

# Integrating Wind Generation Into Utility Systems

*The electric power industry has taken notice of the expansion of wind and its potential.*

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As anyone who follows this industry knows, wind power is a growing source of electricity around the world. In the U.S. alone, from 2000 to 2005, over 6,615 MW of nameplate capacity have been installed, for a total of 9,171 MW. Wind power is now “utility scale” and presents unique challenges for bulk electric power system planning and operation.

The main focus on utility wind integration has always been wind’s variable nature. The resulting areas of concern are impacts on the operating costs of the nonwind part of the system, as well as overall electrical system integrity. Since the early 1990s, the Utility Wind Interest Group, now the Utility Wind Integration Group (UWIG), has conducted research to quantify these impacts and examine practices and technologies to mitigate them.

The electric power industry has taken notice of the expansion of wind and its potential and actual effects on system operation, planning and reliability. Last November, the Power Engineering Society of the Institute of Electrical and Electronics Engineers published an issue of its *Power & Energy Magazine* focusing on the integration of wind into utility

power systems. Earlier this year, UWIG developed and issued a summary of those findings. This article addresses many of the key points raised in that summary.

## **Managing impacts**

UWIG and its membership have observed that the impacts of wind generation can be managed through proper plant interconnection, integration, transmission planning, and system and market operations.

On the cost side, at wind penetrations of up to 20% of system peak demand, system operating cost increases from wind variability and uncertainty amount to about 10% or less of the wholesale value of the wind energy.

It should be noted that these conclusions will need to be reexamined as results of higher-wind-penetration studies – in the range of 25% to 30% of peak balancing-area load – become available. However, achieving such penetrations is likely to require one or two decades. During that time, other significant changes are likely to occur in both the makeup and the operating strategies of the nation’s power systems.

Depending on the evolution of public policies, technological capabil-

ities and utility strategic plans, these changes can be either more or less accommodating to the natural characteristics of wind power plants.

These incremental costs, which can be assigned to wind-power generators, are substantially less than imbalance penalties generally imposed through Open Access Transmission Tariffs under the U.S. Federal Energy Regulatory Commission (FERC) Order No. 888. A variety of means – such as commercially available wind forecasting – can be used to reduce these costs. In many cases, customer payments for electricity can be decreased when wind is added to the system because the operating cost increases can be offset by savings from displacing fossil fuel generation (most notably natural gas).

In addition, UWIG has found evidence that with new equipment designs and proper plant engineering, system stability in response to a major plant or line outage can actually be improved by the addition of wind generation.

Since wind is primarily an energy – as opposed to capacity – source, no additional generation needs to be added to provide backup capability provided that wind capacity is properly discounted in the determination

of generation capacity adequacy. However, wind penetration may affect the mix and dispatch of other generation on the system over time, since nonwind generation is needed to maintain system reliability when winds are low or not blowing.

Wind generation can also provide some additional load-carrying capability to meet forecasted increases in system demand. This contribution could be up to 40% of a typical project's nameplate rating, depending on local wind characteristics, and match with the system load profile. Wind generation may require system operators to carry additional operating reserves.

Given the existing uncertainties in load forecasts, the studies analyzed indicate that the requirement for additional reserves will likely be modest for broadly distributed wind plants. The actual impact of adding wind generation in different balancing areas can vary, depending on local factors. For instance, managing large wind output variations and steep ramps over a short period of time could be challenging for smaller balancing areas, depending on the specific situation.

Key areas addressed in our review of the state of the art in wind integration include the following:

- wind plant interconnection;
- wind plant integration;
- transmission planning and market operation; and
- accommodating future wind generation.

These are discussed in more length below.

### **Wind plant interconnection**

An overriding concern with the connection of any form of generation to the electric power system is ensuring reliability. Multiple organizations, including transmission system owners/operators, load serving entities and others share responsibility for ensuring the reliability of the North American grid.

That the grid is itself a highly interconnected system demands close

coordination and cooperation between all of these stakeholders. The North American Electric Reliability Council (NERC), organized in response to blackouts in the northeastern U.S. in the 1960s, is responsible for developing policies and standards to ensure the reliability of the bulk power system.

Since its inception, NERC has relied on the mutual self-interest of its members to implement and abide by policies that govern how the U.S./Canadian power system is designed and operated. However, under the U.S. Energy Policy Act of 2005, NERC was recently approved by the FERC as the Electric Reliability Organization of the U.S., with legal authority to enforce reliability standards on all owners, operators and users of the bulk power system.

Standards and policies instituted by NERC and its eight Regional Reliability Organizations (shown in Figure 1) encompass a wide range of activities. Of particular interest to the wind industry, however, are those

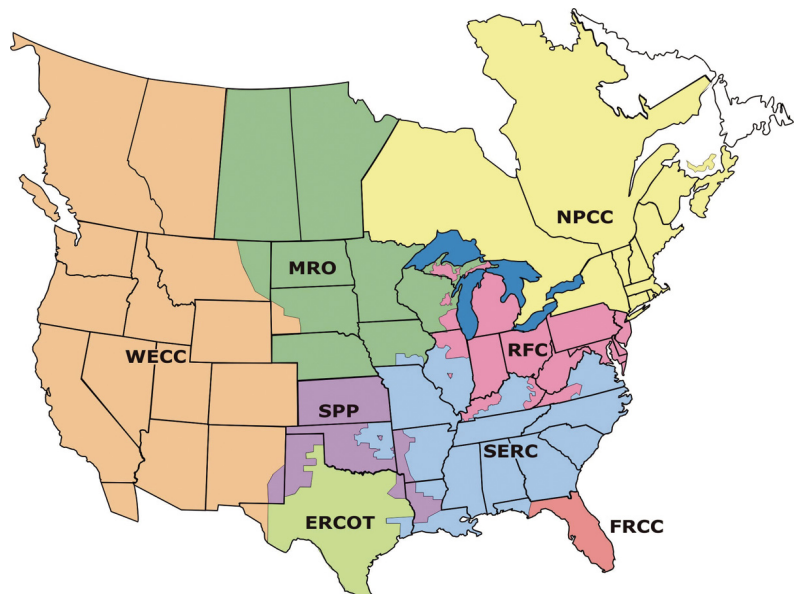
that govern procedures and policies for adding new components – generation, transmission and distribution – to the grid.

These ensure that network reliability and performance are not compromised. Critical to compliance with these standards are analytical studies that consist of steady-state power flow analysis or stability analysis, which assesses the component's effects on the ability of the power system to recover from disruptions.

Key elements of these studies are computer models that help assess performance. Models of individual wind turbines and wind plants have been developed and refined as more wind generation is interconnected to the power system. The technology deployed in the turbines to convert mechanical force to electrical energy presents unique challenges in developing and using the models. Other factors, including the utilization of sophisticated power electronic controllers, can make modeling wind plant performance a challenge.

Figure 1

### **The Eight Regional Reliability Organizations Of The North American Electric Reliability Council**



Source: UWIG

A trend that has been in effect for some time has been a push to formally establish requirements and performance standards for wind generation. In the U.S., FERC, through its regulatory process, developed and issued an interconnection rule (Order 2003A) for wind facilities over 20 MW in capacity. A number of organizations, including the American Wind Energy Association and the Western Electricity Coordination Council, one of the NERC regional reliability organizations, provided input during the process and are engaged in a continuing dialog on the subject.

The provisions of the order, often referred to as a "grid code," focus on such issues as low-voltage ride-through and reactive power capability. In addition, there is activity in Canada, under the auspices of the Canadian Wind Energy Association, to develop a Canadian grid code.

Several fundamental conclusions have been reached about interconnecting wind plants to the bulk power system:

- Wind power plant terminal behavior is different from that of conventional power plants but can be compatible with existing power systems. With current technology, wind plants can be designed to meet in-

dustry expectations, such as riding through a fault, supplying reactive power, controlling terminal voltage and participating in SCADA system operation.

- Increased demands will be placed on wind plant performance in the future. In addition to the current capabilities of low-voltage ride-through and reactive power control, current technology also provides for voltage control, output control and ramp rate control. Future requirements are likely to include post-fault machine response characteristics more similar to those of conventional generators.

- Better dynamic models of wind turbines and aggregate models of wind plants are needed to perform more accurate transmission planning and system operation studies.

- In areas with limited penetration, modern wind plants can be added without degrading system performance. System stability studies have shown that modern wind plants equipped with power electronic controls and dynamic voltage support capability can improve system performance by damping power swings and supporting post-fault voltage recovery.

Because of spatial variations of wind from turbine to turbine in a

wind plant – and to a greater degree from plant to plant – a sudden loss of all wind power on a system simultaneously due to a loss of wind is not likely.

### Wind plant integration

Integrating wind plants into the electric power system presents a number of challenges to power system planners and operators. These problems are largely due to the unique characteristics of wind generation as well as the lack of familiarity with these characteristics in the traditional power system engineering circles.

Utility-scale wind plants are a relatively new development in the electric power industry, and experience with them is not uniform across the electric power industry as compared to thermal or hydro generation. Unlike other generation assets, wind power is not readily dispatchable, which affects the ability of power system operators to control them. This affects their ability to participate in the balancing of load and generation.

As mentioned previously, wind is more of an energy resource than a capacity resource – indeed, capacity credits for wind plants rarely approach nameplate ratings. With all of this in mind, the key question becomes how the variations in wind plant output affect the operation of the power system and what the associated costs are.

UWIG, along with a number of utilities and organizations, has studied this issue and found that the costs tend to be lower than initially expected. This finding has been attributed to wind's tendency to behave more as a negative load than traditional generation and that the power system is designed to handle significant load variations in a routine fashion.

Analyzing the integration of wind plants, one must address the following questions:

- How does wind generation affect net load variability?
- To what extent are dispatchable generation reserves required and when?

Table 1

### Operating Impacts Study Results

A summary of wind plant ancillary costs

Study	Relative Wind Penetration (%)	\$/MWh Regulation	Load Following	Unit Commitment	Total
Xcel/EnerNex	15	0.23	0	4.37	4.60
PacifiCorp	20	0	2.50	3.00	5.50
BPA	7	0.19	0.28	1.00-1.80	1.47-2.27
Xcel/UWIG	3.5	0	0.41	1.44	1.85
We Energies I	4	1.12	0.09	0.69	1.90
We Energies II	29	1.02	0.15	1.75	2.92

Source: UWIG

- How will the reliability of the system be maintained?
- What are the system operating cost impacts due to variability?
- How should wind plant capacity credit be calculated?
- What role and value does forecasting have to play and offer?
- Do results vary with different penetration levels of wind?
- How has wind changed system operating strategies in use, so far?

A number of wind integration studies have been conducted to date, the results of which are summarized in Table 1.

Key highlights from analysis of these studies include the following:

- Wind generation's primary value lies in its ability to displace energy produced from the combustion of fossil fuels and to serve as a hedge against fuel price risk and future restrictions on emissions.

- Because it is used primarily as an energy resource, the addition of a wind plant to a power system does not require the addition of any back-up conventional generation. When the wind is not blowing, the system relies on existing dispatchable generation to meet the system demand.

- Wind plants provide additional planning reserves to a system, but only to the extent of their capacity value. Capacity for day-to-day reliability purposes must be provided through existing market mechanisms and utility unit commitment processes.

- The capacity value of wind generation is typically 10% to 40% of nameplate rating and depends heavily on the correlation between the system load profile and the wind plant output.

- The impact of adding wind generation can vary depending on the nature of the dispatchable generating resources available, market and regulatory environment, and characteristics of the wind generation as compared to the load.

- Commercially available wind forecasting capability can substantially reduce the costs associated

with day-ahead uncertainty.

Implementation of wind plant output forecasting in both power

*Wind generation poses unique challenges to transmission planners and market operators because of its variability.*

market operation and system operations planning in the control room environment is a critical next step in accommodating increasing amounts of wind penetration in power systems.

#### **Transmission planning and market operation**

It is common knowledge in the power industry that there are shortcomings in the infrastructure of the North American power grid, most notably in the area of transmission. Over the years, transmission has been built in areas where there is a population to purchase the electricity supplied by the system.

The best wind resources tend to be located away from these populated areas. Therefore, there is an inadequate amount of transmission capacity to transport wind-generated electricity to where it is needed. Wind plants can take a relatively short amount of time to site, construct and commission. However, it can take years to permit, site and construct transmission.

The 2005 U.S. Energy Policy Act attempted to address this problem by both increasing incentives to construct transmission as well as identifying national corridors for development of transmission to relieve congestion and deliver power from wind and other resource-rich areas to where it is needed.

Much as with the integration issue, wind generation poses unique challenges to transmission planners and market operators because of its variability and limited dispatchability. These shortcomings are even more apparent in established and developing electric power markets, where planners and schedulers typically "buy" dispatchable generation capable of producing the full rated level of power when needed.

As previously discussed, this is not inherently the case with wind generation. Improvements and enhancements in forecasting can help planners and operators better determine how much wind generation will be available at a given point, but forecast errors of 20% to 50% have been observed.

As an added pressure, increasing numbers of states are implementing renewable portfolio standards. This development, coupled with the current version of the federal production tax credit as well as the clean renewable energy bonds, has spurred a tremendous number of wind generation projects that will need to interconnect to the grid.

Transmission planners and system operators are developing creative approaches to address these issues. In addition, power market rules may need to be implemented or modified to accommodate the nondispatchable nature of wind while ensuring fair and competitive market operation.

UWIG has issued the following conclusions:

- Upgrades or additions to transmission facilities may be needed to access locations with large wind-energy potential. Current transmission planning processes are able to identify solutions to transmission problems, but the time required for implementation of solutions often exceeds wind-plant permitting and construction times by several years.

- Well-functioning hour-ahead and day-ahead markets provide the best means of addressing the variability in wind plant output.

- Energy imbalance charges based

on actual costs or market prices provide appropriate incentives for accurate wind forecasting. Since wind plant operators have no control over the wind, penalty charges applied to wind imbalances do not improve system reliability. Market products and tariff instruments should properly allocate actual costs of generation energy imbalance.

- Wind turbine output or ramp rates may need to be curtailed for limited periods of time to meet system reliability requirements economically.

- Consolidation of balancing areas or the use of dynamic scheduling can improve system reliability and reduce the cost of integrating additional wind generation into electric system operation.

#### **Accommodating future wind generation**

As more wind comes online, it is important to understand and quantify the impacts that wind generation can have on electric power system operation and reliability. To do this, it is important to focus on the power system as a whole and the interplay between current as well as future forms of generation, transmission and load.

The North American electric grid is designed to cope with substantial amounts of variability and uncertainty. That said, for wind to continue expanding its role in the nation's generation mix, we need to develop a better understanding of wind plant characteristics, wind plant output forecasting, and wind plant integration techniques to ensure the most efficient and reliable system operation possible.

To that end, UWIG suggests that a number of steps can be taken to improve the ability to integrate increasing amounts of wind capacity on power systems. These include

- improving wind-turbine and wind-plant models;
- improving the operating characteristics of wind plants;
- carefully evaluating wind-integration operating impacts;
- incorporating wind-plant forecasting into utility control-room operations;

*'Power market rules may need to be implemented or modified to accommodate the nondispatchable nature of wind.'*

- making better use of physically (in contrast with contractually) available transmission capacity;
- upgrading and expanding transmission systems;
- developing well-functioning markets and expanding access to them;
- adopting market rules and tariff provisions that are more appropriate to weather-driven resources; and

- consolidating balancing areas into larger entities or accessing a larger resource base through the use of dynamic scheduling.

#### **Conclusion**

The expansion of wind power is at full bore with nameplate capacity increasing not only in the U.S. but also around the world. This underscores the need for improved understanding of the unique characteristics of this energy source and the role that proper power system planning and operation can play in not only addressing its impacts but also enhancing its potential. **SWP**

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