IMPACTS OF VARIABLE, INTERMITTENT POWER ON GRIDS by Willem Post; April 5, 2010

INTRODUCTION
The increased generation of variable, intermittent wind power will present a challenge to the management of the power on the New England Electric Grid, NEEG. Because wind power is variable and intermittent, spinning reserves (nuclear plants, regulation velocity less than 1%/min, thermal plants, 1%/min; combined cycle gas turbines, 2.5%/min; simple cycle gas turbines, 4%/min, hydro plants with or without pumped storage, 100%/min) need to be kept in operation to quickly supply power as needed and when wind power is absent during no wind and too much wind conditions. Accordingly, the CO2 reductions due to wind power wiil be less than forecast by wind proponents, etc. Note: solar power is not mentioned because it is likely to remain only a minor fraction of wind power.

The grid management challenge of wind power has been successfully met by Denmark and Spain during the past 25 years. Let us look at the following topics to shed some light on the subject:

THE DANISH MODEL
THE SPANISH MODEL
THE BONNEVILLE ADMINISTRATION MODEL
The NORTH SEA COUNTRIES' OFFSHORE GRID INITIATIVE
THE NEW ENGLAND ELECTRIC GRID
HYDRO-QUEBEC

THE DANISH MODEL
Denmark has huge wind power potential. It started to develop it after the oil shock of 1973. In 1996, Denmark, Norway, Sweden, and Finland created Nord Pool, which trades in and manages power flow between these nations. The main sources of power are hydro (56.9%), nuclear (21.9%), coal (6.3%), biofuel (5.1%) and wind (2.6%, mostly Danish); only about 13% is from fossil fuels. As the generating modes differ and are distributed differently in the various nations, the need for power will vary from nation to nation and at different times. Nord Pool helps to optimize the use of available power and reduce local deficits. Electricity prices would be higher if all the Nordic nations had to build enough generating capacity to be individually self-supporting.

Denmark has about 5,500 wind turbines (about 89% are from VESTA), total capacity about 3,125 MW; this capacity has not changed by more than 1% since 2004. Denmark has two electric grids: West grid (about 4,300 wind turbines, capacity 2,430 MW, output 5.6 TWh/yr) and East grid (about 1,200 wind turbines, capacity 695 MW, output 1.6 TWh/yr). They are not interconnected. The West grid has robust connections to Norway, Sweden and Germany. The East grid has robust connections to Sweden and Germany.

As a result of Denmark's early start in wind power, VESTA has become the No. 1 turbine supplier in the world with about 19.8% of the world market; GE is No. 2 with 18.6%. VESTA has about 4,900 wind turbines with a total capacity of 2,434 MW in Denmark. It has about 39,000 wind turbines worldwide with a total capacity of 35,400 MW. It installs one turbine every 3 hours around the clock, as does GE.

Denmark's 5-yr average windpower PRODUCTION is about 19-21% of its total production; wind varies year-to-year. Denmark's 5-yr average windpower CONSUMPTION is about 9% of its total consumption.

After 30 years of rebuilding its two electric grids and using nationwide electric demand/supply management (smart meters, smart appliances, load control switches), Denmark's grids are capable of accommodating about 10% of variable, intermittent wind power. During windy times when electric demand decreases in Denmark, etc., selected wind farms are idled, as part of electric supply/demand management. Any production increases beyond about 9%, due to a good wind year, or due to future increases of Denmark's wind capacity, currently mostly offshore, are/will be exported. Denmark's production cannot rise quickly because modifications to the grids of Germany, Sweden and Norway would need to occur in tandem requiring major coordination and "horse trading" to move forward.

Denmark has a population of 5.5 million with about 2.5 million households connected to district heating loops. Denmark has about 550 distributed small (coal, gas, biomass) combined heat power, CHP, plants, aka cogeneration plants. Instead of exporting all of the excess wind power, it has been proposed to use some of it for heating HTHW loops of the district heating sytems, i.e., a form of thermal storage. Denmark's announced goal of 50% of its electricty PRODUCTION from wind by 2025 means that nearly all of it will be exported and/or used for augmenting hydro power in Sweden and Norway, for heating HTHW loops (proposed), and for charging hybrid/all-electric vehicle batteries (far into the future).

Graphs of the daily power supply profiles and the daily production and exports of wind power for both grids show that more than 50% of all windpower is exported to the grids of Norway (total production 137 TWh/yr of which 27,528 MW of hydro provides 98% = 135 TWh/yr) and Sweden (total production = 135 TWh/yr of which nuclear provides 47% = 63.5 TWh/yr and 16,209 MW of hydro provides 44% = 59.4 TWh/yr) and Germany (total production = 606 TWh/yr of which thermal provides 62% = 375.7 TWh/yr and nuclear provides 28% = 169.7 TWh/yr).

The only reason Denmark's high level of windpower production "works" is because robust connections exist to LARGE nearby grids that are willing to cooperate (by modulating the outputs of their hydro plants and pumped storage) and because the exported windpower is mostly sold about 5-10% below spot prices; i.e., a mutually beneficial arrangement.

However, the spot prices for wind are below Danish production costs, i.e., Danish households are subsidizing wind power exports which has contributed to Denmark having the highest RESIDENTIAL electric rates in Europe (energy $0.15/kWh + fees, taxes, transmission 0.19/kWh = 0.34/kWh, about double the price in the UK and about triple the price in France which gets about 80% of its power from its load-following nuclear plants and most of the rest from hydro. France has one of the lowest residential electric rates in Europe. The Danish COMMERCIAL rate is kept at about 1/3 of the residential rate for international competitive reasons; an illegal trade subsidy?

IAEA data for 2004, 2005; Danish Annual Energy Statisitcs 2007; Danish Energy Authority October 2008.
http://www.claverton-energy.com/danish-wind-power-and-electricity-export-in-2007.html
http://www.windaction.org/documents/262

http://www.theoildrum.com/pdf/theoildrum_1735.pdf
http://en.wikipedia.org/wiki/Power_supply_in_Norway
http://blogs.wsj.com/environmentalcapital/2009/03/25/wind-shear-ge-wins-vestas-loses-in-wind-power-market-race/
http://incoteco.com/upload/Cien.158.2.66.pdf
http://en.wikipedia.org/wiki/Wind_power_in_Denmark

THE SPANISH MODEL
Spain and Portugal have huge wind power potential. In November, 2009, a major weather front passed over Spain and Portugal, almost all of their wind turbines were spinning, and Spain's wind power production was more than 50% of Spain's normal consumption for about 5 hours. Spain's electricity consumers never noticed this power surge, because it was smoothed by increased exports, by increased pumping to fill up hydro power reservoirs and by ramping down hydro power and combined-cycle gas turbine plants.

Spain and Portugal have grids that have little connection with the grids of Europe, as do the grids of the UK and Ireland. At the end of 2008, Spain had 16,740 mW of installed wind capacity which, at an average capacity factor = 0.217, produced 31.4 TWh, or 11.1% of the 282.1 TWh consumed.

Spain has about 19,000 MW of hydro plants of which 3,272 MW are with pumped storage. Hydro power production varies from 30 TWh/yr to 40 TWh/yr, depending on rain fall and pumped storage. At least 2,500 MW of hydro plants with pumped storage are under construction or planned.

IBERDROLA is a utility company that has a worldwide electric generating capacity of 43,925 MW. It is Spain's second largest electric utility. Its capacity in Spain is 26,700 MW, including 5,130 MW wind and 8,800 MW hydro of which 2,300 MW is pumped storage. It has the mix of power plants that enables it to play a major role in smoothing variable, intermittent wind and solar power.

In Spain (and Portugal and Denmark), hydro power plants are the preferred option to "firm" wind power because:
- they are the most flexible of the technologies in performing continuous startups and shutdowns without a significant detrimental effect on the equipment's service life.
- their load variation speed is high. For example, it is possible to vary the power by about 100%/min.
- their minimum load is low, often less than 10% of the installed power.
- their fuel cost is zero.
- they do not produce CO2.

http://en.wikipedia.org/wiki/Pumped-storage_hydroelectricity
http://www.renewableenergyworld.com/rea/news/article/2009/10/pump-up-the-volume-using-hydro-storage-to-support-wind-integration
http://www.symbioticsenergy.com/news/wind-hydro.html
http://en.wikipedia.org/wiki/Wind_power_in_Spain
http://www.indexmundi.com/spain/electricity_consumption.html
http://en.wikipedia.org/wiki/Wind_power

THE BONNEVILLE POWER ADMINISTRATION MODEL
The BPA, a non-profit, was created in 1937 to deliver and sell power from hydro power plants on the Columbia River. Over the decades, 31 hydro plants and one nuclear plant, total capacity about 10,500 MW, and a transmission system were built covering the states of Washington, Montana, Oregon and Idaho. The system is interconnected with the Western Interconnection which covers the Western United States, Alberta, British Columbia, and small portions of Mexico. Starting in 2000, total wind capacity connected to the BPA system was about 150 MW, will be about 2,100 MW (22 wind farms) by end 2009, about 6,500 MW by end 2013, about 10,000 MW by end 2016.

The BPA reserves parts of its hydro power system to back up wind in case unscheduled wind power up/down ramps occur unexpectedly. Historically, the BPA has used the Federal hydrosystem to provide reserves for all variability that occurs within its transmission network, but wind has presented unprecedented variability. The PBA is considering adding pumped storage to its hydro power sytem and CO2-producing gas-fired gas turbine-generators to provide more flexibility for integrating future wind power. This follows the way taken by Denmark and Spain. If a total of 1,000 mW of pumped storage and gas turbines is added, the cost will be about $2 billion. Will this be paid for by the BPA, the utilities it sells to (i.e., ratepayers), or the wind farms?

In March, 2009, there was an instantaneous peak of 1,733 MW from wind; almost all of the wind turbines were spinning at about 83% of rated output. Graphs of wind power and total demand show windpower usually varies from 0 MW to 1,000 MW and usually is about 0% -10% of total demand. Water is quickly diverted from and to hydro plant turbines to deal with the variability of incoming wind power. The impact on fish limits some operations. The diverted water could have produced CO2-free hydro power at about $0.025/kWh, well below the cost of wind power. The BPA is building additional weather stations to better predict and anticipate wind power variability. Wind integration costs vary from about $2/MWh-$9/MWh nationwide, in the Northwest about $5.5/MWh. Currently, the BPA is charging about $5.7/MWh to integrate wind power.

http://www.bpa.gov/corporate/pubs/fact_sheets/09fs/BPA_supports_wind_power_for_the_Pacific_Northwest_-_Mar_2009.pdf
http://www.wind-watch.org/news/2009/08/01/bonneville-power-administration-sets-rules-to-deal-with-explosive-power-growth/
http://www.newenergyworldnetwork.com/renewable-energy-news/by_technology/wind/north-western-united-states'-wind-power-reaches-milestone-on-bonneville-power-administration-system.html
http://nucleargreen.blogspot.com/2009/08/how-wind-power-let-bpa-down.html
http://www.harvestcleanenergy.org/conference/HCE7/PDFs/Mainzer.pdf
http://seattletimes.nwsource.com/html/localnews/2009542434_apwabalancingwind.html
http://eetd.lbl.gov/EA/EMS/reports/2008-wind-technologies.pdf
http://pepei.pennnet.com/display_article/368873/6/ARTCL/none/none/1/Coping-with-lsquo;Explosiversquo;-Wind-Power-Growth/

THE NORTH SEAS COUNTRIES' OFFSHORE GRID INITIATIVE
The UK (England, Wales and Scotland) and Ireland have huge wind power potential. Development of even a small percentage of it would

overwhelm their electric grids with variable, intermittent wind power. Robust inter-connections with the European mainland are needed to spread this power over much larger grids. Europe aims to have 20% of its electricity from renewables by 2020.

On December 7, 2009, energy ministers from the UK, Germany, France, Belgium, the Netherlands, Luxembourg, Denmark, Sweden and Ireland signed an agreement to develop the world's first large-scale offshore wind energy grid in the North and Irish Seas, providing a boost to Europe's fast-expanding offshore wind industry.

The North Seas Countries' Offshore Grid Initiative requires member nations to co-operate on the development of a new offshore energy grid that would allow energy generated by offshore wind farms to be transmitted between North Sea nations. The ministers said the initial aim of the initiative is to develop a strategic work plan in early 2010 that would co-ordinate offshore infrastructure development. This plan would then be formally enshrined in a Memorandum of Understanding to be signed later in 2010.

Europe has about 28 offshore wind farms in operation, about 1,684 MW (only two of the 28 farms have GE wind turbines, the rest have European wind turbines, mostly from Vestas and Siemens), another 17 farms, about 2,792 MW, mostly less than 200 MW each, will be operating by 2011 and an additional 14 farms, mostly greater than 500 mW each, are proposed; the US has zero offshore wind farms in operation. The experience gained by Europeans will be useful all over the world, including the US. If the US does not quickly get going, the train will have left the station, as it did for land-based wind power.

http://www.businessgreen.com/business-green/news/2254540/uk-signs-north-sea-super-grid
http://en.wikipedia.org/wiki/List_of_offshore_wind_farms
http://www.ewea.org/fileadmin/ewea_documents/documents/publications/briefings/75gw.pdf

THE NEW ENGLAND ELECTRIC GRID

The NEEG, managed by ISO New England, capacity about 34,020 MW, power supplied about 130,000 GWh/yr, includes over 350 central power plants and 8,000 miles of high-voltage transmission lines to provide power to about 6.5 million customers. The NEEG power is 62% from CO2-producing fossil fuels, 26% from CO2-free nuclear, 6% from CO2-free hydro, 4% from CO2-producing wood waste, 2% from CO2-producing solid waste and 1% other (i.e., CO2 -free wind, solar, etc.). Almost all of this power is STEADY power and the NEEG is designed accordingly. Note: The reason the 5 New England nuclear plants, a total of 4,486 MW, produce so much electricity is because their average CF is about 0.92, much higher than of most plants on the grid.

The VPIRG "Repowering Vermont" report, proposed renewable power to be 15.4% solar and 27.4% wind, for a total of 42.8% = 3,595 GWh/yr by 2032. Based on Denmark's and Spain's 25-year experience with wind power, that quantity of variable, intermittent power cannot be fed into the Vermont grid, unless an economical way is found to store it, such as heating HTHW loops, charging hybrid/all-electric vehicle batteries, using compressed air energy storage, CAES, and augmenting hydro power with pumped water storage, none of which are feasable in Vermont at present. That means Vermont has to feed the subsidized, expensively produced wind power and subsidized, very expensively produced solar power into the NEEG and likely sell it at about 5-10% below spot prices, just as the Danes do.

Each New England state has its own renewable power targets. For example: Maine, with huge wind power potential and much better winds than Vermont, has 5 operating wind farms, totaling 174 MW, plans to have 2,000 MW by 2015 and 3,000 MW by 2020. Maine will need to feed almost all of this power into the NEEG or the Hydro-Quebec grid. Massachusetts' Cape Cod, also with huge wind power potential and much better winds than Vermont, will need to do the same. Their wind power will be more competitive than of Vermont, New Hampshire and Rhode Island. Many years of major coordination and "horse trading" would be needed to move forward.

To sum up:
- at present the NEEG is not designed for large variable, intermittent power inputs
- there are few HTHW loops for thermal storage in the NEEG grid area
- using CAES may not be feasable in the NEEG area
- charging batteries of hybrid/all-electric vehicles and NEEG-wide supply/demand management systems are many years hence
- "firming" NEEG wind power using hydro power plants will be limited because hydro power is only 6% of the NEEG power production

HYDRO-QUEBEC

There may be a way forward similar to the one found by Denmark and Spain about 15 years ago when their wind power production exceeded the stability limits of their grids. THEY "FIRMED" IT BY STORING IT; Denmark by exporting to the hydro power systems of Norway and Sweden, Spain by building more hydro power and pumped storage capacity within its borders.

The way forward will likely be government-owned Hydro-Quebec, HQ, in Canada. It has 59 hydro power plants and one nuclear plant, total capacity 36,429 MW, serves 3.9 million customers who enjoy among the lowest power rates in North America. HQ's present and planned hydro capacity may be large enough to "firm" the power of the Canadian and New England wind farms. Significant expansion of high voltage transmission systems between Quebec and New England will be required. A 750 mile, 2,000 MW high-voltage DC power line to New England was completed in 1992.

HQ and Vermont signed a 328 MW power supply agreement in 1990 that expires in 2015; negotiations are being held to renew it by 2010.
HQ exported 21,300 GWh to neighboring states and the US in 2008.
HQ signed an agreement with New Brunswick on October 29, 2009 enabling HQ to double its power sales to New England by 2011.
HQ aims to "firm" the power of 4,000 MW of Canadian wind farms by 2015.

http://www.ucsusa.org/assets/documents/clean_energy/wpne-pollution.pdf
http://www.newenglandenergyalliance.org/downloads/NuclearBackgrounder.pdf
http://www.elp.com/index/display/article-display/256362/articles/electric-light-power/volume-84/issue-3/industry-report/wind-amp-hydro-a-match-made-in-heaven.html
http://en.wikipedia.org/wiki/Hydro-Québec
http://www.ebmag.com/index.php/Industry-News/Hydro-Quebec-files-strategic-plan-2009-2013.html