Industrial Wind Energy Primer (5/12/08)

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1. How a large wind turbine works

Wind turbines catch the movement of the wind with large wing-like blades to turn a rotor shaft which—not getting needlessly technical—spins magnets to generate alternating current (AC) in wire coils.

Usually, three blades (each currently about 50 yards long) are mounted on a hub that connects them to the rotor shaft. The blades work like airplane wings and can be pitched to modulate how much they are moved by the wind. This is done to maintain a steady rate of rotation through the range of wind speeds in which the turbine is active. A steady rotation rate is necessary to generate electricity that matches the wave frequency of the grid.

The hub is attached to one end of the "nacelle"—the housing for the gearbox and generator. When the wind is blowing adequately, the 100-ton blade and nacelle assembly is turned by motors to face it.

The rotation rate of the rotor blades is increased several times by a large gearbox—which requires hundreds of gallons of cooling and lubricating oils—to create a much faster spinning rate in the generator.

The generator requires power from the grid to work (if there's a power outage, the wind turbines are out, too, unless they have an on-site backup generator). As the wind rises to the "cut-in" speed at which the turbine begins to operate, the generator works as a motor to start the blades spinning. As the wind speed continues to rise, the torque from the blades allows electricity to be produced (pushed *out* by the generator) rather than consumed (pushed *in* by the grid).

The cut-in wind speed is typically 7-9 mph. The amount of electricity generated increases as the wind rises in a cubic relation to the wind speed (i.e., increasing eight times with every doubling of wind speed): from none at the cut-in speed to full capacity at the "rated" wind speed, which is typically 25-35 mph.

When the wind reaches a speed of, typically, 55 mph, the blades are "feathered" to prevent damage and the turbine shuts down. This is the "cut-out" wind speed. The blades are not re-pitched to catch the wind until the wind drops to a speed of, typically, 45 mph, which is called the "cut-back-in" speed.

2. Electricity and the grid

In electricity, **energy is power times time**. Thus, a megawatt (MW) is a measure of power, or the rate of producing or using energy, and a megawatt-hour (MWh) is a measure of energy, representing 1 megawatt of power produced or used for 1 hour. A 100-watt lightbulb burning for 10 hours would use 10 x 100, or 1,000 watt-hours of energy, which is 1 kilowatt-hour. Kilowatt-hours (kWh) are familiar as the unit used in your electric bill. The "kilo" prefix means "thousand"; "mega" means "million"; 1 MWh equals 1,000 kWh equals 1,000,000 watt-hours.

If it were to operate at full capacity for all 8,760 hours of a calendar year, a 1-MW generator would produce 8,760 MWh of energy over the year. The actual amount it produces is called its *load capacity*, or *capacity factor*, which is expressed as a percentage of its rated capacity.

Thus if a generator were shut down for maintenance 10% of the time, its load capacity would be 90% and it would produce 7,884 MWh of energy annually per MW of rated, or installed, capacity. If it is a generator that is used only when very high levels of electricity are needed, it may be operated only 30% of the time. In which case it would produce 2,628 MWh annually per MW installed capacity.

Wind turbines are unable to respond to customer demand, and their output varies in response to the wind. As a result, their average output over a year, or load capacity, may be anywhere between 10% and 40%, depending on the site. In North America, it is usually between 20% and 30%.

Because not all generators will be available all of the time, and because of the high variability of demand, the grid includes a substantial amount of "excess" capacity to guarantee reliability. In the U.S. the total installed capacity is about two times the average electricity demand (or *load*). On most systems, the excess capacity is 20-30% higher than peak demand.

In 2002, the U.S. used a total of 3.66 billion MWh of electricity. That represented an *average* load, or rate of production and consumption of almost 418,000 MW and an annual per-capita use of 12,600 KWh. The load varies from a low base in the middle of the night to very high peaks during weekdays, especially in the summer. Managers of the electric grid dispatch different power plants to provide base, intermediate, and peak loads as customer demand varies through the day.

3. How wind energy works on the electric grid

Because the electricity generated by wind turbines varies with the wind speed and cannot be called up when needed, it is not like other sources of energy on the grid. It cannot provide peak energy unless by chance the wind is up at the same time demand rises, and it cannot provide base load because it is not steady.

For this reason, wind energy does not reduce the need for other sources to supply reliable energy as needed.

Wind is more like a large customer, varying its burden on the grid in a significantly unpredictable way.

When the wind rises and the turbines turn, the grid is usually required to accept that incoming energy. To maintain the balance between supply and demand, the grid must therefore reduce the energy production from another source. In theory, this is how wind energy would reduce emissions and pollution: by allowing fossil fuel-fired generators to be used less. In practice, however, it isn't so simple.

If the amount of wind energy entering the system is within certain tolerances, the grid manager may simply allow the voltage on the system to rise slightly. Or if the grid has hydro power, that is the likely source to be cut off by wind. Obviously, neither of these options would reduce fossil fuel use.

Only with more wind on the system might it become necessary to reduce production from fossil fuel-fired plants. But that comes at a cost, because running such plants at lower capacity reduces their efficiency, requiring more fuel per megawatt and burning it with more emissions. More frequent "ramping" or switching off and on also requires more fuel. It is like your car's gas mileage in the city versus on the highway.

In addition, thermal plants that use steam to turn turbines take hours to warm up. They can't be switched off if they might be needed again soon, which is always the case with wind, since it fluctuates minute to minute. So they are simply taken off line in terms of energy generation but continue to burn fuel to remain on standby.

In other words, the effect that wind energy on the grid has on fossil fuel emissions is not at all straightforward. It may not affect fossil fuel-fired plants at all, plants may continue to burn fuel while on standby, and added inefficiencies may cancel much of the possible savings.

A further aspect of wind energy on the grid is the burden on transmission. As an intermittent source whose output varies with the wind speed, a wind facility's average annual output will be only 20-30% of its nameplate capacity. And even though two-thirds of the time the output will be less than its average, occasionally the output will be near capacity. Besides new transmission lines to connect the facility, the existing grid often has to be upgraded to handle those occasional surges of wind-generated output. Alternatively, many utilities around the world limit the amount of wind capacity they will allow, or they reserve the ability to turn the wind turbines off when the lines are too full.

3. Adverse impacts of industrial wind energy

These include noise and vibration disturbance of wildlife; fragmentation and degradation of habitat; danger to birds, bats, and insects from the blades; water table and runoff problems from foundations, clearance, and roads; noise and visual disturbance of human neighbors (from loss of enjoyment of one's property to loss of sleep and in many cases serious health effects); shadow flicker; strobe lights; devalued property; destruction of rural and wild vistas; loss of recreational areas; interference with wireless communications, and so on.

4. Drivers of wind energy development

First, wind energy provides tax avoidance through the 10-year federal production tax credit (which was 2.0 cents per kWh for facilities connected in 2007) and 5-year double-declining accelerated depreciation. These provide two-thirds of the capital value of an industrial wind turbine. State subsidies may provide another 10% of the cost with grants and tax breaks.

This taxpayer support allows the wind company to sell the energy to utilities at a competitive price.

In addition to selling the actual energy, the company may then sell an "equivalent" amount of renewable energy credits (RECs, or green tags) with which people can claim the alleged environmental benefit of or obligation to buy wind energy without actually using it.

Finally, renewable portfolio standards (RPSs), renewable energy standards (RESs), renewable obligations, and the like are enacted by legislators to require a certain amount or percentage of electricity to be obtained from renewable sources. Most of them favor wind (e.g., they usually don't count large hydro); some of them even specify that a certain amount has to be wind. Thus, utilities are forced to buy into big wind whether or not it is practical or affordable for them.

All of these schemes guarantee markets and large profits for developers.