countries, demand peaks in wintertime can be 50% higher than in summer as electricity is used for domestic heating. Figure 1 illustrates the dynamics in electricity use in a Scottish region and in Portugal.

The demand fluctuations caused by individual users switching equipment on and off have a stochastic nature and do generally not exceed 2% of the mean momentary demand.

Network operators need to be able to control the output of the generators in a supply system to cope with these short-term fluctuations in demand. These generators can then be used for frequency regulation, load following and as spinning / non-spinning reserve. Network operators predict the demand pattern for the next day and contract sufficient capacity to meet the sharp rise in power in the morning and the peak in the afternoon.

Steam-based power plants typically need a couple of hours for preheating before they can deliver electricity. Their ramping-up capacity is about 2 to 3% of their nominal power per minute. Power stations can also fail to start up or trip at full load. That is why a contingency reserve is required, which can be spinning reserve (running and on line) as well as standby reserve (non-spinning, but ready to come on line). The non-spinning reserve power
has to come on line as soon as the bulk of the spinning reserve has been used. It will be clear that a generator owner has to be compensated financially for such so-called system services (or 'ancillary services' in the North-American literature). Reciprocating engines and aero-derivative gas turbines have a faster ramping-up rate than steam based power systems and are often used for this type of services.

Generators based on hydro energy from water reservoirs can also react quickly to demand fluctuations. Countries such as Italy and Portugal have the landscape and climate to make extensive use of hydro power, even though the available energy varies from year to year and depends upon the time of year. Existing hydro systems make it relatively easy to apply pumped storage, so that excess electricity from other sources can be used to pump water into the reservoirs for later use. The energy efficiency of such pumped-storage systems lies between 75% and 80%. In the EU, pumped storage capacity equals about 4% of the total installed generating capacity.

**Electricity production characteristics of renewables**

Electricity production from wind energy and photo voltaics depends on the local weather conditions and is largely not controllable (non-dispatchable). If the wind increases in strength, there is a high risk that the wind turbines will suddenly have to cease operation while running at rated capacity, to avoid damage caused by overspeed. To cope with these situations, the network needs spinning capacity that can instantaneously take over the load from the wind turbines. Also, if the wind speed falls drastically over a wide area, much standby reserve has to be put on line. In both cases, the network operator has to pay for these services, which can reduce the intrinsic economic value of the electricity from renewables down to almost nothing, therefore the real economic value of the electricity produced depends on the extent to which the network operator can use it to match demand.

Photovoltaic electricity peaks normally at noon, so it is of benefit only in situations where air conditioning requires much energy, such as in Spain and Italy in the summer. Solar power will not reduce the total installed generating capacity needed to meet the winter peak from 4 pm to 9 pm since solar irradiation is very low at that time.

Biomass-based power plants differ in this respect, however, since their fuel can be stored close to the power plant, making the output more dispatchable. Liquid biofuels are ideal for diesel engines that can act as spinning and back-up reserve for electricity from wind and solar sources.

**Electricity from wind**

Wind speed has a stochastic character. The average wind speed at offshore locations is normally higher than that at land-based sites, giving a higher capacity factor. The capacity factor of a wind mill is the total amount of electricity produced in a year divided by the electricity that would be produced if the generator was running 100% of the time at full load. Figure 2 illustrates typical production duration curves for windmills at an average site and at an excellent site. In addition a windmill will also have downtime for maintenance.

A new offshore wind park of 110 MW near the coast of the Netherlands (Shell/NUON) is expected to have a capacity factor of 30%. The specific capital investment in that park is 2100 €/kW. For a commercial fixed interest rate of 10%, the specific capital costs will be 8 €/kWh. Insurance costs as well as operation and maintenance costs will easily result in production costs of more than 11 €/kWh. That is rather high for non-dispatchable electricity. Land-based wind installations are considerably cheaper than offshore installations (1200 – 1500 €/kW), but their capacity factor is generally just slightly above 20%.

The country with the highest relative share of wind-energy-based electricity is Denmark. In 2004, 16.3 % of the total 40.5 TWh electricity was produced by wind power. However, the capacity factor for the total installed wind power was just 24%. Assuming that on average 5% of the windmills were not available for production because of maintenance and repairs, the available wind capacity was 0.95 x 3.1 GW = 2.9 GW. Total annual net electricity generation from all sources in Denmark is 38.4 TWh, which means a time-averaged production of 4.4 GW. Comparing this with the demand patterns in Figure 1, it is easy to see that wind power in Denmark will exceed the nightly minimum weekday demand if the 2.9 GW active wind capacity is on line with a favourable wind. With a policy of unlimited grid feed in by wind power, the only solution in this situation is to export. That explains why Denmark has relatively high electricity exports compared with four typical EU-25 countries.

The problem of having too much electricity production on line is worsened in wintertime in Denmark since the demand for heating is often met by combined heat and power units. That means that especially during cold windy nights even more excess electricity is produced. If there are high winds, much fuel-based or hydro-based spinning reserve and back-up power has to be available in case the critical wind speed is exceeded. This is quite costly and results in spoiled fuel consumption.

On the other hand, wind speed levels are low for a significant part of the year, so power plants based on fuels have to take
over. As a result, the utilisation factor for conventional thermal plants in Denmark is only 37%, while the general optimum for the sector lies between 50 and 55%. Denmark also actively uses electricity imports to cover peaks in demand (see Figure 3). Denmark itself has no pumped hydro storage, but uses Norway’s storage capacity to some extent.

Without wind power that can freely feed into the grid, nuclear and coal-based power plants normally cover the base load power generation, so that capacity factors of up to 85% can be reached. However, with a high amount of wind power such as in Denmark, especially nuclear power is not attractive since it would have to be shut down during nights with much wind. The nuclear process is not suitable for this sort of operation, and it would also substantially increase the specific capital costs of electricity.

In summary, the stochastic character of wind energy makes it necessary to install additional dispatchable and flexible back-up power plants that will run with a low utilisation factor. Electricity in Denmark for domestic users cost 24 cts/kWh in 2004, twice as high as the EU-25 average. To be able to produce 16.3% of all the electricity used by wind, the wind capacity had to be 23% of the total capacity, while the total installed generation capacity had a utilisation factor of only 34.6%.

Electricity from photo voltaics

The energy radiated to the earth by the sun exceeds the energy required for human activities many times. The challenge is in capturing the radiation. Current photovoltaic (PV) systems have an efficiency ranging from 10 to 15%. In the Netherlands, with an average solar radiation of 115 W/m², the energy catching efficiency of straw is only 2% and that of trees less than 0.3%.

The main problems with PV, however, are the high capital investment of about 5000 €/kW of rated power, and a capacity factor ranging from only 10% in Denmark to 23% in the Sahara. Under standard commercial financial conditions, this would result in specific capital costs of 58 €cts/kWh in Denmark. Moreover, Figures 4 and 5 show that the electricity production of PV systems peaks at noon while it is relatively low in the wintertime. So the capacity is not available at the peak hours after 4 pm and not at times of peak demand in the wintertime. Since its production peaks at noon, proportionately even more peaking power capacity has to be made available.

Electricity from biomass-based generation

Denmark had in 2004 a total of 474 MW of electricity production capacity based on wood waste and 312 MW based on municipal waste. Together these account for 5.9% of the total generation capacity in Denmark. The utilisation factor of this capacity was 51%, and it covered 8% of the electricity need.

These steam-based systems have the advantage that the electricity produced is dispatchable and more controllable than that based on wind and solar radiation. However, even though the fuel costs are relatively low (and even negative in the case of waste), the specific investment is around 3000 €/kW, resulting in specific capital costs of 7 €cts/kWh, with specific maintenance costs of 2 €cts/kWh.

These steam-based power plants lack the rapid load response needed for offering substantial spinning reserve and back-up reserve as network services. Nevertheless, they are an attractive way of utilising the energy available in solid biomass and waste. Small-scale wood-based generators in the power range 2-5 MW are often used in forest-rich countries such as Finland and Sweden. In most cases, the most economic way to use biomass is co-firing in coal-fuelled power stations.

Electricity from biogas and liquid biofuels

Biogas primarily originates from sewage treatment plants and landfills, but digesters using farm and forest residues are also increasingly used.

Liquid biofuels are based on rapeseed, jatropha and palm oil or animal fats. Such fuels can easily be used with a high efficiency in reciprocating engines with a power capacity of up to 18 MW. The specific capital investment in such decentralised installations (€/kW) is about the same as for large-scale generators. The small-scale character of these installations means that electricity can be produced close to the users so that the heat released can also be used ( cogeneration), resulting in total fuel efficiency exceeding 85%. The starting time of such installations is less than 10 minutes so that their output can serve as back-up power in the electricity supply system.

A hybrid solution to effectively integrate renewables

In the opinion of the author, solar electricity may offer interesting options in the future to tap the energy influx from the sun. At present, however, the specific investment cost as well as the amount of energy needed to produce the photo voltaic elements are far too high. Germany, for example, subsidises PV electricity with 50 €cts/kWh, which is almost 10 times as much as the costs of base-load electricity from existing power stations. This indirect way of stimulating the photovoltaic industry is counterproductive since it is a burden on the economy. It would be much better to directly subsidise extensive research into more cost-effective PV equipment.

The basic character of wind power means that the installed wind capacity cannot be considered as controllable, and sufficient alternative capacity is needed to at least cover the peaks in demand. Simple load shedding during conditions when the wind mills cannot produce is generally not acceptable. Since wind capacity reduces the utilisation factor of non-wind capacity, it is necessary to have a back-up capacity with a low specific investment. In addition, the non-wind generators need to have high ramping up...
and ramping down rates. That is required in times when wind power covers the base load (a maximum of 20 to 30% of the time), since then the other generators have to take care of the rapid rise in demand associated with the intermediate load on weekday mornings. A rapid response is also required in case the wind power suddenly stops because of excessively high winds.

Fuels are certain to become scarcer during the planned life of at least 30 years for future generating equipment, so that high fuel efficiency is very important. Power plants consisting of generators driven by reciprocating engines can have a simple-cycle electrical efficiency of up to 45%, can ramp up to full power in 2 minutes (ramp rate 50 % per minute) and start from standstill to full load within 10 minutes. Such units also have the advantage of a quite flat efficiency curve in the upper load range, which is attractive for offering spinning reserve. Moreover, the specific investments for gas-fuelled installations are only about 500 €/kW. Installations running on bioliquids can cost up to 700 €/kWh. An attractive option is the use of dual-fuel engines. Such engines can run on renewable liquid fuels if these are available and switch over to liquid or gaseous fossil fuel when renewable fuels are not available.

The electrical efficiency of such installations can be further improved to roughly 50% by adding a steam cycle or organic rankine cycle. Until now, the additional investment of about 1200 €/kW for such a topping cycle has been considered uneconomic. However, compared with wind power it is quite attractive, since here again the ‘fuel’ is free except in the case of high-temperature cogeneration. The capacity is also more controllable than that of wind power.

As mentioned before, using substantial wind capacity will reduce the utilisation factor of other installed generating capacity. That, in turn, will result in higher specific capital costs for the non-wind capacity. In an honest comparison, these extra costs should be attributed to that of electricity from wind. For gas-engine-driven installations, the specific capital costs of electricity production will increase from 1 €cts/kWh if the utilisation factor decreases from 55% to 35%. The difference would be at least three to six times higher for coal-fuelled and nuclear power plants (see Table 1).

Power stations based on reciprocating engines have multiple units that run in parallel. That guarantees high reliability and availability. By using engines with a unit power capacity ranging between 5 MW and 18 MW, the size of such power stations can easily match the output of wind-power parks. The power stations can be built at suitable locations, preferably close to heat users for cogeneration. Generating units at different locations can even be combined into virtual power plants. The units based on reciprocating engines should be equipped with heat recovery as much as possible. Heat storage systems may be needed to make sure that sufficient heating capacity is available in case the cogeneration units cannot run during cold nights because much wind capacity is on line.

In conclusion, liquid biofuel-fired and gas-fuelled power plants based on efficient and flexible engine-driven generators, with rapid starting and ramping up capabilities, as well as a flat efficiency curve in the upper load range create cost-effective and energy-efficient reserve power for wind stations.

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Table 1: Example of the effect of a lower utilisation factor on the specific capital costs of generators.

<table>
<thead>
<tr>
<th>Power plant type</th>
<th>Specific investment</th>
<th>Specific capital costs</th>
<th>Specific capital costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas engine</td>
<td>500 €/kW</td>
<td>55% utilisation</td>
<td>35% utilisation</td>
</tr>
<tr>
<td>Coal/steam</td>
<td>1200 €/kW</td>
<td>1.5 €cts/kWh</td>
<td>4 €cts/kWh</td>
</tr>
<tr>
<td>Nuclear/steam</td>
<td>2500 €/kW</td>
<td>5.4 €cts/kWh</td>
<td>8.5 €cts/kWh</td>
</tr>
</tbody>
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Fig. 4 - Typical variations in solar irradiation in three European cities during the year.

Fig. 5 - Solar irradiation during a typical day in summer and winter in Madrid.
Wärtsilä enhances the business of its customers by providing them with complete lifecycle power solutions. When creating better and environmentally compatible technologies, Wärtsilä focuses on the marine and energy markets with products and solutions as well as services. Through innovative products and services, Wärtsilä sets out to be the most valued business partner of all its customers. This is achieved by the dedication of over 18,000 professionals manning 160 locations in 70 countries around the world. Wärtsilä is listed on the Nordic Exchange in Helsinki, Finland.