WHY WIND WON'T WORK

Energy enables modern society by heating our homes and businesses, providing vast transportation systems, and producing electricity. Consumption of electricity accounts for about 39 % of all energy use in the United States (which includes nearly a third of the energy produced for heating and a tiny fraction involved in transportation). Electricity demand doubled from 1970-2000 and is on pace to increase another 20% by 2009. However, because electricity production and use has become more efficient over this time, the rate of consumption, though it continues to climb, is not nearly as large as the growth rate of the general economy.

We expect electricity to be reliable, affordable, and secure, which is made difficult because supply and demand must be kept in continuous balance. Unlike the water supply, large-scaled electrical power can't be stored.

Ten regional networks known as electricity "grids" have evolved to:

- assemble the most dependable, economical, efficient, and controllable sources of power,
- forecast demand with 99% accuracy, in real time, and
- transmit that power at specified frequencies over a range of distances (often hundreds of miles) to a variety of users within their respective regions.

The overall goal is to achieve reliable *capacity*. To ensure reliability at the lowest cost, grid operators consider capacity in four basic ways as they evaluate electricity generators:

- R*ated Capacity*, sometimes known as *Installed* or *Nameplate Capacity*, describes a power generating machine's (maximum) performance output in megawatts (millions of watts—MW);
- ***Capacity Factor*** is the **average output of the machine over time** (typically one year), and expressed as a percentage of its rated capacity multiplied by the hours in the period, **often expressed as kilowatt (thousands of watts) hours—kWh;**
- ***Capacity Credit*** is a statistical average, for planning and security purposes, of the percentage of rated capacity forecast to be available for use at peak demand periods (for, by ordering power supply well ahead of the time it is used, the grid can lessen unit cost by purchasing bulk supplies and provide for grid security by maintaining adequate supply, including sufficient reserve margins); and
- ***Capacity Value* or *Effective Capacity*** is the percentage of a machine's rated capacity that grid operators can be confidant will be available for use at any 15 minute time-ahead interval. (This is the key to reliable system performance, since it means the unit's power will be available on demand when needed.)

Conventional generators—coal, natural gas, nuclear, and hydro, which together account for 95% of the nation's electricity power—must pass stringent tests of reliability and performance before they are deployed. All of their electricity generation is capable of being dispatched on command. Typically, they produce their Rated Capacities when asked to do so, and they maintain a steady energy level throughout their operating time, except when they are called upon to ramp up or back in response to demand changes.

In the case of large coal and nuclear plants, their response to a grid manager's request for power is relatively slow but within a well-understood time period. They often require days to ramp up and back. However, they are very predictable and dependable. They supply basic demand levels and have Capacity Factors approaching, even exceeding, 90%. (Last year nuclear achieved 92% in the US). They provide essential power, and are typically taken off line only for scheduled maintenance and retooling.

Power from smaller conventional units is dispatched on an "as needed" basis, primarily in response to changes in demand. These changes can be slowly incremental over the course of a day, or rapidly dynamic and measured in fractions of seconds as people and industries continually turn their appliances off and on. Small to mid-sized flexibly responsive units are deployed to handle such circumstances. These may have Capacity Factors ranging from 1%-70%. A small diesel unit, for instance, might be used only a few hours a year at times of peak demand on a hot day or in emergencies.

Conventional generators often see limited usage not because of the intrinsic nature of their power source but rather because of a combination of changing demand levels, cost factors, and scheduled maintenance necessary for efficient operation. Of course, there are rare unscheduled outages, but these are kept to a minimum by continual performance testing and maintenance. Unreliable performance would result in the unit's removal from the system.

Because of this predictable reliability, grid operators can count on the availability of conventional generating units to meet demand forecasts (as well as normal deviations) on a variety of schedules—ranging from a year to minutes ahead of deployment—by which to contract for the lowest prices. Such predictability provides a Capacity Credit of well over 90% for each unit and a Capacity Value exceeding 99%.

How does wind power fit into this complex but delicately balanced mix? Wind turbines rarely produce their Rated Capacity, don't generate dispatchable energy, and have frequent unpredictable daily outages. They don't have to pass tests of performance reliability, for unreliability is the norm.

Since wind power is proportional to the cube of the wind speed, small changes in wind velocity affect output enormously. For example, a doubling of wind speed from 11 mph to 22 mph increases power from 6% to 73% of Rated Capacity—a 12-fold increase. Of course, the converse applies as wind's speeds decrease. Large wind turbines typically don't begin producing energy until wind speeds reach 5-6 mph and shut down (for safety reasons) as wind speeds approach 55 mph. They generally produce their Rated Capacities at wind speeds between 29-35 mph. A few wind plants located in wind-rich locations may produce some level of energy up to 92% of the time; but no one can be sure how much of their energy will be available at, say, 4:00 PM tomorrow—much less next week, or next month. The wind machines themselves may be ready for action but if the fuel isn't there—that is, if the wind isn't blowing in the right speed range—the units will not be available for service. Moreover, even when a turbine is producing power, it is never certain what the power level will be, since it's continuously changing.

A wind turbine's output varies continuously between zero and 100% of its Rated Capacity, always skittering, extremely sensitive to small changes in wind speed. This fluctuating output, averaged annually, produces a Capacity Factor of between 18% and 35% for industrial wind projects, depending upon a number of factors. In reviewing the performance of over 7000 widely scattered turbines in Germany, E.On Netz, manager of one of that country's largest grid systems, showed that at no point in 2003 did wind power from the whole array exceed 80% of its Rated Capacity. For more than half the days in 2004, the sum of wind output to the grid was lower than 11% of its Rated Capacity. By contrast, conventional generators steadily and dependably produce nearly 100% of their Rated Capacity throughout the time they are deployed.

In most wind rich areas of the world, the wind blows hardest at times of lowest demand, and typically blows least during times of highest demand. On the other hand, most conventional generators work independently of external factors (with the exception of hydro in times of drought, although hydro, at times intermittent, is never unpredictable). The disparity between wind availability and demand, as well as wind's skittering output, has grave implications for wind's Capacity Credit—that is, for reliable expectations of its availability at any future peak demand time.

Statistically, the historical data can show that a certain amount of wind energy was available at any critical point in a wind plant's history. Operationally, however, because wind behavior is randomly unique for any future time (in much the same fashion as a baseball player's batting average can't foretell the outcome of his next at bat), statistical history is not sufficient to ensure firm reliability. In short, due to the random nature of its power source, ***wind energy can never be depended upon to be available on demand*.** This has consequences for increased consumer prices, for if there is a shortfall from the energy projected in wind's Capacity Credit, grid operators must supplement supply with more expensive power purchased at the moment on what is known as the **"spot market."**

Because wind energy provides no Capacity Value, it cannot be considered as a reliable source of supply for operational purposes. And neither can it be used to augment reliable power to meet new and increased demand—unless it is partnered with highly flexible conventional generators, which, as E.On Netz's various wind reports have shown, must be maintained at levels of 80%-90% of wind's total Rated Capacity in order to assure grid stability.

To illustrate how these concepts apply to wind installations in the real world, let's use the Meyersdale wind facility in southern Pennsylvania as an example, and plug in the numbers. With twenty 1.5MW turbines, the plant has a Rated Capacity of 30MW. It has an observed Capacity Factor, over three years, of about 27%—meaning that it erratically produces on average 8MW (expressed in kWh) for the regional (PJM) transmission grid, which generates up to 140,000MW at peak times.

More than half the time, however, Meyersdale generates less than 15% of its Rated Capacity—about 5MW. At peak demand on the hottest summer days, it often produces nothing. According to performance data, it has a Capacity Credit of about 12% (3MW), which is produced by averaging the times when this amount of wind power was available at peak demand during the three-year history. Operationally, however, statistical history will not be good enough to ensure firm reliability at any specific future time—thereby reducing the plant's Capacity Value to zero.

The hope for wind energy stems from a belief that it will offset significant carbon emissions as it substitutes for dirty burning coal plants. But what is the evidence for this? Many factors influence the volume of carbon emissions that wind energy might offset in the production of electricity, including calculating the CO_2 emitted in the manufacture, transportation, construction, and maintenance involved in the installation of wind projects. Any analysis examining this issue must account for (1) what happens as wind energy enters the grid, causing grid operators to turn conventional generators off or back on in response (or hold back generators that might otherwise have been deployed if there were no wind energy), and (2) what happens as operators seek to integrate wind's wild fluctuations.

To keep costs low, grid systems typically dispatch the lowest cost (usually based upon the fixed wholesale price of fuel), most flexible power units to supply increments of demand. As wind unpredictably wanders into and off of the grid, it often depends upon the grid's fuel mix, and the relative costs for each, as to what fuel(s) wind energy will actually displace or avoid.

When it enters the grid, volatile wind energy behaves much like fluctuations in demand, where appliances are continually turned off and on, often randomly, although, after a hundred years of assessing them, grid controllers can now predict demand fluctuations with great accuracy. However, wind flux is *in addition to* demand flux—and much less predictable. Wind adds another layer of instability that must be smoothed out so that demand and supply are balanced precisely. Controllers respond to the wind influx by dialing back the generation from the operation of conventional units, much as they do when demand decreases. And as the level of wind energy flutters about the grid, rising and falling at random, rapidly responsive conventional generators are deployed to balance this ebb and flow. When wind energy disappears from the grid, it is as if demand has again increased, and more power is required from conventional sources to match it.

Nuclear and large coal plants operate much too slowly for their steady generation to be displaced or avoided by the dynamic volatility of wind

production. Wind energy cannot therefore be a sporadic substitute for these indispensable power sources, as many believe. In most cases, wind would be a stand-in for hydro and natural gas units, which can be turned on and off quickly. If the former, there would be no carbon savings; if the latter, only minimal carbon savings could accrue, since natural gas units burn 60% cleaner than coal plants. However, since their fuel is more expensive, natural gas plants are more likely to be displaced or avoided by wind generation due to economic dispatch considerations.

Integrating wind's skittering energy levels within the mix of reliably steady conventional generation is a daunting challenge. Achieving this integration insures there will be increased financial and environmental costs. The now-you-see-it, now-you-don't nature of wind necessitates that it be continuously accompanied by reliable compensatory generation in order to maintain a steady power flow matched to demand. Consequently, wind can only be one ingredient in a larger fuel mix. **Contrary to one of the industry's most persistent claims, it cannot of itself power any home under modern standards of reliable performance.**

Since the ramping limitations of nuclear and large coal plants preclude their ability to provide balancing compensation for wind volatility, in most cases that compensation will come, ironically, from the same power sources dialed back to be displaced by wind in the first place: natural gas units, supplemented by a few flexible coal-fired plants. Hydro generation could also accomplish this task in areas where water abounds for electricity production. In any case, wind's companion generation must be deployed in a highly dynamic, off-and-on way. **But the efficiency of cleaner-burning natural gas plants, when they are repeatedly throttled up and back, is reduced, effectively negating much of the greenhouse gas offsets that wind substitution may have produced. For instance, researchers from the Renewable Energy Foundation in Britain demonstrated that a 2% increase in inefficiency for such fossil-fueled units can result in a 16% increase in carbon emissions throughout a grid system, much like the increased emissions from an automobile in stop-and-go traffic compared to a steady 60 mph drive on the highway**

Between the: (1) uncertainty about what power sources wind energy would replace or avoid from minute to minute, (2) the operational inefficiencies inherent in switching conventional power sources off and on to accommodate wind's continuously changing intensity, and (3) the emissions created in the construction and operation of the wind power facilities, actual measurement of emissions offsets due to wind installations is difficult to calculate accurately, and the results would vary from grid to grid. Moreover, consumers of electricity will be charged not only for the cost of the wind power itself but also for the cost of wind's companion generation.

Given the possible scenarios, system-wide carbon emissions offsets are likely to be miniscule throughout most of the nation's grids. **The Electric Power Research**

Institute in California affirmed this circumstance, agreeing that it is technically incorrect to assume that wind energy will displace fossil generated power and decrease CO_2 emissions on a kWh for kWh basis. Its report concludes that in a real operating situation, because large-scale storage of electricity is not possible, any CO_2 saving will be small.

Consider an analogy between the internal combustion automobile and a hypothetical windmobile. The auto has a Capacity Factor of about 25%, limited by a combination of operator choice (people generally don't drive them 24 hours a day each day of the year) and by the need for ongoing maintenance and continual refueling. However, when it is asked to work, it will do so with a high rate of reliability—99.9% of the time. This is its Capacity Value.

Contrast this with the windmobile, which one can never be sure if it will start or not. If that wouldn't be annoying enough, most of the time its speed lurches between extremes, often stopping without warning. And if the windmobile became popular (due to substantial federal and state financial incentives), there would soon be an array of traffic accommodations created to enable it, such as requiring a host of new traffic controls and patterns, not to mention the borrowed cars, buses, taxis, and late appointments involved in going hither and yon. This activity corresponds to the way the grid is increasingly called upon to provide special means to integrate wind's unreliable volatility.

A 1600MW coal plant produces a reliable, steady stream of 1600MW day and night throughout the year. It is also contained within a relatively small area and can be equipped with scrubbers to eliminate most noxious emissions, such as sulfur dioxide, nitrous oxide, and mercury. Contrast this with a wind plant consisting of 2650 turbines, each rated at 2.0MW stretched out for hundreds of miles, delivering a skittering annual average of 1600MW based upon a 30% Capacity Factor—*but producing no Capacity Value.*

Although the annual energy contribution of the two facilities would be equivalent on paper, the wind plant could never replace the coal plant in terms of its capacity. In fact, one should ask how many such wind facilities must be built to equal the Effective Capacity of that single coal plant. Or any conventional generating plant. And then one should ask about the thermal implications, as well as the environmental consequences, of such a vast enterprise.

The essence of "green" technology is that it strives to leave no trace. Wind is not a "leave no trace" technology. The premise behind the idea of whether we should have wind installations instead of conventional generation is badly skewed. Better to ask whether we should have phlogiston instead of oxygen in the air we breathe. Wind is a supernumerary producer of electricity enabled because the slap and tickle of wind propaganda flatters the gullible, exploits the well intentioned, and nurtures the craven. It is made possible because there's no penalty for lying in the energy marketplace.

Jon Boone

April 26, 2008

A special thanks to Tom Tanton, Lisa Linowes, Dave Beaudoin, Art Pundt, Mary Kay Barton, and Barbara Boone, each of whom reviewed various drafts of this work and provided valuable emendations. John Droz energized both its substance and style; he infused many sections with better text and improved clarity—for which I'm most grateful.