Integrating Wind Power Into the Electric Grid

Perspectives for Policymakers

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With overall U.S energy consumption expected to increase 23 percent by 2030[1] and with growing requirements for renewable energy, states are seeking to meet new demand with energy sources that are abundant, clean and cost-effective. Wind power has become a popular clean energy choice due to its price and the distribution of wind resources across the nation. However, with more states requiring an increase in renewable energy production and serious consideration of a national renewable electricity standard growing in Congress, questions have arisen about how much wind power can be integrated into the U.S. energy supply.

These questions arise because wind is a variable resource—the amount of power produced varies with the strength of the wind. This paper explores how utilities, regulators and policymakers are addressing wind power reliability and integration, enabling more states to meet renewable energy production targets and environmental goals.

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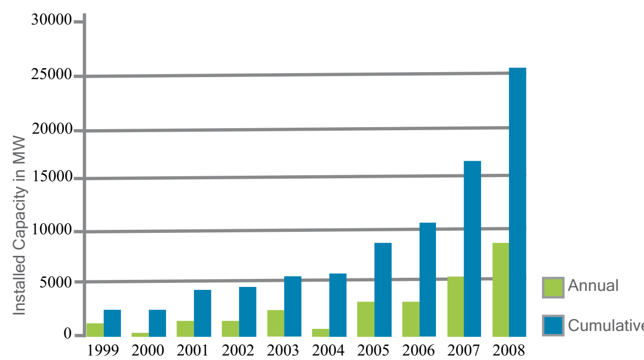
Wind Power Resources in the United States

Installed wind power capacity has increased tremendously during the past few years. In 2007 alone, new wind projects were responsible for 30 percent of all new power generating capacity and increased the nation's wind generating capacity by 45 percent. Massive growth continued in 2008, with more than 8,300 megawatts (MW) of new installed generating capacity, making the United States the world leader in wind power installations. Utility-scale wind projects located in 34 states are expected to generate 49 billion kilowatt-hours of energy in 2008—about 1.5 percent of all electricity produced in the United States and enough to power 5.7 million homes. Figure 1 illustrates the dramatic growth wind power has experienced since 1995, highlighting the significant increase in capacity that occurred between 2005 and 2008. The large fluctuations in annual development prior to 2006 reflect inconsistent federal tax incentives.

Figure 1. Growth in U.S. Wind Energy Installations



Source: American Wind Energy Association, January 2009

Getting More Wind Energy on the System

In 2008, the U.S. Department of Energy (DOE) released a report exploring ways the country could meet 20 percent of its electricity consumption with wind energy by 2030.[2] According to the document, utilities could realistically produce 20 percent of their electricity from wind energy without negatively affecting reliability, although a significant investment in increased transmission capacity would be required. States also have commissioned wind integration studies in anticipation of reaching high percentages of wind in a relatively short time frame.[3]

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In Iowa, MidAmerican Energy already has exceeded a 10 percent penetration level.[4] In Minnesota, Xcel Energy is approaching 10 percent wind as a percentage of peak load and is on track to reach 25 percent by 2020. A comprehensive wind integration study, conducted at the request of the Minnesota Legislature, found that the state could integrate 25 percent wind energy into its energy portfolio with little difficulty. The integration cost was estimated at less than a half-cent per kilowatt-hour (kWh) of wind energy. Minnesota performed this study to determine the cost and infrastructure impacts of its 25 percent renewable electricity standard.

Other studies have produced similar cost estimates for integrating up to 30 percent wind energy.[5] Wind energy often displaces higher-cost energy from other sources. Although there is an incremental cost to integrate wind energy, adding it to the mix of power sources can reduce average electricity costs and provide savings to electricity customers.

Coordinating Energy Supply and Demand

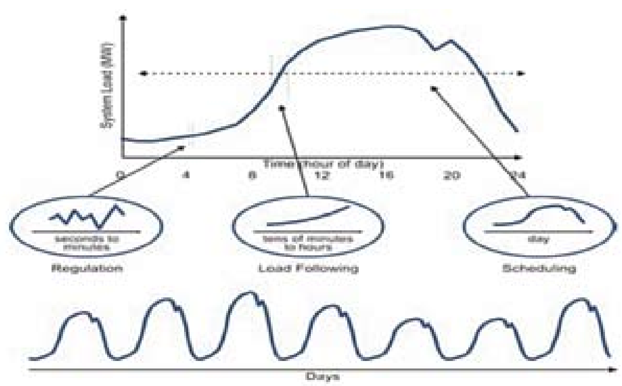
To understand how wind power can be added to the power grid, it is important to recognize how system operators balance supply and demand. The demand for electricity (referred to as "load") can vary widely based on weather—heating and cooling loads dominate utility peak demand. The time of day also influences load, since energy use tends to peak during the daytime when business and industrial needs are highest. Load also fluctuates with the time of year as seasonal changes influence heating, cooling and lighting needs. Although load forecasting is good, loads are somewhat unpredictable. Production also can be unpredictable since power plants and transmission lines can fail unexpectedly or must be taken out of service for maintenance. Wind plants create additional variation because they generate electricity based on wind speed, which changes over time. System operators are responsible for balancing varying demand and supply. They can treat a reduction in wind energy the same as they would an increase in energy demand.

To account for the variations in electricity demand and production, system operators use balancing techniques that focus on three basic time frames: regulation, load following and unit commitment.

Regulation – Fast, unpredictable variations in load occur in short (seconds to minutes) time frames, so energy generation must be ready for increases or decreases to meet the changes. Since variations in wind energy generally take place over longer times, wind power needs only minimal regulation. An automatic generation control system monitors load and generation and automatically balances the two by sending signals to power plants to increase or decrease their output. The cost of regulation related to wind energy variability is fairly low—less than 0.1 cent per kWh of wind energy.[6]

Load Following – Energy demand and wind energy output vary more dramatically over time frames that extend from 10 minutes to several hours. The longer time frames cover the variation from low electricity consumption in the middle of the night to high consumption during the day. To balance energy production and consumption during this longer time frame, system operators deploy various types of generation to meet energy demand at the lowest cost, as shown in Figure 2.

Figure 2. Typical Daily Load Shape



Source: U.S Department of Energy (DOE), *20 Percent Wind Energy by 2030, (2008)*

Unit Commitment – Some generators (including coal-fired power plants) require longer-term planning because they need anywhere from hours to days of preparation before they can generate power. System operators select which generators will be needed for each day's operation through the unit commitment process. They strive to ensure that adequate generation is available to reliably meet load at lowest cost.

System operators are responsible for balancing the continually changing demand and supply despite daily cycles and minute-to-minute changes. To ensure that adequate generation is available to meet electricity demand, system operators typically ensure availability of reserve energy. Reserves that are on-line and available to respond within 10 minutes are known as spinning reserves. Reserves with longer response times are referred to as non-spinning reserves.

To adapt to changes, the grid requires reserve capacity to manage variability in load and wind energy output. Actual experience with wind power integration shows that dedicated back-up generation for wind power is unnecessary; instead, system operators can simply employ existing spinning and non-spinning reserves. Also, wind forecasting is an essential tool to help system operators manage the uncertainty associated with relying upon a significant amount of wind energy.

Just as the combined random actions of millions of consumers turning appliances on and off create a relatively stable demand for electricity, variations in the outputs of wind turbines spread over a large area result in consistent power generation over time periods of 30 minutes or less. This is one of the main reasons that spreading wind projects over larger regions significantly reduces the cost of integration.

Costs of Wind Integration

The size of the electricity market and the load balancing area play a significant role in the ease and cost of wind integration. Larger markets have more resources to cost effectively balance energy demand and supply, which reduces the overall variability in the system. Large regional energy markets also offer a better variety of financial mechanisms that can reduce the cost of wind integration.[7]

Perhaps most important are the region's wholesale market structure and scheduling practices. Regions with sub-hourly markets or sub-hourly scheduling (the large ISOs, for example) have greatly reduced wind integration costs because they can more quickly access the response capabilities of the conventional generators. Regions that only allow hourly scheduling generally have higher integration costs.

The mix of energy generation resources in an electricity market also plays an important role in determining the cost of integrating wind power. Research conducted in California and elsewhere found markets that incorporate large amounts of hydroelectric and natural gas generation—both of which can be easily adjusted to meet changing demand—tend to have lower integration costs than systems that rely on more inflexible generation, such as coal or nuclear power. California found that the cost of integrating wind energy is essentially zero, in part due to the large number of flexible generators in the state and the large balancing area. Other large market areas have found integration costs to be less than 0.5 cents per kWh when wind energy contributes up to 25 percent of energy generation. Demand response policies, which help large electricity users reduce their non-essential electricity use on command, can also be a very cost effective way to accommodate the variability of wind power.

Too much wind power sometimes is a concern. This issue can arise in a system that supplies substantial wind energy output during periods of low demand—generally at night when winds can be high and most demand is met by large, inflexible coal-fired or nuclear plants. Because it is difficult and costly to reduce production in such plants, a large influx of wind energy can cause operational problems and increase costs. Larger power markets, forced curtailment of wind plant output, and addition of new loads that can make use of excess nighttime energy can help avoid this problem. One nighttime load that may become prominent in the near future is charging electric and hybrid vehicles.

Trends in Wind Integration

A decade ago, concern was expressed that the variability and uncertainty of wind would seriously impair the reliability and stability of the electric power system. Today, after considerable practical experience with wind power, power system engineers acknowledge that—even with substantial wind energy contributions—the lights will stay on. The major questions now about wind power growth are "What are the costs associated with its integration into the system, and how can these costs be minimized?"

Integrating wind power into the electricity grid will require changes to the business-as-usual operation of the electric power system, however, many of these changes are already being implemented. Although studies show the potential for modest integration costs due to increased wind power generation, the cost-benefit studies conducted to date find that wind penetration levels as high as 30 percent are likely to have little effect on consumers.[8] State policies, electricity market structure, the size of the balancing area, and the diversity of energy resources influence the ease and cost of wind integration. In some cases, consumer rates will actually decrease because incremental integration costs can be more than offset by savings from reduced consumption of fuels such as natural gas.

The challenge of transforming how the United States produces and distributes electricity is being met head-on by states nationwide. They are using innovative techniques to improve the quality, reliability and stability of the electric grid and simultaneously are increasing the amount of domestically produced clean energy. Although the effort has just begun, states are successfully creating and implementing plans to address the most significant challenges to wind integration.

Notes

1. U.S. Department of Energy, *Annual Energy Outlook 2008* (Early Release) (Washington, D.C.: U.S. DOE, DATE); www.eia.doe.gov/oiaf/aeo/electricity.html.
2. U.S. Department of Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply* (Washington D.C.: U.S. DOE, 2008); www1.eere.energy.gov/windandhydro/wind_2030.html.
3. J. Charles Smith et al., "Utility Wind Integration and Operating Impact State of the Art," *IEEE Transactions on Power Systems* 22, no. 3 (August 2007).
4. U.S. Department of Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, 77.
5. Most of these studies can be found at the Utility Wind Integration Group website: www.uwig.org.
6. M. Milligan, H. Shiu, B. Kirby, and K. Jackson, *Multi-Year Analysis of Renewable Energy Impacts in California: Results from the Renewable Portfolio Standards Integration Cost Analysis* (NREL Report No. CP-500-40058) (Golden, Colo.: NREL, 2006).
7. U.S. Department of Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, 92.
8. Richard J. Piwko et al., "Appendix B, Impact of Intermittent Generation on Operation of California Power Grid" (CEC-500-2007-081-APB) (Schenectady, N.Y.: GE Energy Consulting, July 2007).

Resources

National Conference of State Legislatures Renewable Energy WebPage
www.ncsl.org/programs/energy/RenEnerpage.htm

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