

NERC

NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Reliability Issues White Paper

Accommodating High Levels of Variable Generation

to ensure
the reliability of the
bulk power system

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Introduction

NERC's Mission

The North American Electric Reliability Corporation's (NERC) mission is to ensure the bulk power system in North America is reliable. To achieve this objective, NERC develops and enforces reliability standards; monitors the bulk power system; assesses and reports on future adequacy; evaluates owners, operators, and users for reliability preparedness; and offers education and certification programs to industry personnel. NERC is a non-profit, self-regulatory organization that relies on the diverse and collective expertise of industry participants that form its various committees and sub-committees. It is subject to oversight by governmental authorities in Canada and the United States (U.S.)

NERC assesses and reports on the reliability and adequacy of the North American bulk power system divided into the eight regional areas. The users, owners, and operators of the bulk power system within these areas account for virtually all the electricity supplied in the U.S., Canada and a portion of Baja California, Mexico.

As of June 18, 2007, the U.S. Federal Energy Regulatory Commission (FERC) granted NERC the legal authority to enforce reliability standards with all U.S. owners, operators, and users of the bulk power system, and made compliance with those standards mandatory, as opposed to voluntary. NERC has similar authority in Ontario and New Brunswick, and is seeking to extend that authority to the other Canadian provinces. NERC will seek recognition in Mexico once the necessary legislation is adopted.

The North American bulk power system is regulated by a variety of approaches and resource acquisition approaches vary widely. This white paper does not address market, regulatory or policy issues and is neutral to the market environment that the variable generation interconnects.

Background

Almost 50 percent of North American generation relies on fossil-fuels such as coal, oil, and natural gas. Fossil fuels are *nonrenewable*, that is, they draw on finite resources. In contrast, *renewable energy* resources — such as wind, solar, bio-fuels, biomass, hydro, etc. can be replenished at a generally predictable rate.

Regulations on Green House Gas emissions, notably CO₂, are being promulgated by individual states and provinces throughout the U.S. and Canada. Under mandates in over 25 states, clean energy, such as wind, solar and biomass, must be up to 30% of a utility's energy portfolio in five to 15 years. In 2003, just ten states had such requirements.

As states and provinces begin adopting varying approaches to green-house gas emission regulation, the prospect grows that both federal governments will become more engaged and

nation-wide legislation result. Variable generation, mostly from wind plants, is expanding 30% a year.¹ With the potential for federal CO₂ legislation increasing, the trend toward renewable resources is expected to continue and increase as some states have mandated Renewable Portfolio Standards (RPS). This proposed level of commitment to renewables offers benefits (new generation resources, fuel diversification, greenhouse gas reductions), as well as bulk power system planning and operational challenges. Bulk power system reliability must be ensured with large scale integration of variable generation.

Goals of White Paper

A significant change in resource mix can affect bulk power system reliability. To accommodate a shift in resource allocation, the bulk power system will require changes in system design, operating margins and ancillary service requirements to maintain reliability. The goals of this white paper are to:

- Raise industry awareness/understanding of characteristics of variable generation
- Raise industry awareness/understanding of the challenges associated with large scale integration of variable generation
- Investigate impacts on traditional approaches used by system planners and operators to plan, design and operate the power system.
- In light of large scale integration of variable resource, scan NERC Standards, FERC rules and business practices to identify possible gaps and future requirements to ensure bulk power system reliability

Guiding Principles

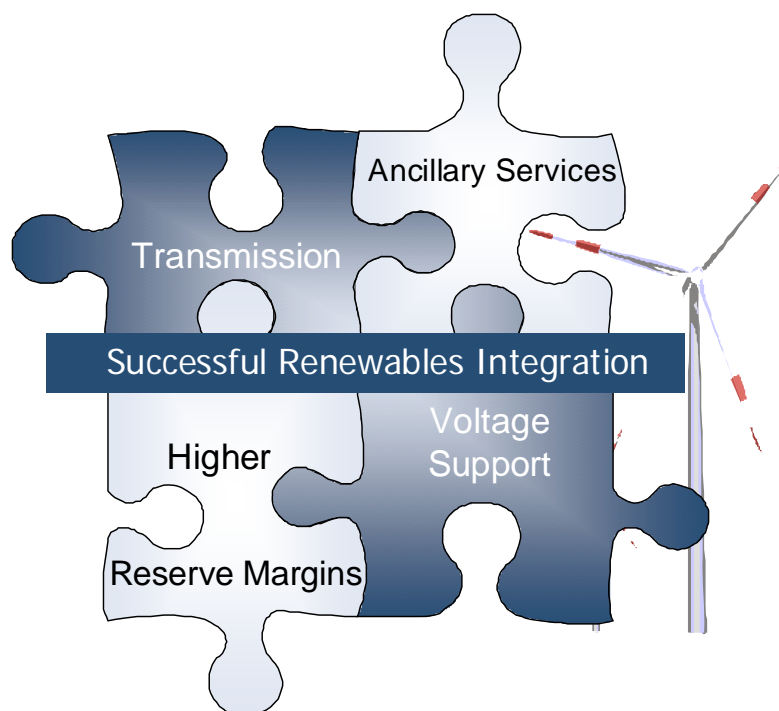
Throughout the white paper, it is vital to frame the discussion within NERC's mission. The guiding principles are:

1. Bulk power system reliability must be maintained, regardless of the variable and traditional generation mix
2. All generation must contribute to overall bulk power system reliability
3. Standards and criteria established must be fair, transparent and performance-based
4. Planners and operators must have a complete understanding of the challenges presented by large scale integration of wind and other variable generation into existing bulk power systems
5. Wind and other variable generation must effectively integrate into planning and operations practices to ensure reliability of the bulk power system
6. Technology developments used to improve variable generation performance will be evaluated in terms of resulting bulk power system reliability improvement.

Overview of Variable Generation

¹ http://www.usatoday.com/money/industries/energy/environment/2007-10-03-clean-energy_N.htm

The unique characteristics and attributes of variable generation require special considerations for planning and operation. For example, they are often remotely located, requiring significant transmission links often over challenging terrain. Wind, solar and ocean resource variability require ancillary services such as voltage support, frequency control, increased base-load unit dispatch flexibility, and spinning reserves. In addition, their available generating capacity at time of peak may be significantly less than their capacity off peak, varying with location unless coupled with



storage technologies or demand-side management options. Those entities responsible for bulk power system reliability must take these unique characteristics and attributes into account to ensure variable resources are reliably integrated into the system. This will be detailed further in the white paper, concentrating on reliable wind integration.

Variable generation quantity and type vary considerably from one geographic location to another. Siting of renewable energy systems therefore requires knowledge of the specific resource characteristics — availability, magnitude, and variability — at any given location. In some cases, especially wind, solar and ocean generation, these “fuel” concerns emulate those of other generation technologies, though fossil-fuels and biomass can have greater portability and predictability. In other cases, especially wind, the lack of portability/predictability of these renewable resources poses greater challenges for the electric delivery system, than generation fueled by other transport systems.

Bulk transmission system construction/modernization is a key element to realize the potential reliability benefits of variable generation. Outlet transmission along with system reinforcements and building-in the require system flexibility to support reliable integration of variable resources must be part of the overall variable resource acquisition strategy employed.

Study of variable generation characteristics, and understanding bulk power system reliability requirements, can help planners and operators understand how to best site and take advantage of the capacity, design plant to incorporate system reliability requirements and develop system/technology strategies increasing their reliability benefits.

In addition, bulk power system planning, operational planning and system operations approaches and methods may need to change to support the integration of large amounts of variable resources.

Bulk power system operations develop simulation models and perform system tests to position the bulk power system for reliable operation. This paper will consider:

- Scheduling and Dispatch
- Ancillary services
- Wind Power Management
- Dispatchable Interties
- Diversity

Outline of Report

The report covers 1) Characteristics of Variable Generation (including Diversity) 2) Transmission and Generation Planning Impacts, 3) System Operations (Current & future resources & tools), 4) Other and Future Considerations and 4) NERC Standard Review. Recommendations are made support bulk power system planning and operations along with next steps. Finally, a glossary is provided to support the report and support consistency in follow-on activities.

Characteristics of Variable Generation

- 2.1 Definition of variable generation technologies
 - 2.1.1 Wind generation technologies
 - 2.1.2 Solar generation technologies
 - 2.1.3 Wave generation technologies
 - 2.1.4 Biomass generation technologies
 - 2.1.5 Geothermal generation technologies
 - 2.1.6 Small hydro generation technologies
- 2.2 Drivers for future growth
 - 2.2.1 Carbon constraints
 - 2.2.2 Sustainable energy policy
 - 2.2.3 General public concerns over environmental impact of fossil fuels
 - 2.2.4 Renewable Portfolio Standards legislation (state and federal)
- 2.3 Existing variable generation installed capacity levels
 - 2.3.1 Existing installed variable generation capacity and energy
 - 2.3.2 Queued variable generation capacity and energy
 - 2.3.3 Expected variable generation capacity and energy
- 2.4 Major technical characteristics of variable generation related to power system operation
 - 2.4.1 Wind Generation
 - 2.4.1.1 Basic Types of Wind Turbine-Generators (individual wind turbines)
 - 2.4.1.1.1 Fixed speed
 - 2.4.1.1.2 Variable slip
 - 2.4.1.1.3 Double-fed variable speed
 - 2.4.1.1.4 Full conversion variable speed
 - 2.4.1.2 Voltage and Reactive Power Control
 - 2.4.1.2.1 Power factor control
 - 2.4.1.2.2 Individual turbine-level voltage control
 - 2.4.1.2.3 Coordinated plant-level voltage control
 - 2.4.1.2.4 Zero-Power Voltage control
 - 2.4.1.3 Low-Voltage Ride-Through
 - 2.4.1.4 Active Power Control Functions
 - 2.4.1.4.1 Curtailment
 - 2.4.1.4.2 Frequency response
 - 2.4.1.4.3 Reserve functions and frequency regulation
 - 2.4.1.5 Technical and performance characteristics of large-scale wind plants [we need to ensure consistency with section on diversity]
 - 2.4.1.5.1 Difference in output characteristics: wind turbine vs. wind plant
 - 2.4.1.5.2 Aggregation and geographic smoothing on various time scales
 - 2.4.1.5.3 Ramp characteristics as a function of aggregation
 - 2.4.2 Concentrating Solar Generation
 - 2.4.2.1 Basic Types of Concentrating Solar Thermal Plants (CSP)
 - 2.4.2.1.1 Solar-thermal, with steam turbines (and thermal storage and/or auxiliary gas-fired augmentation)
 - 2.4.2.1.2 Stirling-type plants (large groups of small units, no storage)

2.4.2.2 Technical and performance characteristics of concentrating solar plants

2.4.2.2.1 Large-scale steam-driven CSP

2.4.2.2.1.1 Output characteristic (ramp) with partial cloud cover

2.4.2.2.1.2 Sunrise/sunset ramps

2.4.2.2.1.3 Ability to provide ancillary services

2.4.2.2.1.4 Performance during system faults

2.4.2.2.1.5 Availability of detailed models

2.4.2.2.2 Dish-Stirling plants

2.4.2.2.2.1 Output characteristic (ramp) with partial cloud cover

2.4.2.2.2.2 Sunrise/sunset ramps

2.4.2.2.2.3 Ability to provide ancillary services

2.4.2.2.2.4 Performance during system faults

2.4.2.2.2.5 Availability of detailed models

2.4.2.2.2.6 Coordination of individual turbines in a significantly larger unit nameplate

2.4.3 Photovoltaic Solar Generation

2.4.3.1 Technical and performance characteristics of PV solar plants

2.4.3.1.1 Distinguishing between “Large” PV and “small”, i.e. rooftop, PV

2.4.3.1.2 Output characteristic (ramp) with partial cloud cover

2.4.3.1.3 Sunrise/sunset ramps

2.4.3.1.4 Ability to provide ancillary services

2.4.3.1.5 Performance during system faults

2.4.3.1.6 Availability of detailed models

2.4.3.1.7 Coordination of individual turbines in a significantly larger unit nameplate

2.5 Impact of variable generators diversity on power system operation

2.5.1 Geographic diversity impacts of variable generation

2.5.1.1 Geographic diversity within a single wind (or solar) power plant

2.5.1.1.1 Smoothing on various time scales: seconds, minutes, hours

2.5.1.1.2 Examples from operating plants in the U.S.

2.5.1.2 Geographic diversity of multiple plants

2.5.1.2.1 Within balancing area

2.5.1.2.2 Within region

2.5.1.3 Diversity between wind generation and load

2.5.1.3.1 Various degrees of correlation over different time scales

2.5.1.4 Impact on power systems operational requirements

2.5.1.4.1 Examples from studies and/or practice in the U.S.

2.5.1.4.2 Increased need for flexibility (ramping)

2.5.1.4.3 Increased need for turn-down capability

2.5.1.5 Implications for Balancing Authorities and mitigation of increased variability of variable generation

2.5.2 Diversity across technology families

2.5.2.1 Example of wind and solar diversity

2.5.2.2 Wind, solar, and load diversity

- 2.6 Technical power system operation challenges with variable generation and current operations practices to address such challenge
 - 2.6.1 Adequacy/security analysis
 - 2.6.2 Operational scheduling based on load forecasts
 - 2.6.3 Regulation needs
 - 2.6.4 Contingency reserve needs and static/dynamic stability issues
 - 2.6.5 Ramping and frequency control
 - 2.6.6 Voltage/reactive power control
 - 2.6.7 Over-generation condition
- 2.7 Technical power system planning challenges with variable generation and current planning practices to address such challenges
 - 2.7.1 System-wide and local capacity adequacy analysis
 - 2.7.2 Transmission planning studies
 - 2.7.3 Reactive planning studies
- 2.8 Variable generation forecasting methods
 - 2.8.1 Wind generation forecasting
 - 2.8.2 Solar generation forecasting
 - 2.8.3 Other technologies

Transmission and Generation Planning Impacts

Representation of Wind Generator Output for Planning Studies

- Wind data required for long-term supply adequacy planning
 - Type of data (chronological? output of existing vs. meso-scale model outputs, etc.)
 - Resolution of data and for how long?
- Wind data required for transmission planning
 - Capacity factor, estimated output at various times of the year
 - Representation of ramping events and impacts on congestion to serve balancing energy from other parts of system?

Long-term System Planning

- Review industry practices/methods to establish capacity assigned to wind plants in meeting system demand during all periods (on and off-peak)
 - Update of summaries written by Milligan/Porter based on more recent information
 - Any experience/methods from Europe?
- Recommendations for uniform approach to including wind plants in supply adequacy evaluations (reference to section above on wind data required)
- Variable Generation Representation and Scenario Analysis for Supply Capacity Planning
 - Models/Approach to be used for reliability planning
 - Statistical analysis of “worst days” vs. probabilistic risk analysis
 - How should models be used for capacity studies
- Recommendations for reliability assessments needed to ensure variable/dispatchable resources influence on reliability/adequacy is reasonably assessed.
 - Is adequate dispatchable generation available?
 - Is adequate ramping capability available?

Transmission Planning

- Review existing standards and associated grid codes for interconnection of wind generation
 - LVRT, reactive requirements, FRT, etc.
 - Technical interconnection requirements for different generator types
- Variable Generation Representation and Scenario Analysis for Trans Planning
 - Review of existing models
 - Deficiencies w/existing models
 - recommended models to be used for dynamic stability, power flow, and short-circuit
 - How should models be utilized for traditional system impact studies?
 - Output levels for wind plant for different scenarios, etc.
 - Recommendations
- Reliability implications/issues with transmission expansion required for integrating wind

- expansion as a means for integration of wind generation
- Dedicated lines from remote wind to large load centers (e.g. HVDC) – particularly true of off-shore wind
- Dynamic thermal ratings for lines and other means of utilizing existing transmission
- Identify improvements to transmission planning approaches:
 - Off-peak/on-peak scenario selection
 - Peak adequacy and energy analysis
 - Need to consider Interactions issues – wind generation near series compensated lines etc.
 - Potential reliability impacts of wind generation predominantly requesting energy resource interconnection service and non-firm or conditional firm delivery service
 - The equivalent of "conditional firm" service for interconnection (not just transmission). That is, allowing transmission development with N-0 reliability instead of N-1 reliability, in recognition of wind being an energy resource as opposed to a capacity resource.
 - System requirements to support ancillary service and reliability requirements
- New tools/analysis requirements
- Recommendations for reliability assessments.

References/Bibliography

Operational Planning & System Operations

Outline:

1. Operational Issues with Variable Generation

1.1 Seconds to Minute Timeframe

Issues and Options to deal with the issues including;

- Frequency control and regulation from or for variable generation facilities,
- Voltage dispatch, control and regulation from or for variable generation facilities,
- AGC,
- Special protection schemes,
- Islanded systems, weakly interconnected systems and strongly interconnection systems².

1.2 Minute to Hour Timeframe

Issues and Options to deal with the issues including;

- Demand side resources,
- Large wind power ramps (ramp rate),
- Forecasting and uncertainty,
- System operator tools and strategies,
- Islanded systems, weakly interconnected systems and strongly interconnection systems,
- Control area performance (CPS1, CPS2),
- Power management on variable generation resources,
- Operation and very low demand levels,
- Restoration after emergencies,

1.3 Hour to Day Timeframe

Issues and Options to deal with the issues including;

- Large wind power ramps (intra-day short term adequacy, unit commitment considerations, operating reserves),
- Flexible generation,
- Forecasting and uncertainty,
- System operator tools and strategies,
- Islanded systems, weakly interconnected systems and strongly interconnection systems,
- Operation and very low demand levels,

1.4 Day to a Week Timeframe

Issues and Options to deal with the issues including;

² The intent of considering islanded through to heavily interconnected systems is that the complexity of the issues may vary.

- Unit commitment, energy, operating reserves,
- Forecasting and uncertainty (maybe this is covered in unit commitment in some jurisdictions),
- Islanded systems, weakly interconnected systems and strongly interconnection systems.

1.5 Week to Year Timeframe

Issues and Options to deal with the issues including;

- Islanded systems, weakly interconnected systems and strongly interconnection systems,
- Outage coordination,
- Inadvertent energy management.

1.6 Beyond 1 Year Timeframe

Issues and Options to deal with the issues when planning for the future including;

- AGC enhancements,
- Frequency and voltage control planning,
- Planning for Large wind power ramps,
- Applications for special protection schemes,
- Demand side management,
- Flexible generation,
- Impact of large scale distribution generation of load forecasting and system operation,
- Expanding control area size,
- Islanded systems, weakly interconnected systems and strongly interconnection systems,
- Dispatchable interconnections,
- Operation and very low demand levels,
- Restoration after emergencies.

2. Differences between solar and wind variability

3. Future balancing standards with variable generation.

4. Recommended measures to overcome challenges with variable generation.

5.0 Other and Future Considerations

- 5.1. Introduction: *Smith, Piwko, O'Malley, Zavadil, Ellis*
- 5.2. Geographical diversity and aggregation of wind plants: *Milligan, Osborn, Morrison*
 - 5.2.1. Implications for variability
 - 5.2.2. Implications for forecasting
 - 5.2.3. Implications for balancing area size
 - 5.2.4. Implications for market size
 - 5.2.5. Implications for market flexibility
 - 5.2.6. Transmission expansion as a tool for aggregation and diversity reduction
- 5.3. Dealing with variability through demand response: *Kirby, Moleski*
 - 5.3.1. Price responsive load markets
 - 5.3.2. Demand response programs
- 5.4. Future outlook for dealing with uncertainty through forecasting: *Smith, Caspary, Grant*
 - 5.4.1. Value of forecasts
 - 5.4.2. Different forecasts for different time periods
 - 5.4.3. Forecast error and uncertainty
 - 5.4.4. Forecasting data requirements
 - 5.4.5. Central vs. plant forecasts
 - 5.4.6. Moving forecasts into the operating environment.
- 5.5. Storage technologies: *Nickell, Smith*
 - 5.5.1. Sources of system flexibility
 - 5.5.2. Dedicated vs. system storage
 - 5.5.3. Findings regarding storage in existing wind integration studies
 - 5.5.4. Modeling storage technologies
 - 5.5.5. Outlook for storage technologies
 - 5.5.6. Plug-hybrid electric vehicles
- 5.6. Future wind generator/plant behavior: *Piwko, Paquette, Zavadil*
 - 5.6.1. Inertial behavior
 - 5.6.2. Governor droop (frequency response) characteristic
 - 5.6.3. No-load var production and voltage control
 - 5.6.4. Voltage ride through
 - 5.6.5. High speed cut-out
 - 5.6.6. AGC participation and SCADA data requirements
 - 5.6.7. IEC 61400-25 Communications Protocol
- 5.7. Continued development of generic turbine models: *Zavadil, Ellis, Pourbeik*
 - 5.7.1. Dealing with new wind turbine architectures
 - 5.7.2. Long term model maintenance
 - 5.7.3. Model data reporting requirements for turbine manufacturers
- 5.8. Cumulative impacts of Distributed Generation on Bulk System Behavior: *O'Malley, Eriksen?, Smith*
 - 5.8.1. IEEE 1547 anti-islanding requirements and conflict with LVRT requirements
 - 5.8.2. Cell architecture of Energinet.dk for high wind penetration
- 5.9. Conclusions and Recommendations: *Smith, Piwko, O'Malley, Zavadil, Ellis*

NERC Standard Review

- NERC Standards must ensure bulk power system reliability. They are technology-neutral and performance-based.
- Review NERC Standards for systems with high variable/traditional resource mixes
- Suggest modifications and identify gaps
- Scan existing standards and identify gaps
- Identify needed standard or business practices not addressed
- Recommend what needs to be done in the next phase.

Conclusions & Recommendations

Minimum Standards

- Recommendations for performance-based standards for high variable/traditional generation resource mixed systems.

Appropriate Transmission & Supply Planning

- Recommendations for planning methods and tools to properly consider variable/dispatchable resource bulk power systems.

Future work

- Storage technologies
- Demand side technologies
- Recommendations for traditional/variable bulk power system operations
- Advances needed to ensure bulk power system reliability
- Education - provide information and educate industry, public and policy makers.

Glossary

- Variable resources
- Dispatchability
- etc.