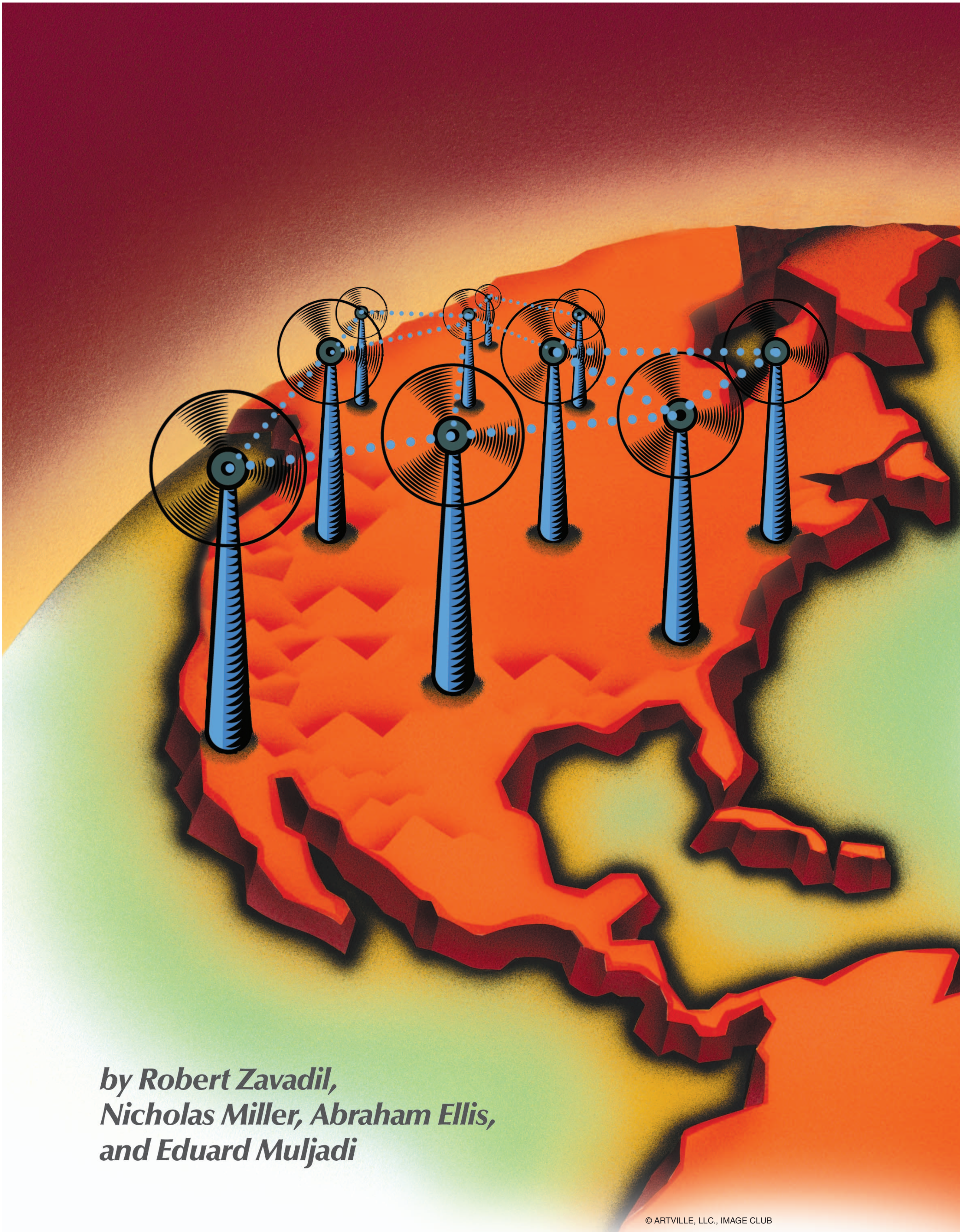

by Robert Zavadil,
Nicholas Miller, Abraham Ellis,
and Eduard Muljadi

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Making Connections

Wind Generation Challenges and Progress

LARGE-SCALE WIND GENERATION FACILITIES HAVE BECOME A VERY visible component of the interconnected power grid in many portions of the United States. Only a decade ago, wind generation facilities were viewed by most power engineers as a novelty, and by simple engineering judgment, it could be safely concluded that the effects of these unique but smaller facilities on system reliability would be negligible. Now, with individual wind generation facilities approaching the output rating of conventional power plants, a deeper understanding of their potential impacts on the interactions with the bulk electric power system is needed.

Designing for Reliability

Large interconnected power networks are among the most complex machines devised by man. As critical infrastructure for modern economies, the requirements for robustness, fault tolerance, and reliable operation are, understandably, very high. Power system engineers must ensure that these requirements are met as the system evolves over time to meet new demands. This challenge and the complexity of the fundamental technical issues have driven the continuous development and improvement of analytical tools and techniques for analyzing power systems. Theories and calculation techniques developed many decades ago have been refined and adapted for a range of computer programs that comprise the toolbox that power system engineers use to ensure that the interconnected power system operates reliably.

Multiple organizations, including transmission owners, load serving entities, and regional transmission organizations, share in the responsibility for maintaining the reliability of the bulk power supply in North America. The interconnected nature of the bulk system demands close coordination and cooperation between these individual entities. The North American Electric Reliability Council (NERC) was formed in response to the blackouts in the northeastern United States in the 1960s to establish policies and standards for ensuring the reliability of the power system. NERC relies on the mutual self-interest of its members to implement and adhere to policies that ultimately govern how the interconnected power systems in the United States and Canada (Figure 1) are designed and operated.

NERC standards and guidelines for system reliability are implemented by the ten regional reliability organizations (RROs) in North America. Because of the substantial diversity of these systems, owing to factors like geographic size and population density and system makeup, implementation of certain NERC policies may not be entirely uniform at the regional level. This practice provides the RROs with the flexibility that is

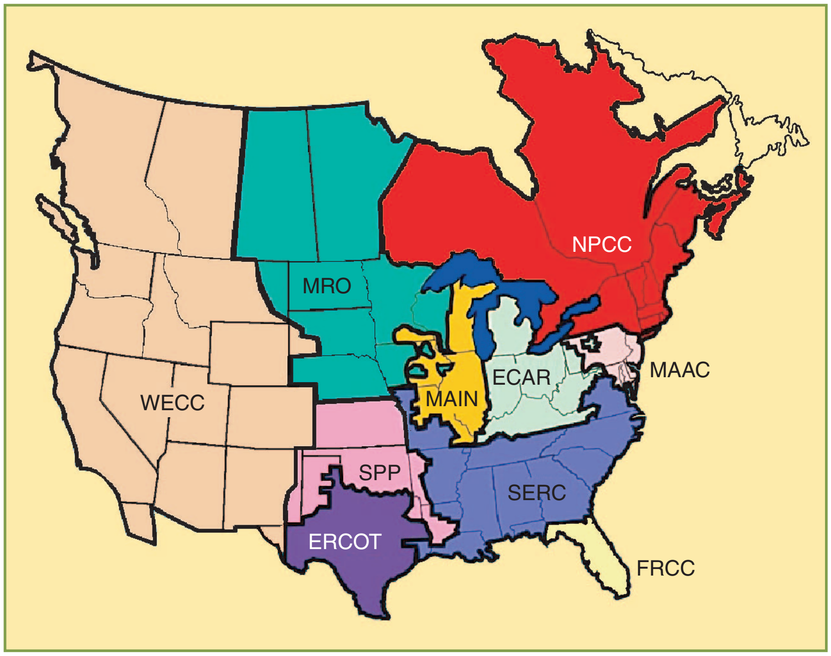

figure 1. NERC footprint and member RROs. (Source: NERC Web site, http://www.nerc.com.)

programs are capable of performing power flow calculations and dynamic simulation of very large power systems. The ability to handle large-scale power systems is made possible by the use of simplified positive-sequence models. RROs, through various subcommittees consisting of member technical representatives, invest substantial amounts of time in developing, validating, and maintaining system models to help ensure consistency in the studies conducted for their respective footprints.

Simulation tools that capture individual phase, point-on-wave phenomena (such as PSCAD/EMTDC and versions of EMTP and other tools such as DigSilent and MATLAB) are used by the power industry for a variety of sophisticated and special studies requiring more detailed representations. The number of users relative to those who perform bulk system studies is quite small. Models for one or both of these platforms, however,

sometimes necessary to achieve the system reliability objectives in the context of their specific system.

Compliance with NERC and RRO reliability standards encompasses a wide range of analytical studies. Of particular interest are the standards that govern the procedures and policies for adding new elements (transmission lines, generators, substations, and auxiliary equipment) to the transmission network. In general, it must be shown for all new equipment connected at transmission network voltage (facilities operating nominally at 115 kV and above, although sometimes voltages below 100 kV are included) that the reliability and performance of the network will not be negatively affected. The analyses from which the conclusions regarding impacts are drawn typically consist of two primary elements:

- ✔ steady-state (power flow) analysis utilizing appropriate base cases that are developed, maintained, and updated by the RRO
- ✔ a stability analysis, to assess the effects of the new facility on the ability of the power system to recover from major disturbances without cascading outage of additional equipment.

These studies might also be used to determine the ability to move large blocks of power from defined sources to defined sinks within the footprint of the RRO or across interfaces to neighboring areas. Transmission planners in North America use one of two computer programs to conduct these studies:

- ✔ PSS/E, from Siemens Power Technologies International
- ✔ PSLF, from GE Energy.

These programs have become the de facto standards for the majority of power system studies in North America. Both

are important since they can be used to address a range of technical questions and issues that fall outside the scope of the simulation packages for large system analysis. In addition, once validated, detailed models are also useful for developing and validating simplified models, as would be the case for the PSS/E or PSLF programs.

A Different Learning Curve

Until only a decade ago, the majority of the wind generation in the United States was located in the prime wind resource areas of California. Power from the potpourri of turbines in the Altamont Pass of northern California was collected and injected into a relatively strong portion of the network, reducing the importance of grid-friendly wind turbine and wind plant features. In the south of California, however, many plants were plagued by voltage problems due to inadequate reactive power supply and a relatively weak transmission network. Even so, the details of the power engineering challenges, problems, and solutions were known to only those who followed the wind industry closely.

Development of significant wind generation facilities outside of California began in the mid-1990s. The engineers of the transmission service providers in Texas and the upper Great Plains—regions that saw the earliest of this round of developments—had no familiarity or experience with the wind generation technology of the time. The nameplate rating of many of these wind plants was large enough to necessitate a formal analytical assessment of their impacts on the existing network.

Early studies of wind generation facility impacts on the bulk network were performed with very coarse models and many simplifying assumptions in lieu of validated representations and significant hands-on experience. Standard induction machine models from the PSS/E or PSLF component libraries were frequently used to represent the wind generation facility, even when more advanced turbines with better attributes for network interconnection were to be used in the prospective project. Where the size of the proposed facility was still small compared to the capability of the network at the interconnection point, no problems were revealed during the studies.

The location of the good wind resource areas relative to the center of electric demand presents a significant challenge for onshore wind generation in North America. With the exception of some developable wind resource areas in the eastern United States, the wind generation facilities usually interconnect with relatively weak regions of the bulk power networks. With the size of individual wind generation projects growing, this creates difficulties both for designing an appropriate interconnection and in securing transmission capacity to move energy to load centers. The availability of good models and characterizations of wind plant operations are key to analyzing and understanding both of these issues.

During this period, the electric power industry also found out that the lead time for designing and constructing a wind generation facility is quite short relative to most conventional generation projects. This has created situations where the development of wind generation in weak areas of the transmission network sometimes outpaces the ability of system planners to secure approval for and construct facilities to bolster the transmission network. Coordination of wind project development with transmission system enhancement can result in delays in project development or, occasionally, temporary operational constraints on wind project operation.

While not a panacea, improved models for wind turbines and wind plants are an important element of the overall solution to the transmission challenges facing wind generation in North America. However, as industry history with modeling conventional generating equipment attests, the process for developing these models and an enhanced understanding of wind generation facilities in the context of power system analysis will likely not be short. This is due to both the complexity of the models and the rapid advances being made in the technology itself.

Wind Plant Modeling Challenges

Models for conventional power system elements, such as generators and their various control systems, are generally well understood by power system analysts. Commercial bulk wind plants contain large numbers (dozens to hundreds) of so-called megawatt-class turbines (1–2+ MW) interconnected by a substantial medium-voltage network. These plants exhibit static and dynamic characteristics that differ fundamentally from that of conventional generators. As a result, wind power plants do not fit the template for models of conventional generating facilities.

The size of the existing network models and the requirements for model maintenance practically limit the complexity of a wind plant model. Some simplification without loss of important detail is necessary. For some applications, such as power flow studies, the wind plant can be treated as a single large generator. In dynamic studies, a single large generator may not represent the full range of dynamic behavior of the wind generation facilities for all types of system disturbances. Because each individual wind turbine is a relatively sophisticated machine and experience with them is quite limited to date, determining the dynamic behavior of the aggregate plant model is far from intuitive.

A subsystem-level block diagram of a generic wind turbine is shown in Figure 2. Most of these elements have counterparts in conventional electric generation systems but differ greatly in their implementation details. The prime mover in wind turbines consists of power extracted from the wind, which is converted to rotational mechanical power via the aerodynamic properties of the turbine blades. Mechanical power is transmitted through a drive train, usually containing a gearbox to match the slow rotational speed of the blades to the much higher speed needed for the electrical generator to produce output at the grid frequency.

The technology employed for electromechanical energy conversion in large commercial wind turbines deviates

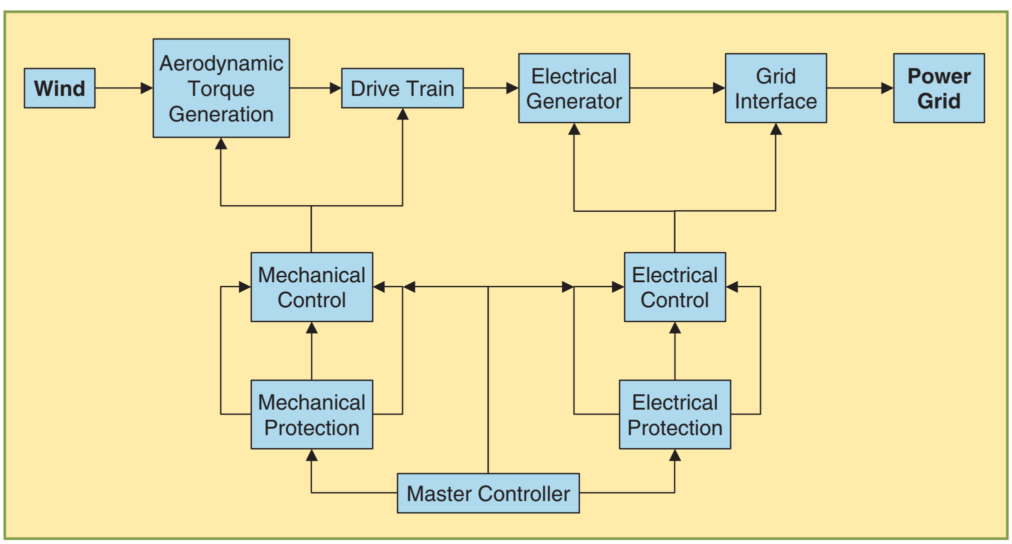

figure 2. Wind turbine generator subsystems.

Wind power plants do not fit the template for models of conventional generating facilities.

from the much better understood conventional generation equipment. Induction machines, rather than synchronous generators, are used in most commercial wind turbines for large plants in North America at the present time. Furthermore, some of the turbine designs employ sophisticated power electronic controllers that alter the fundamental behavior of the induction machines in both steady-state and dynamic operation. Based on electrical topology, commercial wind generators in the 1–2+ MW range can be organized into four categories.

- ✔ *Standard squirrel-cage induction generator connected directly to the grid:* These machines have a gearbox to match the rotational speed of blades with that of the generator. Mechanical power may be regulated through an inherent aerodynamic stall characteristic of blades or with active control of blade pitch.
- ✔ *Wound-rotor induction generator with variable rotor resistance:* These machines have a gearbox for coupling an electrical generator to a turbine hub. They also have pitch control of blades for maximizing energy capture and controlling turbine speed within range of the generator and a small range of variable speed operation (e.g., 10% of generator synchronous speed).
- ✔ *Doubly fed asynchronous generator:* These are essentially wound rotor induction machines with variable frequency excitation of the rotor circuit, incorporating rotor current control via power converter. The rotor circuit power converter may be four-quadrant, allowing independent control of real and reactive flow in either direction (rotor to grid or grid to rotor), or confined to unidirectional (grid to rotor) real power flow. Rotor current control may be based on a field-orientation scheme. These machines have a gearbox for coupling the generator shaft to turbine hub, active control of turbine blade pitch for maximizing production and controlling mechanical speed, and variable speed operation depending on the rating of power converter relative to turbine rating (e.g., ±30% of generator synchronous speed).
- ✔ *Synchronous or induction generator with full-size power converter:* In these machines, the generator is coupled to the grid through a fully rated ac/dc/ac power converter. They also have a gearbox to match generator speed to variable rotational speed of blades and variable speed operation over a wide range, depending on electrical generator characteristics.

For analytical studies of large power systems, the time frames of interest range from tens of milliseconds to steady state. Device and component models, therefore, must accurately reflect behavior over the entire bandwidth. Because the purpose of the models under consideration here is to facilitate the investigation of electrical power system issues, certain details of the mechanical system or energy conversion process may not be represented if they have no impact on electrical performance. In conventional models for large power plants, for example, details of the mechanical system, e.g., combustion process, steam cycle control, and governor, are included only to the extent that they influence the electrical behavior of the plant during the time frames of interest in a particular study.

Emergence of Grid Codes for Wind Generation

The push for codifying requirements and performance standards for large wind generation facilities is a natural and appropriate result of wind generation achieving commercial viability. Formalization of still-evolving interconnection requirements in the United States was in large part initiated by the regulatory process under the auspices of the Federal Energy Regulatory Commission (FERC) of the U.S. federal government. In response to the FERC regulatory process, industry players—including the American Wind Energy Association (AWEA) and Western Electricity Coordinating Council (WECC), one of the ten regional reliability organizations under the NERC umbrella—in conjunction with their stakeholders, are developing proposed interconnection standards and guidelines for wind generation, which have come to be characterized as grid codes. In addition, NERC has begun to play a role from a reliability perspective. An update of the recent and related activities of these players is provided in the following.

FERC

In light of the nonuniformity in interconnection practices of and requirements for new generators, including wind generators, FERC issued Order No. 2003 in July 2003, which proposed a large generator interconnection procedure (LGIP) and a large generator interconnection agreement (LGIA), which would apply to all new generators greater than 20 MW seeking interconnection to the transmission system. This order made no distinction between plants using conventional synchronous generators or those using variable speed machines with power electronic converters, such as those employed by many wind turbine manufacturers. Following a stakeholder comment period, FERC issued a revised Order No. 2003A in March 2004. Recognizing the differences in technology and how they affected the interconnection requirements, FERC provided an opportunity for the wind industry to propose modifications to the standard requirements to recognize the unique concerns of wind plant developers through an Appendix G. A final rule on Appendix G, Order No. 661, was issued by FERC on 5 July 2005.

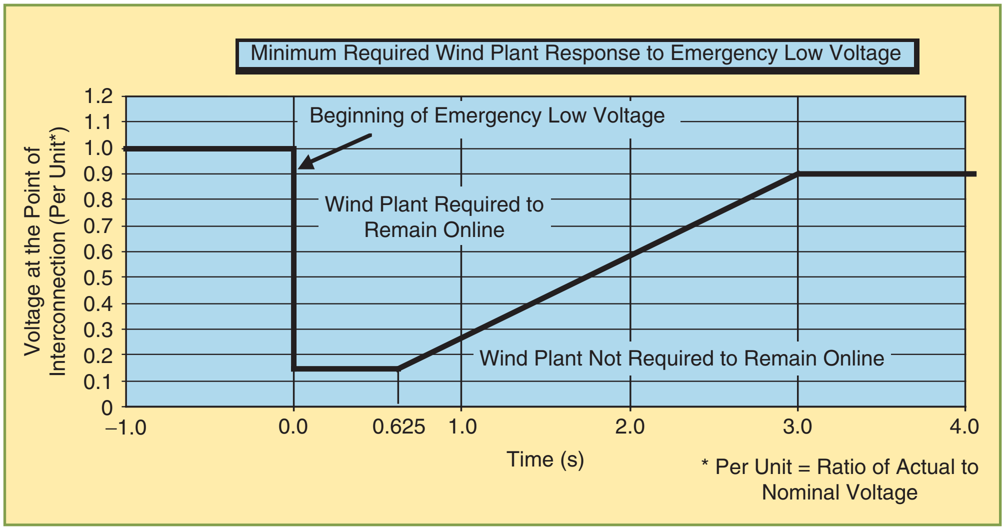

figure 3. LVRT requirement for wind generation facilities per FERC Order No. 661.

AWEA

The AWEA initiated an activity referred to as the *grid code* to propose language for Appendix G to recognize the unique requirements and characteristics of the wind power plants. This activity resulted in AWEA filing a petition in May 2004 for rulemaking at FERC related to Appendix G. The petition covered a number of issues, including four major technical areas of concern:

- ✔ *Low voltage ride-through (LVRT) capability for wind plants and wind turbines:* AWEA recommended adoption of an LVRT requirement developed by E.ON Netz (Figure 3), if required, on a case-by-case basis. E.ON Netz is a German grid operator faced with a significant and growing penetration of asynchronous wind generation capacity on the German grid. The E.ON Netz standard requires that the machine stay connected for voltages at the terminals as low as 15% of nominal per unit for approximately 0.6 s.
- ✔ *Supervisory control and data acquisition (SCADA) equipment for remote control:* AWEA recommended the requirement of equipment to enable remote command and control for the limitation of maximum plant output during system emergency and system contingency events and telemetry equipment to accommodate reliable scheduling and forecasting information exchange.
- ✔ *Reactive power capability:* AWEA recommended that wind plants connected to the transmission system be capable of operating over a power factor range of ±0.95.
- ✔ *Current wind turbine simulation models:* AWEA recommended that transmission providers and wind turbine manufacturers participate in a formal process for developing, updating, and improving engineering models and turbine specifications used for modeling the wind plant interconnection.

FERC responded by holding a technical conference in the fall of 2004 to solicit industry input on the proposal. Order No. 661, issued by FERC in early summer 2005, adopts an LVRT requirement for wind generation, as shown in Figure 3, along with a wind plant power factor range of ±0.95. With respect to both of these requirements, however, the burden is placed on the transmission provider to prove they are necessary for system reliability.

WECC

WECC initiated its own operating standards and guidelines on this question. The initial proposal would have required all generating units in the WECC footprint to remain connected to the system during three-phase faults with normal clearing and single-line-to-ground faults with delayed clearing and to tolerate the postfault transient characteristic specified in WECC Table W-1. Generator disconnection as part of a special protection scheme was permitted. Generators of less than 10-MVA capacity were exempt from this requirement, unless a proven reliability concern existed. An important distinction between this and the standard proposed by AWEA is that applicability is universal and not on a case-by-case basis. After continued discussion of various versions of this requirement, WECC issued a standard in the spring of 2005 for wind plant LVRT, as shown in Figure 4.

NERC

In early 2005, NERC established a wind generation task force to

- ✔ address the planning and reliability issues associated with wind turbine generators connected to the bulk electric power system

- ✔ determine the need for any new or revised NERC reliability standards
- ✔ develop appropriate standard authorization requests for consideration by the standards authorization committee, using the NERC standards development process.

The initial item of business for the task force consisted of assembling comments in response to the ongoing FERC deliberations concerning interconnection requirements for wind generators. While NERC was generally supportive of the requirements being proposed as Appendix G at that time in the FERC proceeding, there was concern over whether the FERC process was the appropriate venue for addressing power system reliability issues. In addition, concern was expressed over certain details of both the LVRT and power factor requirements. Subsequent to the issuance of FERC Order No. 661, NERC has filed a request for rehearing on the following two aspects of the ruling:

- ✔ the LVRT requirement in Order No. 661 (Figure 3), which in NERC's view should be modified to require that wind plants, like other generating facilities, be required to ride through a "normally cleared single line to ground or three-phase fault on a transmission line connected to the (wind) plant switchyard or substation." This would have the effect that a wind plant be able to stay connected to the grid if the voltage at the high side of the substation transformer were reduced to zero for a period up to about 0.15 s.
- ✔ placing the burden of proof for LVRT and reactive requirements on the transmission provider. NERC asserts that "[s]hifting the burden to transmission providers of justifying on a case-by-case basis what most regard as good utility practice is unwise."

NERC and AWEA were ordered by FERC to convene a committee to resolve the issues associated with Order No. 661. As this article goes to press, representatives from the respective organizations are meeting to produce a joint filing with alternate requirements and language that meets the needs of both groups.

Grid Codes for Wind Generation in North America—Status

In the last two years, there has been a flurry of activity in North America. As of the date of this publication, it is clear that the final discussions of interconnection requirements and standards for bulk wind generation are yet to come and may actually be some years into the future. As the previous discussion shows, there is still no consensus on certain technical performance requirements among the various jurisdictional bodies that hold sway on process and reliability requirements for the power industry in the United States. Discussions related to this recent activity, however, have assisted greatly in identifying the key technical issues and provoking communications and coordination between the stakeholder groups. There are some indications of slowly developing consensus, although the final outcome is still difficult to predict. More importantly, the wind industry has been quietly and steadily developing technical solutions to address the concerns of the power industry.

Summary: Recent Progress and Status

Against this sometimes hard to follow backdrop, engineers in the electric power and wind industries are making some progress on technical issues and questions related to the interconnection of large wind generation facilities to the transmission system. As previously noted, there is much to do in a relatively short time period given the rapid growth of the wind generation industry and the increasing concerns in certain regions of the United States and Canada regarding possible impacts on the bulk transmission system.

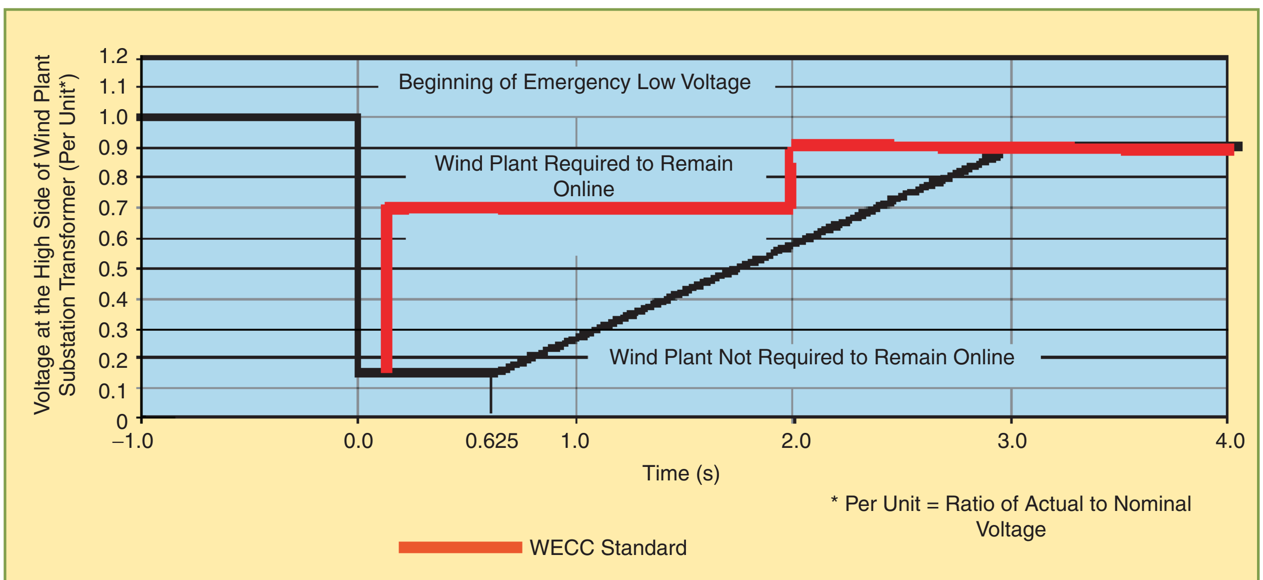

figure 4. The WECC LVRT standard as presented at the California Energy Commission hearing on 10 May 2005.

There is still no consensus on certain technical performance requirements among various jurisdictional bodies on process and reliability requirements for the power industry in the United States.

Development of the first technology-specific dynamic models of commercial wind turbine technologies for use in power system planning was a key first step in the recent progress. Because of the uniqueness of wind generation technology, an initial understanding of how wind turbines would respond to grid disturbances was gained from detailed transient models developed in close cooperation with wind turbine manufacturers. Important details of the electromechanical energy conversion system and related controls were identified and used to construct the reduced-order representations necessary for power system planning tools. Since little measurement data from operating turbines is available, results from simulations with the transient models were used to provide some analytical validation of the planning models. Figure 5 provides an illustration.

The initial set of dynamic models provided transmission planners and engineers with information critical for assessing network impacts of specific wind generation facilities. The pace of technical development in wind turbine technology, however, has been a challenge for those who develop and maintain such models. Comprehensive validation of the models through rigorous field or laboratory testing is also generally lacking.

The value of appropriate models for wind generation interconnection studies has already been demonstrated in practice (see "New Mexico Wind Energy Center Case Study"). Several large wind generating facilities have been designed to operate successfully in regions of the United States where the transmission network is exceptionally weak. Good models of wind turbine technology allowed the project engineers to thoroughly quantify the technical problems associated with the weak grid and unique characteristics of wind generation and to design solutions to these problems before actual construction of the plants.

Industry stakeholders are also organizing to address some of the overarching analytical questions related to modeling wind generation in power system studies. The National Renewable Energy Laboratory (NREL), for example, is addressing fundamental questions about how wind generation facilities should be modeled for power system studies. An objective of this work is to develop various models of varying levels of detail and sophistication for existing wind generation facilities and to compare their performance in the types of studies critical for assessing the viability of wind plant interconnections and power system reliability. Figures 6 and 7 are examples of the transient response of a wind farm to an eight-cycle, three-phase fault on the grid. In Figure 6, the impact of grid stiffness on the wind farm output response is shown. Figure 7 is used to illustrate the simulation of a very large wind farm represented as groups of wind turbines with

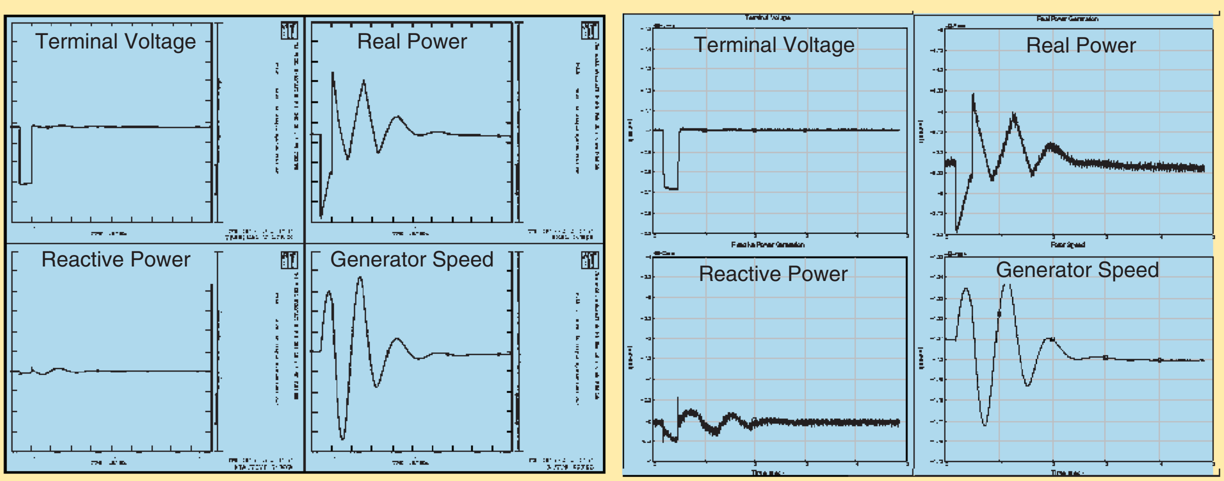

figure 5. A comparison of wind turbine dynamic response in two simulation platforms.

unique characteristics. It is assumed that each group of wind turbines is located at a significant distance with respect to each other, thus the local wind speeds are different from each other. The line impedance between each group and the point of common coupling is assumed to be different, and the number of wind turbines in each group is assumed to be different as well. When a fault occurs, each group presents its own unique response to the power system network. Instability in one group of turbines in the wind farm does not necessarily reflect instability of the entire wind farm. Thus, a very large wind farm has its own advantage compared to a single large conventional generator of the same size (that is, a fault event may drop some of the turbines but not necessarily the entire wind farm).

Field measurements currently are being undertaken in many different wind farms. These monitoring efforts will be useful to validate the models and support the research findings.

New Mexico Wind Energy Center Case Study

Public Service Company of New Mexico (PNM) is an investor-owned utility headquartered in Albuquerque, New Mexico, providing retail electric service to more than 400,000 retail residential customers. PNM is also a FERC jurisdictional transmission service provider and a NERC certified control area operator. The majority of PNM's transmission system is located in the northern half of New Mexico, near the southeast corner of the WECC interconnected system.

In 2003, PNM interconnected a 204-MW wind generation facility to its transmission system. The New Mexico Wind Energy Center (NMWEC), as it is known today, consists of 136 General Electric 1.5-MW wind turbine generators, arranged generally north to south along the edge of a plateau in eastern New Mexico. Figure A shows the location of the NMWEC relative to the rest of the transmission system in New Mexico.

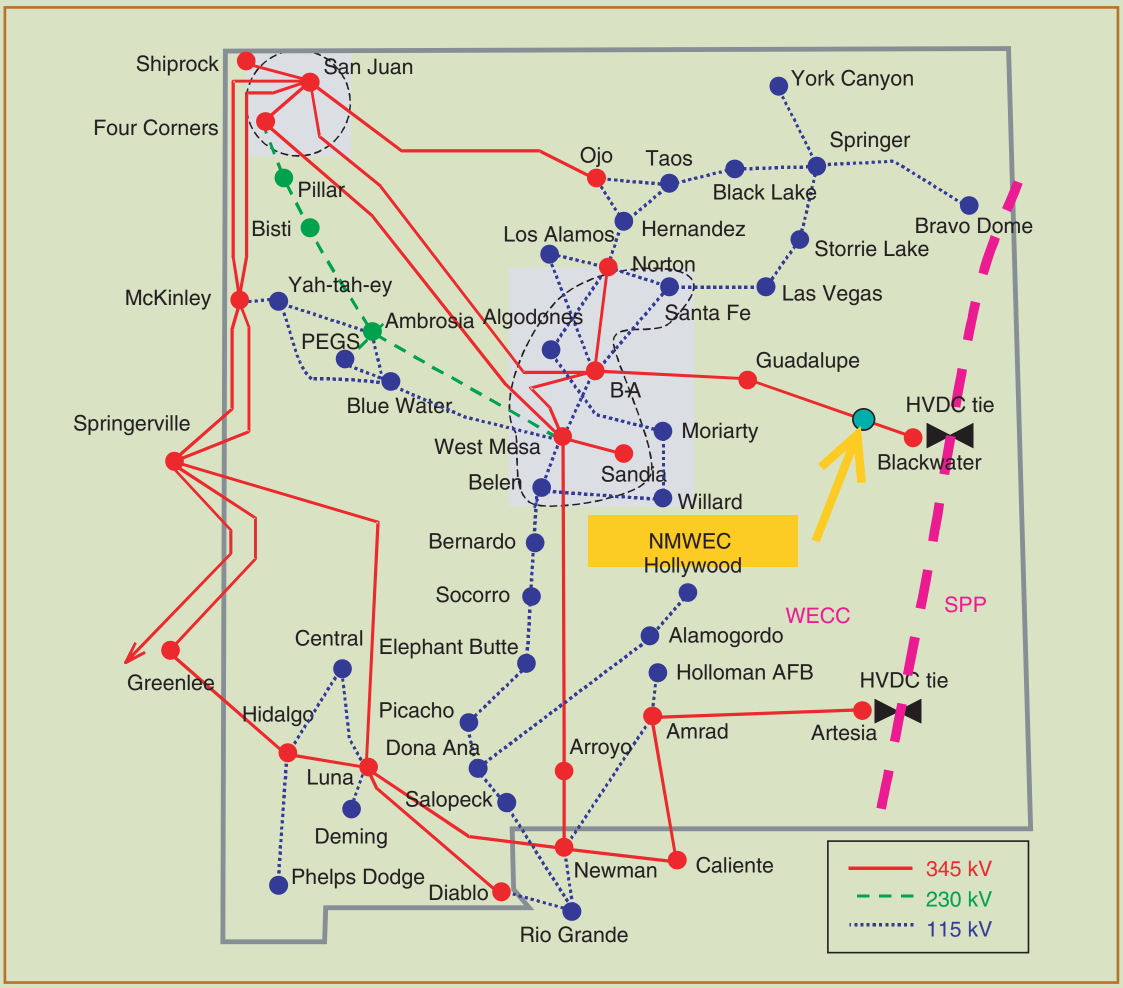

Figure A. Location of New Mexico Wind Energy Center in PNM system.

The Utility Wind Interest Group (UWIG) is also taking on some issues related to this topic. Because of the representation of a wide range of power and wind industry stakeholders in its active membership, it is positioned to address some of the most urgent questions and needs related to wind generation and power system modeling needs.

The IEEE Power Engineering Society (PES) is taking formal steps to apply its resources and expertise to the challenges as well. In 2004, a Dynamic Performance of Wind Generation Task Force was established under the Power System Dynamics Committee to address the complex issues associated with the behavior of power systems with significant wind generation under nonsteady conditions. In 2005, a Wind Power Coordinating Committee under the IEEE PES Technical Council was formed to provide a focal point within the organization for all technical activities related to wind

The location of the project with respect to PNM load centers and the exposed nature of the radial extra-high voltage (EHV) connection, in combination with the size of the wind generation facility relative to the peak load of the PNM control area (approximately 2,000 MW) raised some important system reliability concerns in the initial engineering evaluations. In response, PNM engineers, in conjunction with the project developer and the turbine vendor, worked collaboratively to address technical concerns in three areas during the design of the interconnection.

- ✔ *Electrical grid fault tolerance:* Dynamic simulations showed that single-line-to-ground and three-phase faults on PNM's 345-kV system, or three-phase faults on the 115-kV network external to the BA—Blackwater line, would result in voltages below the standard undervoltage trip setting for the wind generators. In this particular application, tolerance to transmission faults was a very important consideration based on the fact that system performance would be unacceptable if, in addition to a line outage, the wind farm output were lost concurrently as a result of a remote fault. In addition, considering that several other wind generation projects had been proposed in the same area, the loss of large amounts of wind generation due to system faults has significant implications on control area operations. At that point in time, existing NERC and WECC reliability criteria did not specifically address generator fault tolerance for wind generators. To maintain system reliability, PNM formulated a fault tolerance standard that could be applied in a uniform and nondiscriminatory fashion to the NMWEC as well as future generation projects seeking to connect to the BA—Blackwater 345-kV line. PNM's fault tolerance standard required all generators interconnected on the BA—Blackwater 345-kV transmission line to tolerate normally cleared 345-kV single-line-to-ground and 115-kV three-phase faults (12 and five cycles, respectively) at BA station (see Figure A). The NMWEC was one of the earliest applications in North America to feature enhanced fault tolerance based on an interconnection requirement.
- ✔ *Voltage control and reactive power capability:* The BA—Blackwater line voltage profile is difficult to control due to the length of the line (223 mi) and its radial nature. Interconnection studies indicated that dynamic reactive power capability would be needed to maintain an acceptable voltage profile on the line, taking into consideration the expected high variability of wind output. The wind generators proposed for this project (doubly fed induction generators) had the ability to control power factor at their terminals within a nominal range of 0.95 leading to 0.90 lagging. For this application, a supervisory control system was implemented to allow the wind farm to effectively control voltage at the 345-kV level by continuously adjusting power factor of the individual wind generators. Due to the effects of the collector system and individual generator equipment limitations (temperature and terminal voltage), the effective reactive power range that can be expected at the 345-kV level differs considerably from the nominal range. This range was determined through direct testing after the NMWEC was commissioned.
- ✔ *Control interaction:* Since the NMWEC had the ability to control the 345-kV voltage, studies were conducted to ensure there were no control interactions with the existing Blackwater high-voltage direct current (HVDC) converter. An evaluation of various switching and fault events using a detailed three-phase model identified settings for the wind farm voltage controller that would minimize control interactions with the HVDC converter.

Refined models for the wind farm and HVDC converter were used to capture the special network conditions in the vicinity of the project. At the time the interconnection studies were conducted, planning models for the HVDC converter and wind farm were relatively new and had not been fully validated. The technical challenges were overcome by close collaboration among PNM, the project developer, and the wind turbine manufacturer. This technical collaboration continued even after the project was installed. Several staged tests have been performed, and several disturbance events have been analyzed, which have resulted in material enhancements to planning models as well as operating performance. As a result, transmission operating experience with the NMWEC has been exemplary.

generation. With these two developments, the IEEE PES contribution to the current technical challenges facing wind generation will be accelerated.

The WECC is also continuing its efforts in this area. A new task force has been formed to address the longer-term needs for wind plant modeling. While the numerous available dynamic models for the current fleet of commercial wind turbines is adequate for evaluating prospective new wind generation facilities, there remain issues related to the complexity and maintainability of these models. As wind generation facilities are commissioned, for instance, a suitable representation must be added to the base case models that will underpin future network studies. There is concern that the current models may be too complex to facilitate that critical process.

Finally, it should be recognized that the issues confronting transmission providers and wind generation developers are not unique to North America. Organizations around the globe are making substantial investments to move the power industry up the learning curve in this area. In some countries, further growth of the wind industry is contingent upon settling questions related to wind generation impacts on the power system and the availability of appropriate analytical tools and models for making these assessments. ESB National Grid (ESBNG), for example, established formal requirements for wind turbine models to be used in system studies along with a process for certifying such models as part of their grid codes. The status of models for commercial turbine types is shown in Table 1.

As wind generation grows globally, continued and enhanced coordination between the numerous entities now engaged in developing what is actually a new chapter in power engineering practice will help to keep both the wind industry moving forward and the lights on.

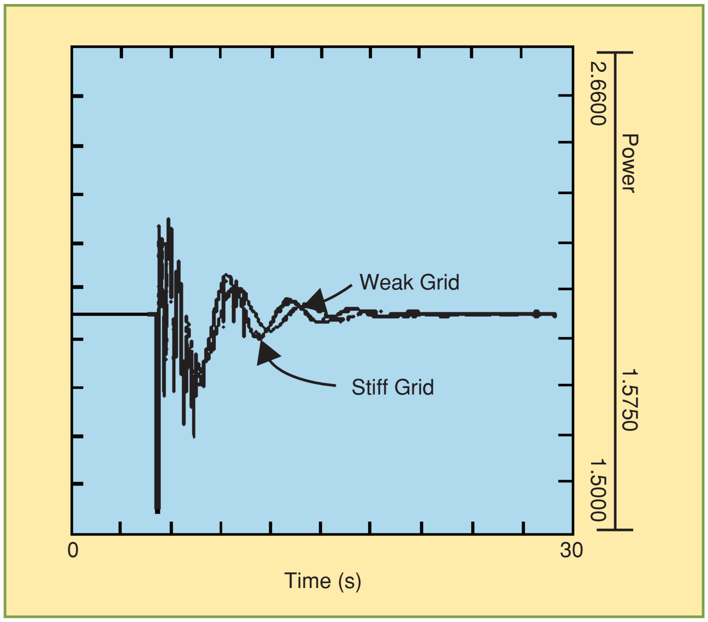

figure 6. A simulated response of a wind plant to a network short circuit.

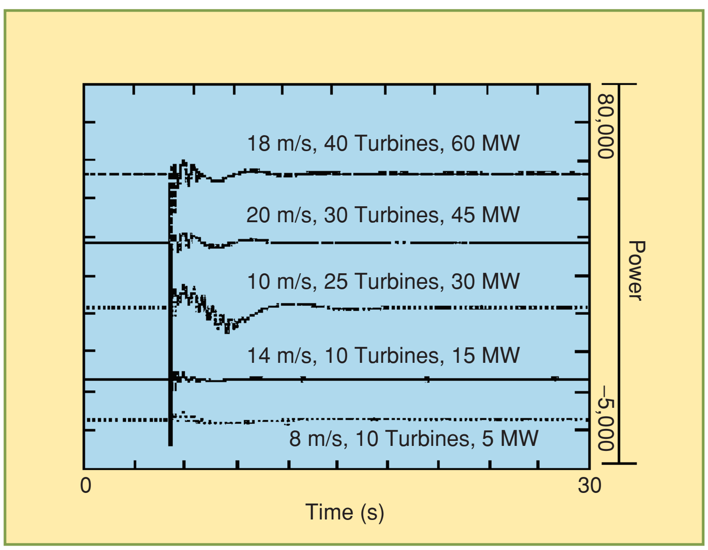

figure 7. The results from an investigation of the effects of turbine aggregation (equivalencing) and operating conditions on the dynamic response of a wind plant containing 115 individual turbines.

For Further Reading

Much of the current activity regarding grid codes for wind generation in the United States is being documented as the discussion and debate continues. Readers may go to Web sites of the respective stakeholders in this discussion to get some perspective on specific details.

FERC, "Interconnection for Wind Energy," Docket No. RM05-4-00, Order No. 661, Final Rule [Online]. Available: http://www.ferc.gov

NERC, "NERC filings with FERC" [Online]. Available: http://www.nerc.com

AWEA Web site [Online]. Available: http//www.awea.org

Biographies

Robert Zavadil received a B.S.E.E. degree, with highest honors, from South Dakota State University in 1982. He is a cofounder of EnerNex Corporation, where he is responsible for developing and overseeing the company's power system engineering consulting business. He has worked on electric power system issues for wind generation for more than 15 years. From 1989 to the summer of 2003, he served in various consulting and product development capacities for Electrotek Concepts and its parent company, WPT. He began his career in the electric power industry in 1982 as a special studies

table 1. ESBI assessment of wind turbine model status.

	WTG Manufacturer	WTG Specific Model	Model Version (As Indicated by Manufacturer)	Grid Code Complaint (Validation Aside)
1	Bonus	1.3 MW	Ver_04	Being tested by ESBNG and may require model tuning for each wind farm connection
2		2.3	Ver_04	
3	DeWind	D5 1.25 MW	V1.2	✓
4		D8 2 MW	V1.2	✓
5	Enercon	E40/6.44 600 kW	V5.1 (wec + wfc)	✓
6		E66/20.7 2.0 MW	V5.1 (wec + wfc)	✓
7		E70/E4 2 MW	V5.1 (wec + wfc)	✓
8		E48 0.8 MW	V5.1 (wec + wfc)	ESBNG testing
9	Garmesa	G8X 2 MW	V5.2	✓
10		G5X (G52 & G58) 0.85 MW	V5.2	ESBNG testing
11	GE	1.5 MW	1.0.0	✓
12		3.6 MW	1.0.0	✓
13	NBG MICON	NM - 72 1.65 MW	1	✓
14		NM - 82 1.65 MW	1	✓
15	Nordex	N80 2.5 MW	Alpha V1.0	ESBNG testing
16	Vestas	V47 0.66 MW	rev 1.0.0	✓
17		V52 0.85 MW	rev 4	Limitation exists in models
18		V66 1.75 MW	rev 4	
19		V80 2 MW	rev 4.1	
20		V90 3 MW	rev 4	

Source: "Dynamic Modeling of Wind Generation in Ireland," http://www.eirgrid.com/EirGridPortal/uploads/Publications/Dynamic%20Wind%20Generation.pdf

engineer in the transmission and distribution engineering division of the Nebraska Public Power District. He is a Member of the IEEE Power Engineering, Power Electronics, and Industrial Applications Societies and serves as secretary of the Wind Power Coordinating Committee under the IEEE-PES Technical Council

Nicholas Miller received a B.S. and M.E. in electric power engineering from Rensselaer Polytechnic Institute, Troy, New York. He is a director for GE Energy Consulting. Recently, he has been extensively involved in development of technical understanding and methods for the application of distributed generation, including microturbines and fuel cells. He is currently leading analytical developments for integration of GE wind turbine generators into power systems. He is a Fellow of the IEEE and a member of CIGRÉ. He is a member of the IEEE Power System Dynamic Performance Committee and chairs the new (2004) Dynamic Performance of Wind Generation Task Force. Nicholas is a licensed professional engineer in the state of New York.

Abraham Ellis received his Ph.D. in electrical engineering from New Mexico State University (NMSU) in 2000. He currently is with the transmission development and contracts department at Public Service Company of New Mexico (PNM), where he works on a wide range of projects related to power system performance analysis, standards development, and regulatory matters. Before joining PNM, he worked at NMSU's Southwest Technology Development Institute in the area of renewable energy applications. Currently, he serves as chair of Western Electricity Coordinating Council's Modeling and Validation Work Group and is a registered professional engineer in the state of New Mexico. He is a Member of the IEEE.

Eduard Muljadi received his Ph.D. in electrical engineering from the University of Wisconsin, Madison. From 1988–1992, he taught at California State University, Fresno, California. In June 1992, he joined the National Renewable Energy Laboratory in Golden, Colorado. His current research interests are in the fields of electric machines, power electronics, and power systems in general, with an emphasis on renewable energy applications. He is member of Eta Kappa Nu, Sigma Xi, and a Senior Member of the IEEE. He is involved in the activities of the IEEE Industry Application Society (IAS) and Power Engineering Society (PES). He is currently a member of the Industrial Drives Committee, Electric Machines Committee, and Industrial Power Converter Committee of the IAS and a member of the Working Group on Renewable Technologies and the Dynamic Performance of Wind Generation Task Force of the PES. He holds two patents in power conversion for renewable energy.