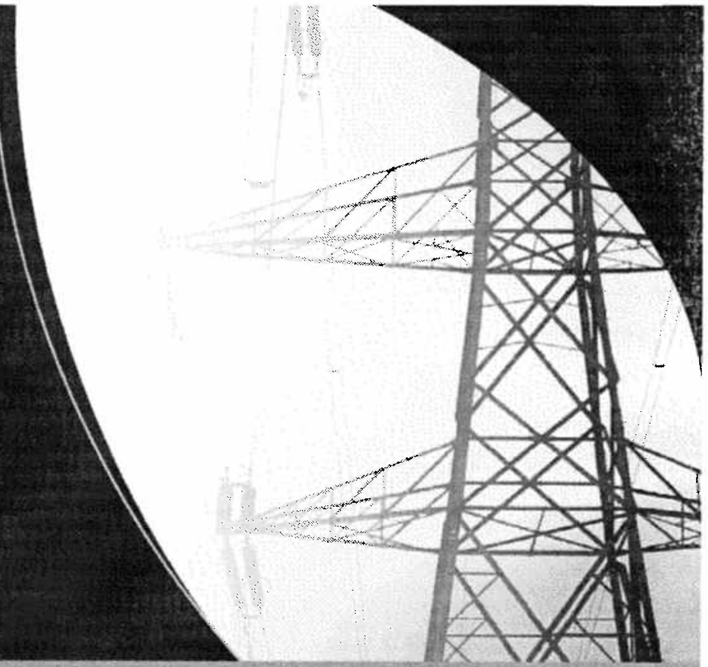

NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Special Report:

Accommodating High Levels of Variable Generation

April 2009

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Executive Summary

Reliably integrating high levels of variable resources — wind, solar, ocean, and some forms of hydro — into the North American bulk power system will require significant changes to traditional methods used for system planning and operation. This report builds on current experience with variable resources to recommend enhanced practices, study and coordination efforts needed to lay the foundation for this important integration effort.

According to NERC's 2008 Long-Term Reliability Assessment, over 145,000 MW of new variable resources are projected to be added to the North American bulk power system in the next decade. Even if only half of this capacity comes into service, it will represent a 350% increase in variable resources over what existed in 2008. Driven in large part by new policies and environmental priorities, this growth will represent one of the largest new resource integration efforts in the history of the electric industry.

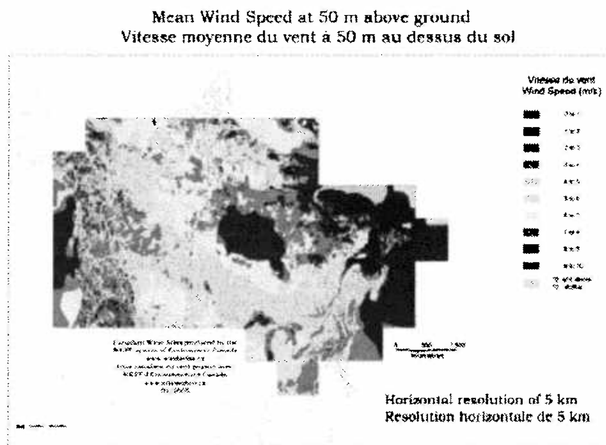

Figure A: Wind Availability in Canada

Today, the bulk power system is designed to meet customer demand in real time – meaning that supply and demand must be constantly and precisely balanced. As electricity itself cannot presently be stored on a large scale, changes in customer demand throughout the day and over the seasons are met by controlling conventional generation, using stored fuels to fire generation plants when needed.

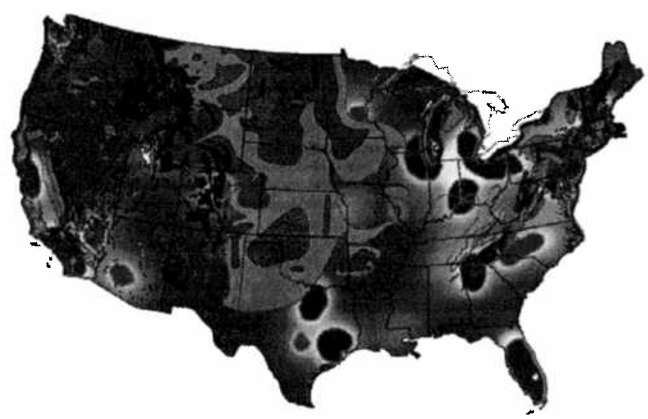

Figure B: Wind Availability and Demand Centers in the U.S.

Blue - high wind potential,
Brown - large demand centers, and
Green - little wind and smaller demand centers.

Variable resources differ from conventional and fossil-fired resources in a fundamental way: their fuel source (wind, sunlight, and moving water) cannot presently be controlled or stored. Unlike coal or natural gas, which can be extracted from the earth, delivered to plants thousands of miles away, and stockpiled for use when needed, variable fuels must be used when and where they are available.

Fuel availability for variable resources often does not positively correlate with electricity demand, either in terms of time of use/availability or geographic location. As shown in Figure B, for example, only seven percent of the U.S. population inhabits the top ten states for wind potential. Additionally, peak availability of wind power, the most abundant variable resource in terms of megawatt value today, can often occur during periods of relatively low customer demand for electricity.

Further, the output of variable resources is characterized by steep "ramps" as opposed to the controlled, gradual "ramp" up or down generally experienced with electricity demand and the output of traditional generation. Managing these ramps can be challenging for system operators, particularly if "down" ramps occur as demand increases and vice versa. Insufficient ramping and dispatchable capability on the remainder of the bulk power system can exacerbate these challenges.

As the electric industry seeks to reliably integrate large amounts of variable generation into the bulk power system, considerable effort will be needed to accommodate and effectively manage these unique operating and planning characteristics. Recommendations included in this report highlight the following areas for further study, coordination, and consideration:

> **Deploying different types of variable resources** (such as solar and wind generation) to take advantage of complementary patterns of production, **locating variable resources across a large geographical region** to leverage any fuel diversity that may exist, and **advanced control technology** designed to address ramping, supply surplus conditions, and voltage control show significant promise in managing variable generation characteristics. As recommended in the report, NERC will develop a reference manual to educate and guide the electric industry as the integration of large-scale variable resources continues. The electric industry is also encouraged to consider developing consistent interconnection standards to ensure that voltage and frequency ride-through capability, reactive/real power control, and frequency and inertial response requirements are applied in a consistent manner to all generation technologies.
>
> High levels of variable generation will require **significant transmission additions and reinforcements** to move wind, solar, and ocean power from their source points to demand centers and provide other needed reliability services, such as greater access to ramping and ancillary services. Policy makers and government entities are encouraged to work together to remove obstacles to transmission development, accelerate siting, and approve needed permits.

Additional flexible resources, such as demand response, plug-in hybrid electric vehicles, and storage capacity, e.g. compressed air energy storage (CAES), may help to balance the steep ramps associated with variable generation. These resources allow grid operators to quickly respond to changes in variable generation output without placing undue strain on the power system. Additional sources of system flexibility include improved characteristics for conventional generators, the operation of structured markets, shorter scheduling intervals, gas and energy storage, and reservoir and pumped-hydro systems. The electric industry is encouraged to pursue research and development in these areas and integrate needed flexibility requirements in power system planning, design, and operations.

Enhanced measurement and forecasting of variable generation output is needed to ensure bulk power system reliability, in both the real-time operating and long-term planning horizons. Significant progress has been made in this field over the past decade, though considerations for each balancing authority will differ. Forecasting techniques must be incorporated into real-time operating practices as well as day-to-day operational planning, and consistent and accurate assessment of variable generation availability to serve peak demand is needed in longer-term system planning. High-quality data is needed in all of these areas and must be integrated into existing practices and software. The electric industry is also encouraged to pursue research and development in these areas.

More comprehensive planning approaches, from the distribution system through to the bulk power system, are needed, including probabilistic approaches at the bulk system level. This is particularly important with the increased penetration of distributed variable generation, like local wind plants and rooftop solar panels, on distribution systems. In aggregate, distributed variable generators can impact the bulk power system and need to be treated, where appropriate, in a similar manner to transmission-connected variable generation. The issues of note include forecasting, restoration, voltage ride-through, safety, reactive power, observability, and controllability. Standard, non-confidential and non-proprietary power flow and stability models are needed to support improved planning efforts and appropriately account for new variable resources. Variable generation manufacturers are encouraged to support the development of these models.

Greater access to larger pools of available generation and demand may also be important to the reliable integration of large-scale variable generation. As the level of variable generation increases within a Balancing Area, the resulting variability may not be manageable with the existing conventional generation resources within an individual Balancing Area alone. Base load generation may need to be frequently cycled in response to these conditions, posing reliability concerns as well as economic consequences. If there is sufficient transmission, this situation can be managed by using flexible resources from a larger generation base, such as through participation in wider-area balancing arrangements or consolidation of Balancing Authorities. These efforts may also help to address minimum load requirements of conventional generation and contribute to the effective use of off-peak, energy-limited resources.

The electric industry in North America is on the brink of one of the most dynamic periods in its history. The ongoing efforts brought together by this report have the potential to fundamentally change the way the system is planned, operated, and used – from the grid operator to the average residential customer. Maintaining the reliability of the bulk power system during this transition will be a critical measure of success as these efforts progress.