NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Special Report

Accommodating High Levels of Variable generation

to ensure the reliability of the bulk power system

Embargoed DRAFT- November 17, 2008

116-390 Village Blvd., Princeton, NJ 08540
609.452.8060 | 609.452.9550 fax
www.nerc.com

This Page Left Intentionally Blank

Table of Contents

Executive Summary

As policy and regulations on Greenhouse Gas emissions, notably CO_2, and mandated Renewable Portfolio Standards (RPS) are being developed by states and provinces throughout North America, the addition of renewable generation into the bulk power system is expected to grow considerably in the near future. The level of commitment to renewables offers benefits such as new generation resources, fuel diversification, and greenhouse gas reductions, and also presents significant new challenges to bulk power system reliability that need to be properly addressed. Unlike traditional mostly non-renewable resources, the output of the wind, solar, ocean and some hydro generation resources varies according to the availability of the primary fuel (wind, sunlight and moving water) that cannot be reasonably stored. Therefore, these resources are considered variable, following the availability of the primary fuel source.

There are two overarching attributes of variable generation that can impact the reliability of the bulk power system:

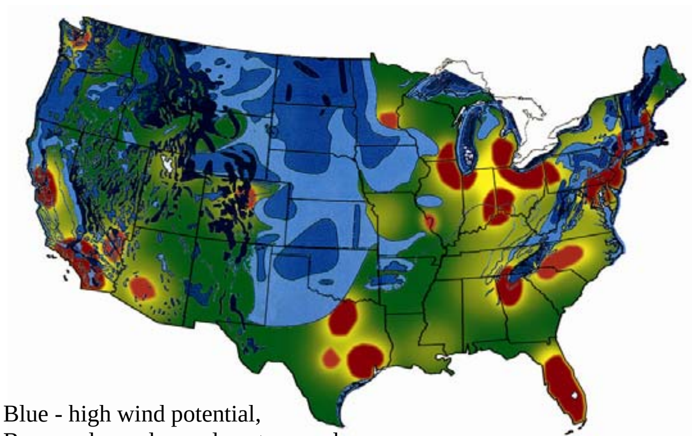
- **Variability:** The output of variable generation changes according to the availability of the primary fuel (wind, sunlight and water motion) resulting in increased fluctuations in the plant output on all time scales.

- **Uncertainty:** The ability to forecast the magnitude and phase (i.e. timing) of variable generation output is less predictable than for conventional generation.

It is necessary to understand the reliability impacts associated with the large scale integration of variable generation and determine practices, standards, approaches, tools and other requirements necessary to reliably integrate these resources into the bulk power system. Given the potential reliability impacts of large scale integration of variable generation, changes will be required to traditional methods used for bulk power system planning and operations to ensure ongoing reliability of the bulk power system.

Reliable power system operation requires ongoing balancing of supply and demand at every moment in time in accordance to prevailing operating criteria. Power system planners and operators are already familiar with a certain amount of variability and uncertainty, particularly as it relates to system demand and, to a lesser extent, with conventional generation. However, large scale integration of variable generation can significantly alter familiar patterns for a system planner and operator, mainly due to its variability and uncertainty. These resources are not fully dispatchable, thereby requiring the use of other controllable or dispatchable resources to balance the supply and demand.

In addition, many of the regions in North America that are well suited to wind generation (i.e. offering a high capacity factor) tend to be in remote regions. This presents a challenge for integrating wind resources into the bulk power system due to a lack of transmission infrastructure. Transmission is also critical in delivering the ramping and ancillary services from a large base of generation across a broad geographical/electric region to keep the supply and demand of electric energy in balance (See Figure 1[1] and Figure 2[2]).



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

Figure 1: Wind Availability Compared to Demand Centers

Anticipating the growth of variable generation, in December 2007, the North American Electric Reliability Corporation's (NERC) Planning and Operating Committees created the Integration of Variable generation Task Force, charging it with preparing a report to identify; 1) technical considerations for integrating variable resources into the bulk power system, and 2) specific actions for practices and requirements, including reliability standards.

This Special Report, *"Accommodating High levels of Variable generation"* describes the characteristics of variable generation and identifies changes to planning and operations practices techniques and tools required to reliably integrate large amounts of variable generation into the bulk power system.

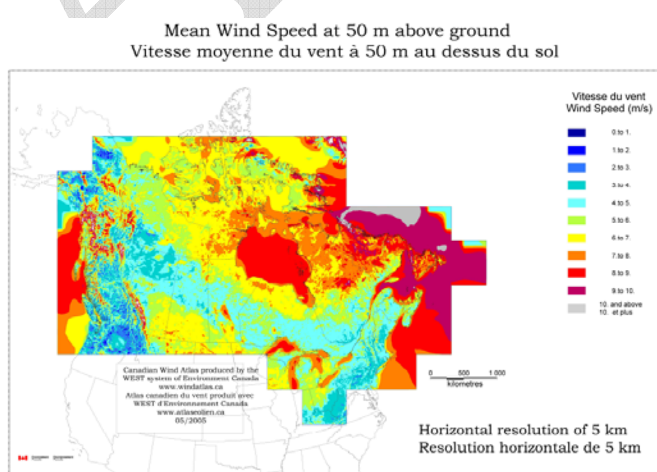


Figure 2: Wind Availability in Canada

[1] Source: NREL and EPRI

[2] http://www.windatlas.ca/en/EU_50m_national.pdf

The following guiding principles respecting the integration of high levels of variable generation were used by the IVGTF in the preparation of this report:

- bulk power system reliability must be maintained, regardless of the generation mix;
- all generation must contribute to system reliability within their physical capabilities; and
- industry standards and criteria must be fair, transparent and performance-based.

This report explores reliability considerations associated with integrating high levels of variable generation with a primary focus on wind generation. The report includes an Introduction which describes the key drivers for the rapid growth of variable generation and three core Chapters which describe the characteristics of variable generation and the impacts on power system planning and resource adequacy, and power system operations:

> **Characteristics of Power Systems & Variable Generation:** This Chapter provides an overview of the power system and technical characteristics of variable generation technologies.
>
> **Transmission Planning & Resource Adequacy:** This Chapter discusses the critical role of transmission in enabling the integration of large amounts of variable generation, identifies key considerations for planning a reliable bulk power system with high penetrations of variable generation and reviews its impact on bulk power system planning practices, techniques and tools.
>
> **Power System Operations:** This Chapter reviews the necessary enhancements to forecasting tools, operating practices and techniques and tools to allow the system operator to manage the increased variability and uncertainty related to large scale integration of variable generation.

The following is a summary of the IVGTF's recommended actions and observations:

1. Planners must consider the impacts of variable generation in power system planning and design and develop necessary practices and methodologies to maintain bulk power system reliability (NERC's Planning Committee)

1.1. Consistent methods are needed to calculate energy and capacity values attributable to variable generation.

1.2. Probabilistic expansion analysis can support study of bulk power system designs to accommodate large amounts of variable generation.
1.3. Resource adequacy and transmission planning processes must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design.
1.4. Variable distributed resources can have a significant impact on reliability and must be accommodated in system design.
1.5. Integration of large amounts of plug-in hybrid electric vehicles; storage and demand response programs may provide additional resource flexibility and can positively influence bulk power system reliability.
1.6. Standard, generic, non-confidential power flow and stability models are required to enable planners to maintain bulk power system reliability.

2. **Operators may require new tools and enhanced NERC Standards to maintain bulk power system reliability (NERC's Operating Committee)**

2.1. Forecasting techniques should be incorporated into day-to-day operating routines/practices and unit commitment, dispatch and operations planning policies.
2.2. The influence of larger balancing areas on bulk power system reliability requires study..
2.3. Enhanced grid codes may be required to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response.
2.4. Balancing Authorities must have adequate communications and control of variable resources.

3. **Planners and Operators would benefit from a reference manual which describes the changes required to plan and operate a bulk power system accommodating large amounts of variable generation.**

3.1. Write a Reference Manual geared to educate bulk power system planners and operators on how to reliably integrate large amounts of variable generation.

In addition, a number of industry actions, which are not activities that fall under NERC are suggested by the IVGTF:

4. **Industry Actions**

4.1. Ongoing industry activities (e.g. Institute of Electrical and Electronic Engineers (IEEE) and Western Electric Coordinating Council (WECC)) assessing short circuit characteristics of variable generation should be supported and an increased awareness of the issues should be encouraged.

4.2. Variable generation manufacturers should provide access to the information and data required to meet NERC's Modeling, Data and Analysis Standards (MOD) and materials. Variable generation manufacturers should be informed of the need for detailed models to support special system studies.
4.3. To the extent possible, practices, minimum requirements and/or market mechanisms (i.e. price signals) should be developed to ensure that conventional generation has the desired characteristics (e.g., ramping requirements, minimum generation levels, shorter scheduling intervals etc.) and also to foster the development of an appropriate resource mix that will support reliability.
4.4. State, provincial, and federal agencies and policy makers should consider:
    4.4.1. The impact of variable generation integration on inter-state and international bulk power system reliability into their oversight and evaluations.
    4.4.2. Collaborative efforts to remove obstacles, accelerate siting, and approve permits for transmission line construction.
    4.4.3. The potential importance of coordinated approach towards transmission and resource planning and assessment efforts.
    4.4.4. The potential benefits of larger balancing areas and the desirability of more frequent scheduling intervals, including sub-hourly schedules or regional dispatch optimization.
4.5. The following industry research and development activities should be encouraged:
    4.5.1. Development of demand side management and storage technologies
    4.5.2. Ongoing monitoring of the impact on reliability of distributed variable generators.
    4.5.3. Ongoing improvements to forecasting methods, in particular, specific applications such as severe weather forecasting.
    4.5.4. Adoption of probabilistic power system planning techniques.

1. Introduction

In 2006, natural gas-fired generation produced 20% of the electricity in the United States while representing 41% of the installed summer generating capacity. Coal-fired generation produced 49% of the electrical energy in North America and represented 32% of the installed summer capacity. Heavy and light oil is primarily used as a back-up fuel for natural gas. Oil-only fired capacity is negligible and total oil generation comprised less than 2% of the electricity produced in 2006.[3] Fossil fuels are nonrenewable, that is, they draw on finite resources. In contrast, renewable energy resources — such as wind, solar, ocean, biomass, hydro, etc. can be replenished at a generally predictable rate.

Government policy is the key driver for renewable energy expansion in the US and Canada. For example, over 50% of (non-hydro) renewable capacity additions in the US from the late 1990s through 2007 have occurred in states with mandatory RPS[4] (Figure 1.1[5]). Other significant motivators include federal, provincial and state tax incentives, state renewable energy investment funds, utility integrated resource planning, voluntary green power markets, and value of renewable energy as a hedge against future fuel price increases and carbon regulation, and the economic competitiveness of variable generation relative to other generation options. Figure 1.1, below, shows a province-by-province and state-by-state breakdown of North American Climate Change Initiatives.[6] The Canadian government has set an overall goal of a 20% reduction in greenhouse gas

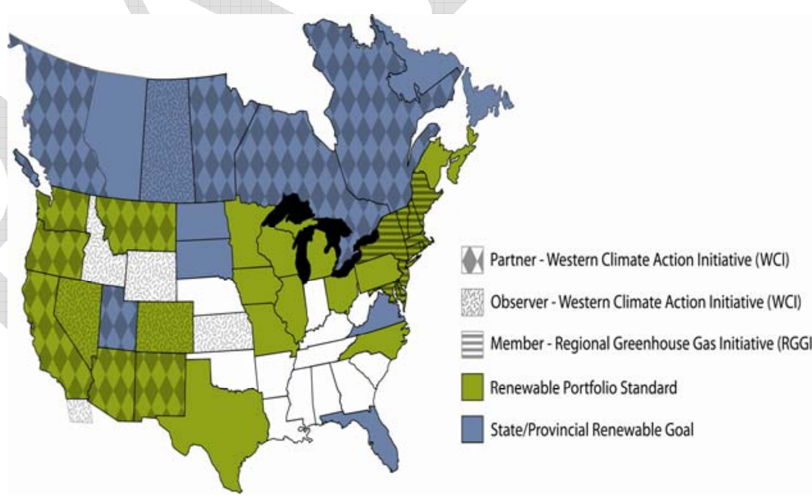


Figure 1.1: Snapshot of North American Climate Initiatives

[3] http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.html

[4] http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm or more detailed resource maps at: http://www.pewclimate.org/what_s_being_done/in_the_states/nrel_renewables_maps.cfm

[5] The Florida Public Service Commission (FPSC) Renewable Portfolio Standard is currently under development

[6] "Renewable Portfolio Standards in the United States", *Lawrence Berkeley National* Laboratory, April 2008.

emissions by 2020 using a 2006 baseline. However, specific energy policies and greenhouse gas emission and renewable energy targets are being developed by each individual province. Most of these North American targets, especially outside the desert Southwest and southern California area are expected to be met by wind, hence the dominance of wind in this report. Based on these powerful economic and policy drivers, wind resources are expected to constitute a significant portion of all new generation being added to the bulk power system in many parts of the NERC regions.[7] This proposed level of commitment to renewables offers many benefits as well as certain challenges.

Unlike conventional mostly non-renewable resources, the output of the wind, solar, ocean and some hydro[8] generation resources varies according to the availability of a primary fuel that cannot be reasonably stored. Therefore, the key differences between variable generation and conventional power plants are that variable generation exhibit greater variability and uncertainty in their output on all time scales. There is already some amount of variability and uncertainty on the bulk power system with regard to the demand in particular, and, to a lesser extent, with the generation. To accommodate higher penetrations level of variable generation, changes will be required to the traditional methods used by system planners and operators in order to maintain ongoing bulk power system reliability.

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. Mindful of NERC's mission, this report does not specifically address market, regulatory or policy issues and is neutral to the market environment in which the variable generation interconnects. Within this context, the following guiding principles were used by the IVGTF in the preparation of this report:

- bulk power system reliability must be maintained, regardless of the generation mix;
- all generation must contribute to system reliability within their physical capabilities; and
- industry standards and criteria must be fair, transparent and performance-based.

[7] http://www.nerc.com/files/LTRA2008.pdf

[8] Hydro, typically large scale using dams are not considered variable in this report.

1.1 Key Aspects of Bulk Power System Planning and Operations Must Change

Appreciating how today's bulk power system is operated and planned can be helpful in understanding potential changes required to integrate large quantities of variable generation. The supply of electricity has traditionally come from nuclear, large thermal, large scale hydro and internal combustion resources. Industry experience with these generating technologies is deep, and is based on many years of accumulated knowledge, expertise and experience. Therefore, the characteristics of conventional resources are well understood, are generally viewed to have very predictable operating performance and are fully integrated into the long-term and short term planning and operations of the electric power system in a highly reliable manner.

There are two major attributes of variable generation that impact the bulk power system planning and operations:

- **Variability:** The output of variable generation changes according to the availability of the primary fuel (wind, sunlight and moving water) resulting in increased fluctuations in the plant[9] output on all time scales.

- **Uncertainty:** The ability to forecast the magnitude and phase (i.e. timing) of variable generation output is less predictable than for conventional generation.

It is important to distinguish between *variability* and *uncertainty* when discussing planning and operations of the bulk power system. The effects of variability are different than the effects of uncertainty and the mitigation measures that can be used to address variability are different than the measures needed to address uncertainty. When accommodating large amounts of variable generation, these two attributes can have significant impact, requiring changes to both bulk power system planning and operations practices and tools in order to ensure bulk power system reliability.

Planning entities develop future plans for transmission facilities required to interconnect generators and meet demand growth while ensuring that associated system additions meet the North American Electric Reliability Corporation (NERC) and regional reliability standards. The NERC regional entities and planning coordinators assess the reliability of the bulk power system by forecasting the long-term supply and demand to evaluate and assess generation and transmission system adequacy. Key issues and trends that could affect reliability are also studied. With this approach, sensitivities and bulk power system weakness are identified and addressed in a pro-active manner.

[9] Plant is a term used to describe a collection of variable generators as they typically occurs in groups, for example multiple wind turbines constitute a wind plant.

Reliable power system operation requires ongoing maintenance of system voltages and frequency and precise balancing of supply and demand in accordance with established operating criteria. System Operators provide for the minute-to-minute reliable operation of the power system by continuously matching the supply of electricity with the demand while also ensuring the availability of capacity for consumer's needs in future hours. Operators are fully trained and certified and have long standing business practices, procedures, control software and hardware to manage the reliability of the bulk power system.

Power system operators are already familiar with a certain amount of variability and uncertainty, particularly as it relates to system demand and, to a lesser extent, with conventional generation. However, large scale integration of variable generation can significantly alter familiar system conditions due to unfamiliar and increased supply variability and uncertainty.

1.2 NERC's Planning and Operating Committee Create a Task Force

To date, North American experience with variable generation has been limited to integration of a relatively small amount of the total generation within a power system or balancing area (i.e. typically less than 5%). Integration of this level of variable generation typically has not appreciably impacted the reliability of the bulk power system. Future projections however (see *2008 Long-Term Reliability Assessment*) forecast a substantial increase in variable generation in North America, especially wind resources (i.e. up to 145 GW of wind generation over the next 10 years). Anticipating substantial growth of variable generation, in December 2007 NERC's Planning and Operating Committees created the Integration of Variable Generation Task Force charged with preparing a report to: 1) Raise industry awareness and understanding of variable generation characteristics as well as system planning and operation challenges expected with accommodating large amounts of variable generation; 2) Investigate high level shortcomings of existing approaches used by system planners and operators, and the need for new approaches, to plan, design and operate the power system; and, 3) Broadly assess NERC Standards to identify possible gaps and requirements to ensure bulk power system reliability.

While the focus of this report is on the integration of wind generation, the conclusions and recommended actions may also apply to the integration of all types of variable generation technologies. The report is organized into a series of Chapters: Chapter 2 reviews and discusses the Characteristics of Variable generation, Chapter 3 focuses on Transmission Planning and Resource Adequacy and Chapter 4 analyses System Operations. Conclusions and recommended actions are consolidated in Chapter 5.

2. Characteristics of Power Systems & Variable Generation

This chapter provides an overview of the inherent characteristics of power systems and variable generation and necessary modeling and analysis required for bulk power system planning and operations. Although there are many varieties of variable generation, this chapter focuses on wind and solar resources which are experiencing the largest growth potential in North America over the next 10 years.

2.1. Power systems

Reliable power system operation requires ongoing balancing of supply and demand at any moment in time in accordance with operating criteria and NERC Standards, in order to maintain reliable operation of the bulk power system. Operating power grids are almost always in a changing state: there are changes in generation, demand, power flowing on transmission lines and interconnection schedules, transmission and generation facilities undergoing maintenance, and there may be unplanned outages and disturbances, to name just a few. The nature and characteristics of the installed power system equipment and actions of system operators play a critical role in ensuring that the bulk power system can survive disturbances and can be restored to a balanced state of power flow, frequency and voltage.

Large scale penetration of variable generation should be considered in terms of timeframes: seconds to minutes, minutes to hours, hours to days, days to one week and beyond. Planners also must address longer time frames such as 1-5 years and 6-10 years for both transmission and resource adequacy assessments.

In seconds to minutes, bulk power system reliability is almost entirely under the control of automatic equipment and control systems such as Automatic Generation Control (AGC) systems, generator governor and excitation systems, power system stabilizers, protective relaying and fault ride through capability of the generation resources. From the minutes through one week timeframe, system operators must be able to dispatch needed facilities to re-balance, restore and position the bulk power system to withstand contingencies and disturbances thereby maintaining bulk power system reliability.

Figure 2.1 illustrates the planning and operations processes and the associated technology issues for various timeframes.[10] For operations closer to a day or days ahead of real time, the reliability

[10] http://www.nyserda.org/publications/wind_integration_report.pdf

of the bulk power system is secured by ensuring that there is adequate generation supply to meet the forecast demand while maintaining bulk power system reliability. As time moves closer to the minutes to a few hours ahead of real time, the operator requires a forecast of demand and generation at much higher accuracies and will also consider the ramp rate capability as well as whether resources can be dispatched or maneuvered to ensure supply-demand balance.

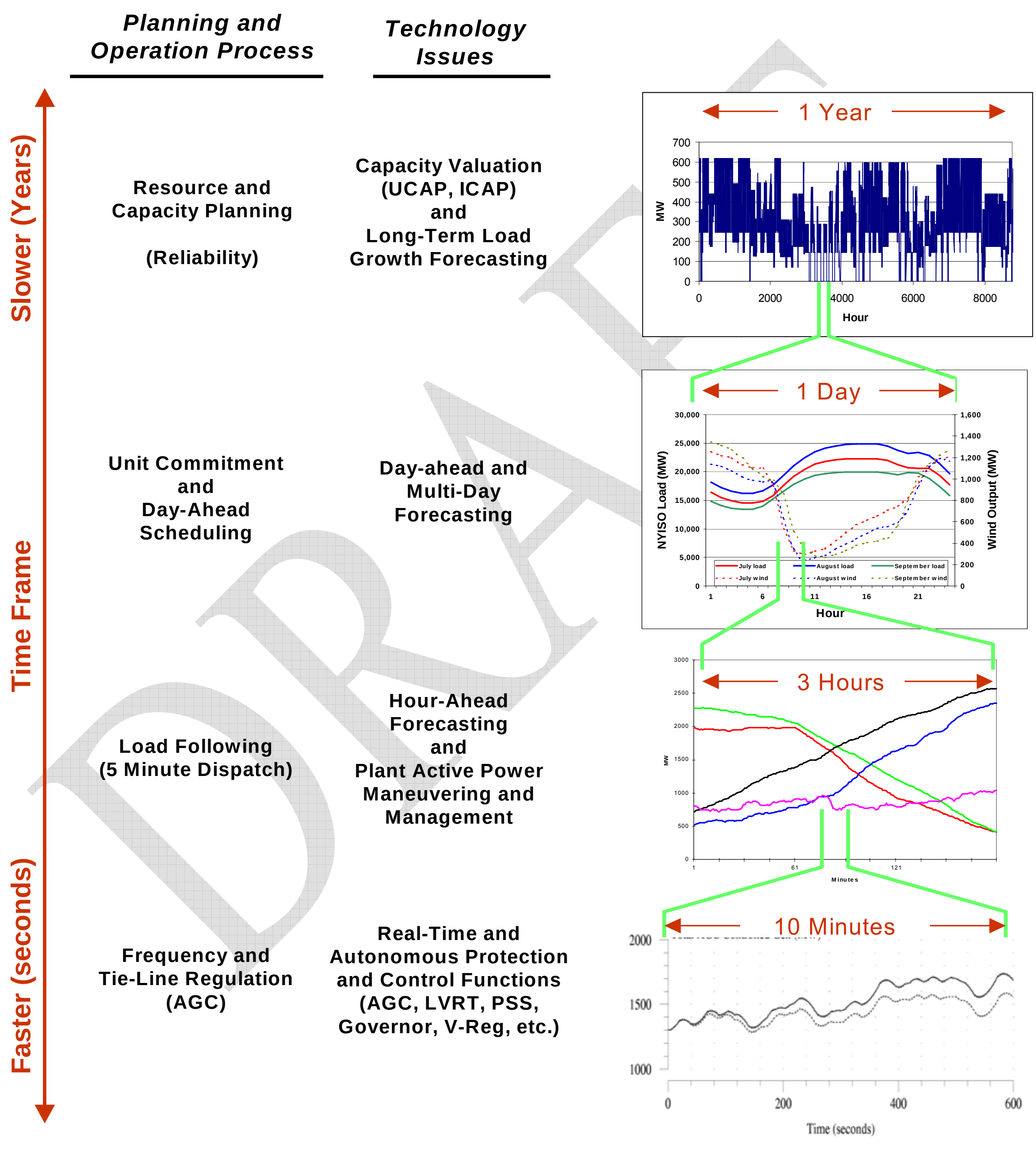


Figure 2.1 Power System Planning and Operation

Regulating reserves and ramping services are critical resources necessary to deal with the short term uncertainty of demand and generation, as well as with the uncertainty in the demand forecasts and generation availability.

Figure 2.2, which shows the total demand variation as well as net demand (demand minus wind generation) variation for Minnesota, demonstrates that wind generation, while generally reducing the net demand can increase the gap between net demand at peak and off-peak hours and illustrates the demand variation over a one week time period.

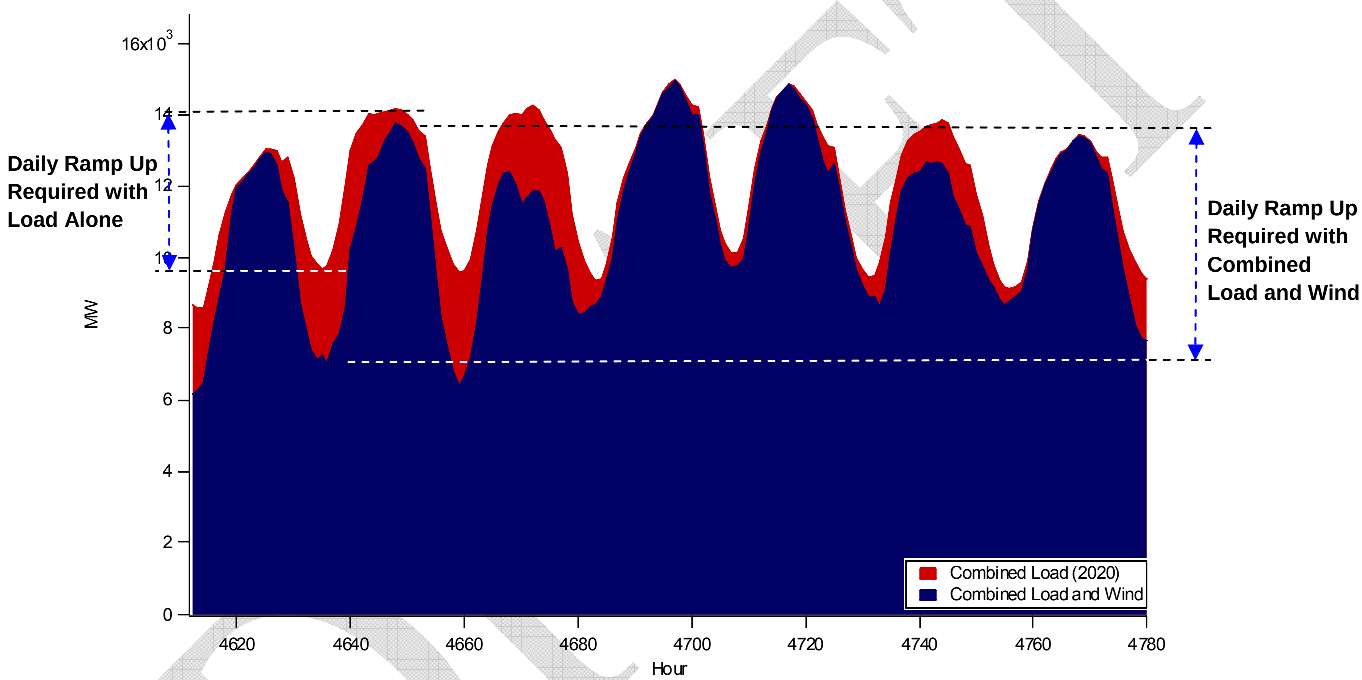
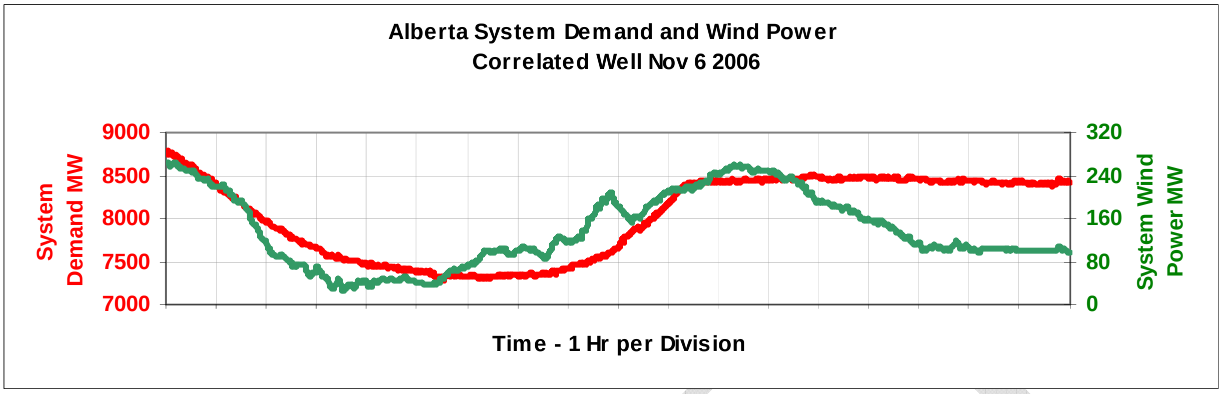


Figure 2.2: Increased System Flexibility is required to Accommodate Variable Generation

One of the important challenges for the system planner is to ensure the right equipment and facilities are in place so operators can serve demand while maintaining bulk power system reliability. With the integration of large amounts of variable generation, bulk system planners must consider a wider range of operating scenarios and explore different solutions (e.g. voltage control on and innovative new approaches to address this challenge.

There are times when variable generation can ramp up in unison with demand easing ramping requirements of the conventional generators. However, when the variable generation is ramping in opposition to the demand increasing the system ramping requirements from the conventional generators this behavior can create operational challenges (See Figure 2.3).



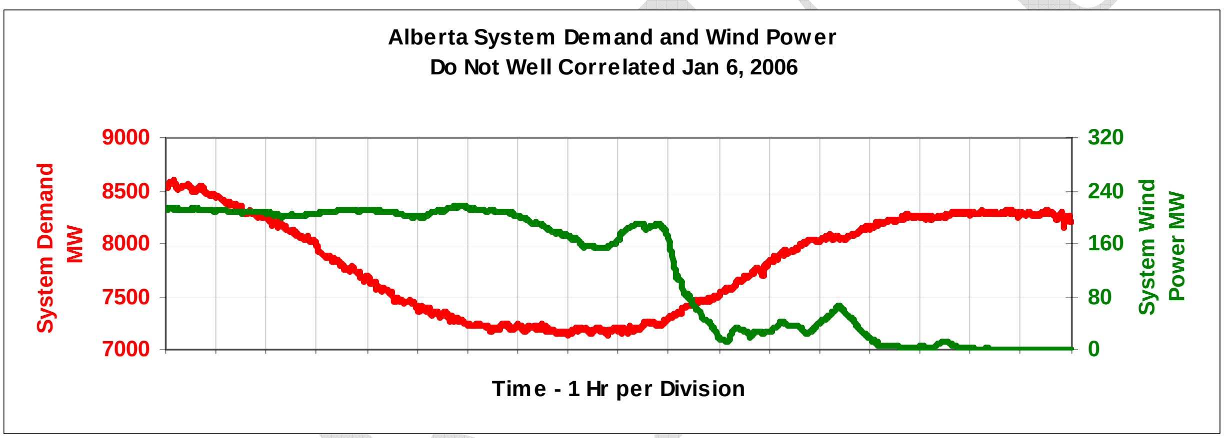


FIGURE 2.3: Wind and load ramps on Alberta Interconnected Electric System[11]

Increased wind penetration in bulk power systems normally increases ramping requirements as the variability of the net demand (demand plus variable generation) that must be served by the non-wind generation fleet becomes more acute. This is true especially during the morning demand pickup or evening demand drop off time periods. During those time periods, it is vital to ensure sufficient ramping capability (flexible generation) is committed and available, which further emphasizes the importance of accurate wind forecasting and proper procedures for committing proper generation and/or demand resources system-wide.

Consequently, this would require more flexibility from the remaining generators and/or demand resources so that the system operator can continue to balance supply and demand on the bulk power system. The flexibility of the generators may be measured by the:

[11] http://www.aeso.ca/downloads/Wind_Integration_Consultation_Oct_19_website_version.ppt

- Range between its minimum and maximum demand;
- Ability to operate at any MW level from minimum and maximum output levels;
- Start time; and
- Ramping capability between the minimum stable MW level and maximum MW level. Ramping capability may require different characteristics to ramp up or ramp down.

Maintaining efficiency and reliability of the power system requires operators to use forecasts of demand and generator availability. Today most generation resources are either base loaded or dispatchable by the system operator. Thus the majority of supply-demand balancing is achieved by dispatching generation resources to meet the changes in demand, with typically a small portion of the generation capacity under automatic generation control (AGC) to deal with short term uncertainty which is often in the intra hour time frame. AGC typically includes both load frequency control and economic dispatch algorithms that work together to optimally move generating units on AGC to maintain system frequency in an economic manner. AGC adjusts supply automatically between re-dispatch intervals to ensure that the balancing area is contributing to maintaining system frequency. In addition to pulsing regulating units to balance short-term, random system variations, AGC also moves units economically to follow some portion of the longer-term system ramping requirement.

The AGC system resides in the system control center and monitors the imbalance between generation and demand in a Balancing Area (BA). On a bulk power system, the imbalance is either due to: a) the net deviation of power flow on the balancing area's interconnections from the schedules; or b) an imbalance within an isolated or islanded area.

> ***NERC Action:*** AGC is expected to play a major role in managing short term uncertainty of variable generation and some of the short term impacts (i.e. intra-hour) associated with variable generation forecast error. Hence, a review and potential modification of the AGC performance criteria and capabilities and technologies is necessary to ensure that these systems will perform as properly in the future as they perform today.

2.2. Grid Codes

There are two aspects to equipment performance and reliability standards, which are interrelated:

- Design standards and requirements (Institute of Electrical and Electronic Engineers, American, American National Standards Institute, International Electrotechnical Commission, etc.) so equipment does not fail under normal and extreme operating conditions thereby creating an unsafe environment.

- Standards related to overall reliability of the bulk power system (NERC, Regional Entities, etc.).

Clearly, there is an interrelationship as the reliability standards may affect the equipment standards and vice versa. For example, the need for low voltage ride through capability has impacted equipment design of wind turbines.

The overall behavior and response expected from a system with high levels of variable generation will change; therefore bulk power system equipment design and performance requirements must be addressed. In this respect, reliability-focused equipment standards must be enhanced and further developed in order to facilitate the reliable integration of additional variable generation into the bulk power system. NERC's focus on standards should be on system performance and neutral to specific technologies.

From a bulk power system reliability perspective, a set of performance standards applying equally to all generation to interconnect resources to the utility grid is vital. In other countries, these standards are commonly referred to as "grid codes." However, there is still considerable work required to standardize basic requirements, such as:

- Power factor range (and thus reactive power capability);
- Voltage regulation;
- Fault-ride through (low voltage and high voltage);
- Inertial-response (the effective inertia of the generation as seen from the grid is often zero);
- The ability to control the MW ramp rates on wind turbines and/or curtail MW output; and
- The ability to participate in primary frequency control (governor action, automatic generation control, etc.).

The ability and extent to which variable generation with its unique characteristics, variable nature and technology (e.g. wind turbine technology does not use the traditional synchronous generation) can provide the above functions, affects the way in which they can be integrated into the power system. Grid codes should recognize the unique characteristics of all generation and be focused on the overall bulk power system performance rather than from the perspective of an individual generator. A single set of grid codes, phased in over a reasonable time frame will provide clarity to equipment vendors regarding product design requirements and ensure efficient and economic implementation. The following action is therefore recommended for the NERC Operating Committee:

> ***NERC Action:*** The NERC Operating Committee should undertake a review of FAC-001 and other relevant standards to ensure appropriate grid codes are in place. If these standards are found to be inadequate, action should be initiated to remedy the situation (e.g. a SAR).

A good example of the developing grid codes is the fault ride through requirement. The bulk of the power grids are outside and exposed to many conditions that can cause faults on the grid. The protective relaying on the transmission system is designed to be fast enough to detect and clear line faults. During this very short period of time, the fault will cause voltage to drop to very low levels and it is important that generation resources do not trip from the grid during the fault period or post fault conditions.

In North America, voltage-ride-through was introduced as an interconnection requirement for wind plants over the last few years. Wind generators must follow a Low Voltage Ride Though (LVRT) requirement to ensure that they do not trip for zero voltage (bolted 3-phase fault) at the Point of Interconnection for 9 cycles. This requirement is shown in Blue (WECC/NERC) and Green (ERCOT) in Figure 2.4. In addition to LVRT requirement, there has been considerable discussion on High Voltage Ride-Through (HVRT) requirements on wind generators. Some industry experts (NERC, ERCOT) have also proposed to include a high-voltage limit as is shown as red in Figure 2.4.

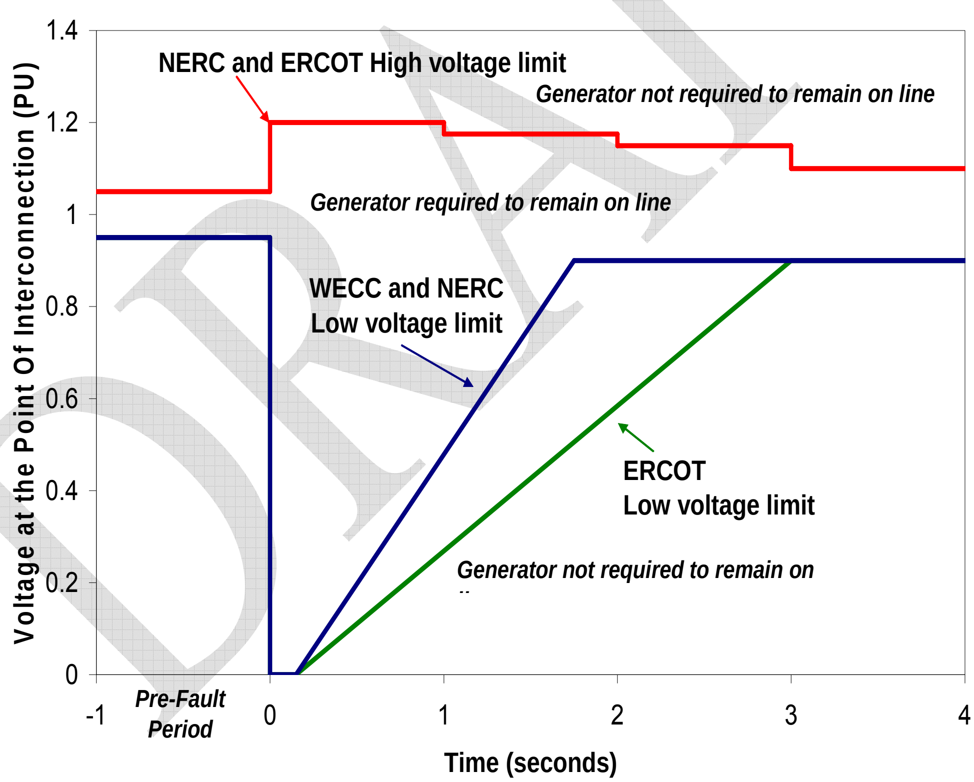


Figure 2.4: Proposed voltage ride-through criteria

In the light of the power system characteristics and the need for grid codes, the following sections will describe the technical characteristics of variable generation and will highlight their inherent characteristics including capabilities and limitations.

2.3. Variable generation Technologies

Variable generation technologies generally refer to those generating technologies where the primary energy source varies over time and the energy source cannot reasonably be stored to address such variation. Variable generation sources which include wind, solar, ocean and some hydro generation resources are all renewable based.[12] As described previously, there are two major attributes of variable generation that distinguish it from conventional forms of generation and may impact the bulk power system planning and operations, variability and uncertainty.

Steady advances in equipment and operating experience spurred by policy incentives and economic drivers have led to the maturation of many variable generation technologies. The technical feasibility and cost of energy from nearly every form of variable generation have significantly improved since the early 1980s and the field is rapidly expanding from the niche markets of the past to making meaningful contributions to the world's energy supply, in particular electricity. The major underlying technologies used in variable generation include:

- **Wind Generation:** Wind power systems convert the movement of air into electricity by means of a rotating turbine and a generator. Wind power has been among the fastest growing energy sources over the last decade, with around 30 percent annual growth in worldwide capacity over the last five years. Onshore and offshore wind energy projects are now being built worldwide with the development of very large wind turbines (up to 5 MW) and very large wind plant sizes (up to several GW).

- **Solar Generation:** Solar generation consists of two distinct technologies, Solar Thermal and Photovoltaic:

  - **Solar Thermal Generation:** Solar thermal plants consist of two major subsystems: a collector system that collects solar energy and converts it to heat, and a power block that converts heat energy to electricity. Concentrating solar power (CSP) produce electric power by collecting the sun's energy to generate heat using various mirror or lens configurations. Other solar thermal systems, like

[12] Note the reverse is not necessarily true i.e. renewable does not imply variable as there can be a storage element. For example biomass is renewable and can be stored and used to fuel a thermal power plant and is therefore not variable. Another example is hydroelectric power with a large storage reservoir.

the solar chimney and solar ponds, collect solar heat without the aid of concentrators are in development.

- **Solar Photovoltaic Generation:** Solar photovoltaic (PV) converts sunlight directly into electricity. The power produced depends on the material involved and the intensity of the solar radiation incident on the cell.

- **Hydrokinetic Generation:** There are three distinct Hydrokinetic technologies.
  - Hydroelectric power harnesses the potential energy of fresh water on land. Hydro electric with reservoirs may not be variable but run of river hydroelectric are. However growth in this type of generation in North America is not expected as most of the resource is being exploited.
  - Wave power harnesses the energy in ocean waves. However to date there is not a single commercial device in operation.
  - Tidal power harnesses the gravitational energy in ocean water movements. There are a number of pre commercial devices in existence. Tidal energy has a unique characteristic amongst the variable generation resources being described here as it is certain as opposed to uncertain as the underlying energy sources, the tides, are predictable.

2.4. Principal Characteristics of Solar and Wind Generation

It is vital to understand the specific attributes of variable generation, which correspond to the type and variety of both their fuel source and environment. This section provides a high-level view of the characteristics of the two variable resources which are undergoing rapid growth: Wind and Solar.

2.4.1. Wind Resource Ramping

Many of the regions in North America that are well suited for wind generation development (i.e. offering a high wind capacity factor) tend to be remote from both demand and other generation sources. Some North American wind examples are the panhandle and western regions of Texas, the southern regions of Alberta, many regions in British Columbia, particularly the North Coast and Vancouver Island, coastal regions of New Brunswick and Maine, many areas of Midwest especially in the Dakotas and Wyoming, and High Desert areas of California.

The degree to which wind matches demand differs widely in different geographic areas and at different times of the year. Therefore, it is not possible to generalize the pattern of wind generation across the NERC Region. One important characteristic shared by all types of wind power is their diurnal and seasonal pattern (i.e. peak output can occur in the morning and evening of the day and in may have higher outputs in Spring and Fall). This is an important characteristic as it is well correlated with the peak demand of many systems. Some wind regimes are driven by daily thermal cycles, whereas others are driven primarily by meteorological atmospheric dynamics. It is critical to ensure that wind data comes from the same time period as demand data whenever demand and wind power are compared. Because weather is a common driver for demand and wind, analysis should take into account the complex correlation between them.

A key characteristic of wind power is its longer term ramping characteristic which is often different then the shorter term characteristics. In the short term variability, there is considerable diversity in the output from wind turbines within a single wind plant, and an even larger diversity among wind plants dispersed over a wider geographic area. Such spatial variation in wind speed makes the combined output from many turbines significantly less variable than that of a single turbine. In fact, the aggregate energy output from wind plants spread over a reasonably large area tends to remain relatively constant on a minute-to-minute time frame, with changes in output tending to occur gradually over an hour or more. These longer term changes are associated with the ramping characteristics. Figure 2.5 below shows an example of California wind generation from 5 geographic areas and how diversity can smooth out the shorter term variability however the ramping characteristic are dominate.

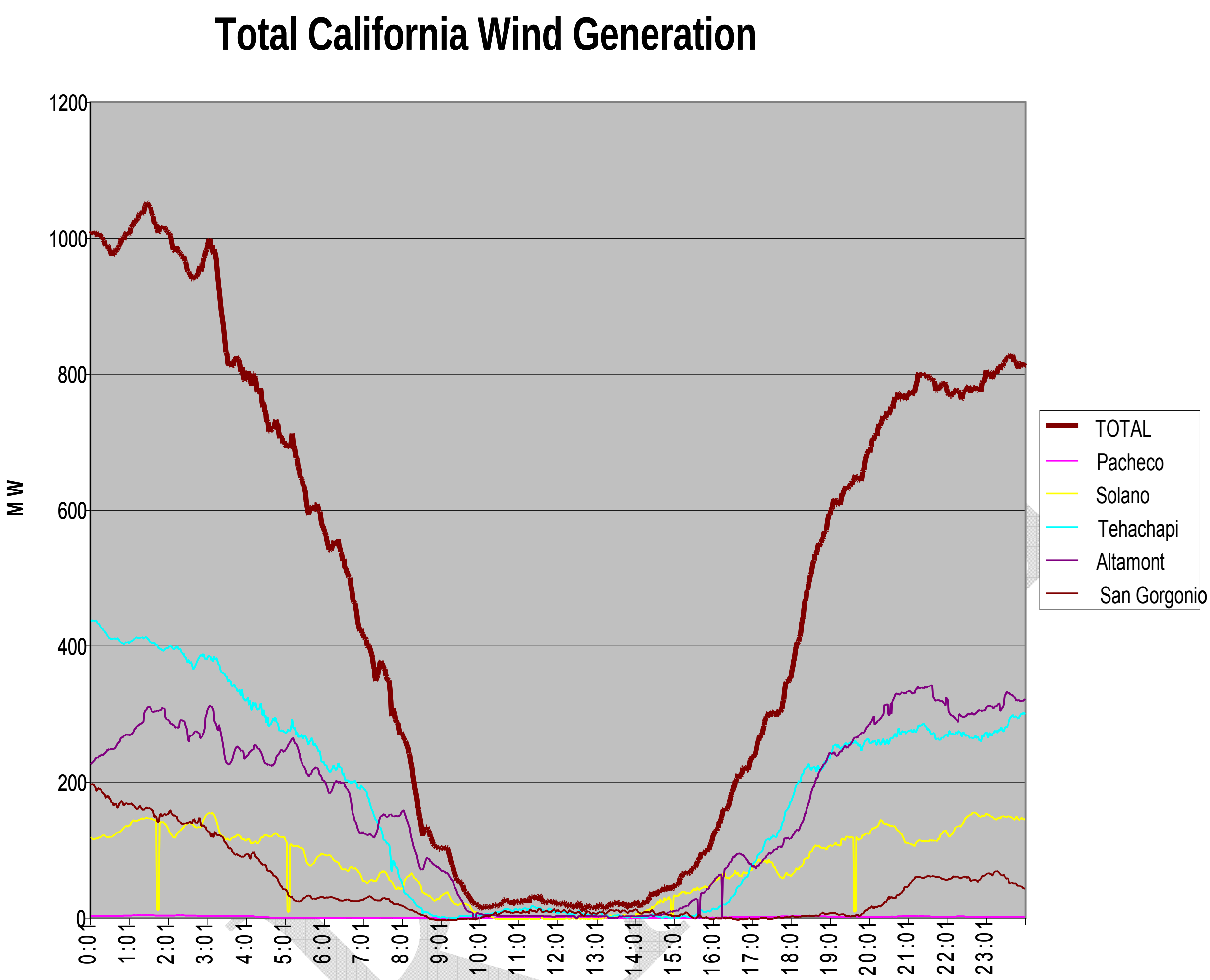


Figure 2.5: California wind power ramps from five locations geographically spread and total

Both cold wintry periods and periods of summer heat are generally associated with stable high-pressure weather systems and low wind levels are meteorologically symptomatic under these conditions. This means that in these periods, the contribution made by wind energy to meeting electricity consumption demand is correspondingly low.[13]

[13] EoN Netz Wind Report 2005

2.4.1.1.Wind turbine technologies

The principal technical characteristics of wind generation are substantially different than traditional synchronous generator technology. This section will pay particular attention to their ability to meet the type of performance that would be required by a set of grid codes (See Appendix I for diagrams of wind turbine generator technologies).

Type 1 Induction Generators - The simplest and earliest form of wind turbine-generator in common use is comprised of an induction generator that is driven through a gearbox. This wind generator, known as Type 1, operates within a very narrow speed range (fixed speed) dictated by the speed-torque characteristic of the induction generator. As wind speed varies up and down, the electrical power output also varies up and down per the speed-torque characteristic of the induction generator. In its simplest form, this technology has a fixed pitch and is aerodynamically designed to stall (i.e. naturally limit their maximum speed). The main advantage of Type 1 induction generators is its simplicity, high reliability and low cost. A major disadvantage is the significant variation in real and reactive power output correlated to wind speed changes. Simple induction generators consume reactive power with the reactive consumption being primarily dependent on the active power production. Type 1 wind turbines generally incorporate reactive compensation in the form of staged shunt capacitors to correct power factor.

Type 2 Variable-slip Induction Generator - The variable-slip induction generator is similar to the Type 1, except the generator includes a wound rotor and a mechanism to quickly control the current in the rotor. Known as Type 2, this generator has operating characteristics similar to the Type 1, except the rotor-current control scheme enables a degree of fast torque control, which improves the response to fast dynamic events and can damp torque oscillations within the drive train. Type 1 & 2 wind turbines have limited performance capability. The performance of wind plants using Type 1 and 2 machines can be enhanced to meet more stringent interconnection performance requirements through the addition of suitable terminal equipment such as SVC or STATCOM in order to control or support power system voltage.

Type 3 Double-fed induction (asynchronous) generator (DFIG) - Power electronic applications have led to a new generation of machines with utility interface characteristics which are much more compatible with the needs for improved operation and system reliability than earlier technology. The double-fed induction (asynchronous) generator (DFIG), or Type 3 wind turbine-generator, includes a mechanism that produces a variable-frequency current in the rotor circuit. This enables the wind turbine-generator wind turbine-generator to operate at a variable speed (typically about 2:1 range from max to min speed), which improves the power conversion efficiency and controllability of the wind turbine-generator. The AC-DC-AC power converters need only be rated to carry a fraction, typically 30 %, of the total wind turbine-generator power output. Although the original incentive for this scheme was variable speed power conversion, the power converters have since evolved to perform reactive power control which, in some cases, can be effectively used to dynamically control voltages, similar to conventional thermal and hydro power plants. Further, DFIGs are lighter overall weight which is important during construction. The fast response of the converters also enables better fast voltage recovery and better low-voltage ride-through capability. Advanced features such as governor-type functions (for speed control in Type 3 & 4 generators) and, in some cases, dynamic reactive power can be supplied even when the wind turbine is not generating real power, if this is desired.

Type 4 Wind Turbine-Generator (full conversion) - The Type 4 wind turbine-generator (full conversion), passes all turbine power through an AC-DC-AC power electronic converter system. It has many similar operating characteristics to the DFIG (Type 3) system, including variable speed, reactive power control, pitch control, and fast control of power output. Type 4 wind turbine-generators also decouples the turbine-generator drive train from the electric power grid, controlling the dynamics of the wind turbine-generator during grid disturbances. However, in common with Type 3 wind turbine-generators, this decoupling means that in the standard design they do not give any appreciable inertial response during a frequency event[14] unless this capability is a specific part of the design requirement. The converter system also reduces dynamic stresses on drive train components when grid disturbances occur. Finally, the output current of a Type-4 WTG can be electronically modulated to zero; thereby limiting its short-circuiting current contribution.

2.4.1.2.Control capabilities of wind turbine generators

Because of the rapid growth of variable generation and the resulting impacts on power system performance, variable generation must actively participate in maintaining system reliability along with conventional generation. In combination with advanced forecasting techniques, it is now possible to design variable generation with the full range of performance capability which is comparable, and in some cases superior, to conventional synchronous generators.[15]

2.4.1.3. Frequency Control and Power Management

Many modern wind turbines are capable of pitch control, which allows their output to be curtailed in real-time by adjusting the pitch of the turbine blades (i.e., “spilling wind”). By throttling back their output, wind plants are able to limit or regulate their power output to a set level or to set rates of change by controlling the power output on individual turbines, as shown by the multiple red traces in Figure 2.6 a & b. This capability can be used to ramp rate limit and or power limit a wind generator and it can also contribute to power system frequency control.

---

[14] Lalor, G., Mullane, A., and O’Malley, M.J., “Frequency Control and Wind Turbine Technologies”, *IEEE Transactions on Power Systems*, Vol. 20, pp. 1903-1913, 2005.

[15] Mahesh, M., Grid Friendly Wind Power Plants, European Wind Energy Conference. Brussels, Belgium, March, 2008.

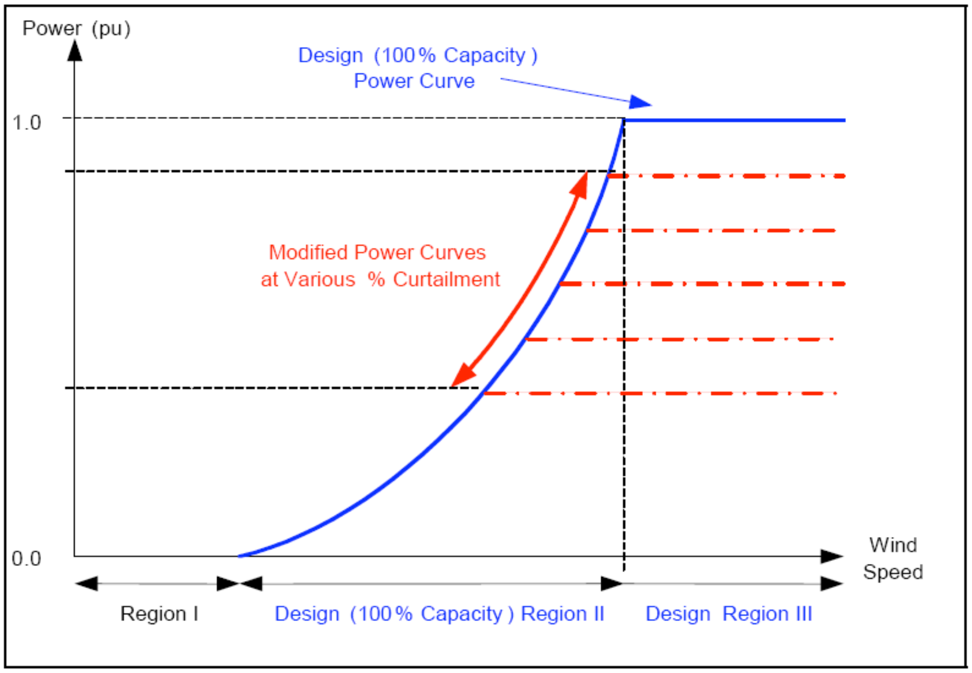


Figure 2.6a: Curtailment of Wind Turbine-Generator output using blade pitch control (Source: BEW report for CEC, May 2006)

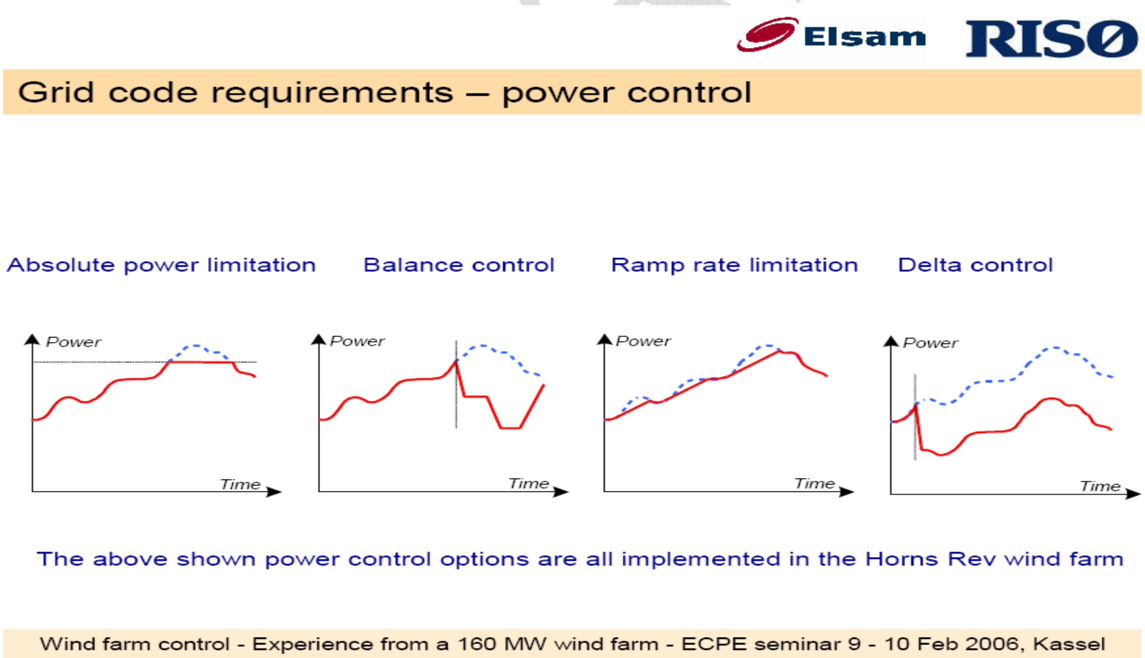


Figure 2.6b: Grid Code Requirements – Power Control Horns Rev Wind Plant[16]

[16] http://www.univ-lehavre.fr/recherche/greah/documents/ecpe/sorensen.pdf

Turbines without pitch control cannot limit their power output in the same fashion. However, a similar affect can be realized by shutting down some of the turbines in the plant. Some Type 3 and Type 4 wind-turbine generators are also capable of controlling their power output in real time in response to variations in grid frequency using variable speed drives. This control feature could be useful or required in island systems or in interconnections with high penetration scenarios, if the turbine is operating below the total available power in the wind.

Type 3 & 4 wind-turbine generator do not necessarily provide inertial response and with large wind penetrations of these technologies very severe and unacceptable frequency deviations could be expected following a major loss of generation.[17] Some manufacturers are now implementing control strategies that will provide inertial response.[18] In addition some grid codes are requiring this capability.[19] It is important to note that unlike a typical thermal power plant whose output ramps downward rather slowly, wind plant can react quickly to reduction requests taking seconds, rather than minutes. Operators need to understand this characteristic when requesting reductions of output.

The ability to regulate frequency and arrest any rise and decline of system frequency is primarily provided through the speed droop governors in conventional generators. Variable generation resources such as wind power facilities can be equipped to provide governing and participate in frequency regulation. Many European power systems have already incorporated these features in some of their wind power facilities and the Alberta Electric System Operator is currently working with stakeholders to incorporate over frequency governing on their wind power facilities. It is envisioned that in the future, with the continued maturing of the technology, wind generators will also be able to participate in AGC systems.

Ramping control could be as simple as electrically tripping all or portion of the variable generation plant. However, more modern variable generation technologies allow for continuous dispatch of their output. For example for wind power, continuous ramp rate limiting and power limiting features are readily available. Many European and some North American areas are requiring power management on wind power facilities such that the system operator can reduce the power level to a reliable limit that be accommodated at that time.[20] Circumstances where

---

[17] Mullane, A. and O'Malley, M.J., "The inertial-response of induction-machine based wind-turbines", *IEEE Transactions on Power Systems*, Vol. 20, pp. 1496 – 1503, 2005.

[18] Reigh Walling, "Wind Plants of the Future", UWIG, Oct 2008

[19] Hydro-Québec TransÉnergie, "Technical requirements for the connection of generation facilities to the Hydro-Québec transmission system", May 2006

[20] Abildgaard, H., Wind Power and Its Impact on the Danish Power System. Washington International Renewable Energy Conference, Washington, DC, March, 2008.

power management could be more readily used are excess energy conditions (peak production of variable generation during low demand periods), unexpected ramp up of the variable generation when demand is dropping and during system emergency conditions (i.e. system restoration).

2.4.1.4.Voltage Control

As variable resources, such as wind power facilities, constitute a larger proportion of the total generation on a system, these resources should provide the voltage regulation and reactive power control capabilities comparable to that of conventional generation. Further, wind plants should provide dynamic and static reactive power support as well as voltage control in order to contribute power system reliability. Figure 2.7 shows an example of the performance of voltage control scheme implemented at a 160 MW wind plant in the western US showing that wind plant can support and control voltage. Table 2.1 summarizes the functional control capabilities of wind turbine generators.

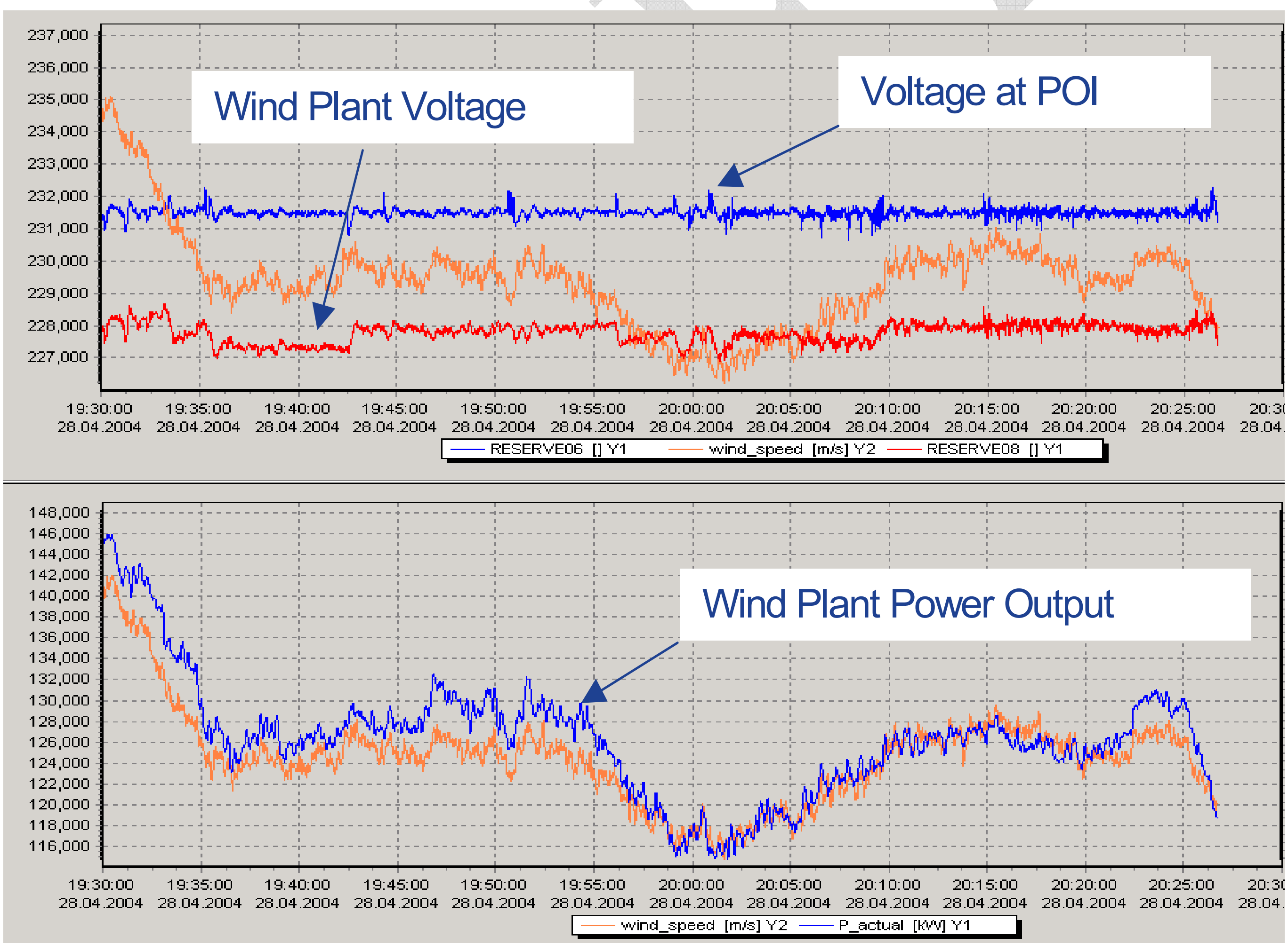


Figure 2.7 Wind Plant voltage control with significant variation in wind power

Table 2.1: Functional Control Capabilities of Wind Turbine-Generators (WTG) by Type

Required control	Type 1: Fixed Speed Induction Generator	Type 2: Variable Slip Induction Generator	Type 3: Double-Fed Induction (Asynchronous) Generator	Type 4: Full Conversion
Constant power factor control	Requires SVC or STATCOM external to the WTG	Requires SVC or STATCOM external to the WTG	Built-in Capability	Built-in Capability
Automatic voltage regulation	Requires SVC or STATCOM external to the WTG	Requires SVC or STATCOM external to the WTG	Built-in Capability	Built-in Capability
Voltage regulation at zero power	Requires SVC or STATCOM external to the WTG	Requires SVC or STATCOM external to the WTG	Built-in Capability	Built-in Capability
Low-voltage ride-through	Requires turbine control augmentation and SVC or STATCOM external to the WTG	Requires turbine control augmentation and SVC or STATCOM external to the WTG	Achieved through control modification	Achieved through control modification
Power curtailment	Limited control via wind plant[21] controls	Limited control via wind plant[4] controls	Achieved through control modification and a wind plant controller	Achieved through control modification
Power ramp rate control	Limited control via wind plant[22] controls	Limited control via wind plant[5] controls	Achieved through control modification and a wind plant controller	Achieved through control modification
Grid frequency regulation[23]	Depends on turbine controls[24]	Depends on turbine controls[7]	Achieved through control modification	Achieved through control modification
Inertial Response	Inherent	Inherent	Must be achieved through control modifications.	Must be achieved through control modifications.

[21] If active-stall turbine control, then may be achievable. If stall controlled, requires discrete control (i.e. tripping individual turbines).
[22] If active-stall turbine control, then may be achievable.
[23] Grid frequency regulation refers to primary frequency control. This can be achieved through modifications in the control system for type 3 and 4 turbines. This is only feasible on active-stall controlled type 1 and 2 turbines (See Appendix I for WTG Technologies).
[24] This is achievable with active-stall units but not feasible for stall units.

2.4.1.5. Communications

For variable generation to provide power plant control capabilities they must be visible to the system operator, and able to respond to dispatch instructions during normal and emergency conditions. [25] Real-time wind turbine power output, availability, and curtailment information is critical to the accuracy of the wind plant output forecast, as well as the reliable operation of the system. In addition, it is critical that the BA operator have real-time knowledge of the state of the wind plant and the ability to control its output under emergency situations. The need for this information was clearly illustrated during the restoration of the UCTE system following the disturbance of Nov. 9, 2006, [http://www.ucte.org/resources/publications/otherreports/] and the communication and control requirements for wind plants of the future must be established as minimum requirements. An international standard communications protocol has been prepared in this regard (IEC 61400-25). Balancing Authorities must work with the wind generator operators to ensure procedures, protocols and communication facilities are in place so control instructions can be communicated to the wind plant operators in a timely manner.

> ***NERC Action:*** The NERC Operating Committee should undertake a review of COM-002, FAC-001 and registry criteria to ensure adequate communications and control are in place. If these standards are found to be inadequate, action should be initiated to remedy the situation (e.g. a SAR).

2.4.2. Solar Generation

There are several methods of converting electromagnetic radiation received directly from the sun into useful electricity. Generally speaking, all of the methods described in this section are classified as "solar" energy. However, it is important to recognize that considerable differences exist in the technical characteristics from one form of solar to another (i.e. CSP, PV). One important characteristic shared by all types of solar power is their diurnal and seasonal pattern (i.e. peak output can occur in the middle of the day and in the summer). This is an important characteristic as it is well correlated with the peak demand of many systems.

Another characteristic of solar energy is that its output may be complementary to the output of wind generation and may be produced during the peak load hours when wind energy production may not be produced during peak hours. The following example in Figure 2.8, illustrates this phenomena and shows average demand, average wind and average solar in California and how the average solar energy increases when average wind energy decreases.

[25] IEC 61400-25, Wind turbines –Communications for monitoring and control of wind power plants – Overall description of principles and models, International Electrotechnical Commission, December, 2006.

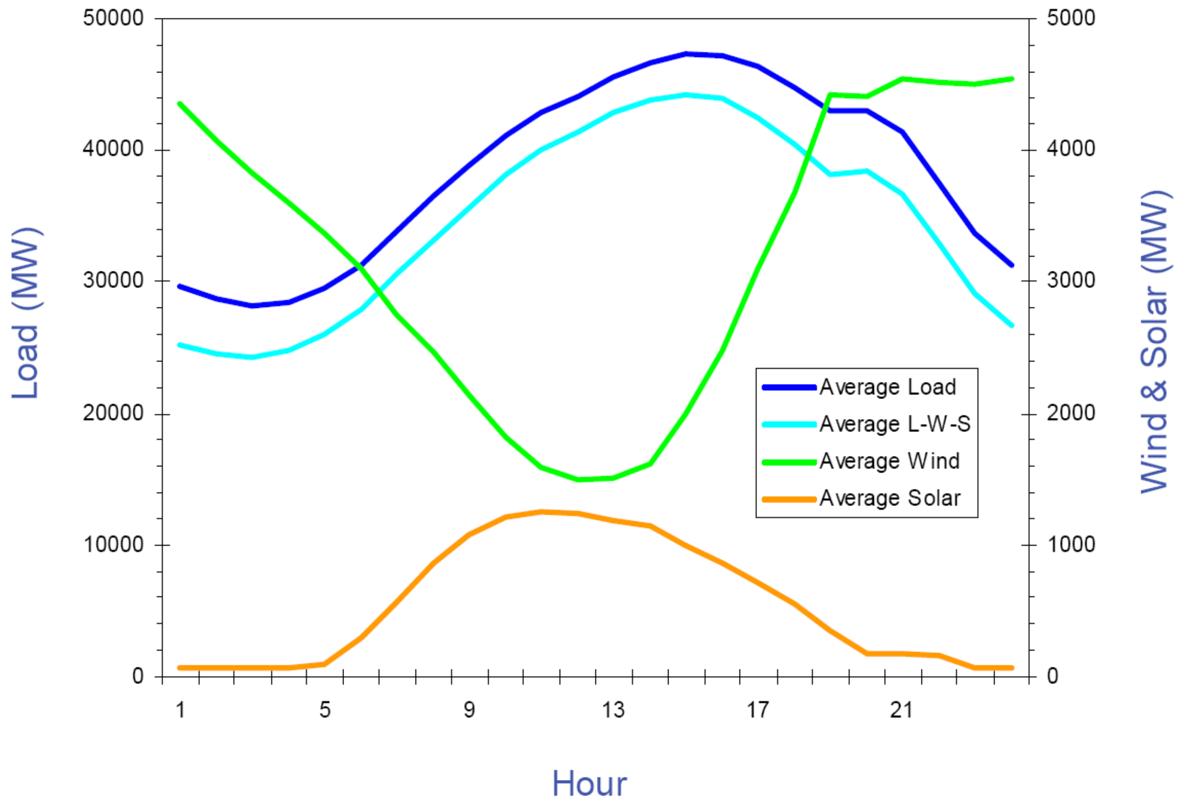


Figure 2.8: California average wind output, solar output, load, and net demand (Load-Wind-Solar), July 2003.

2.4.2.1. Concentrating Solar Thermal Technology (CSP)

Concentrating solar thermal plants use mirrors to focus direct normal irradiance (DNI) to generate intense heat that is used to drive an electric generator. The fact that concentrating solar plants use DNI limits their geographic application within NERC to the southwestern US and northern Mexico. The most widely deployed form of concentrating solar thermal generates steam which ultimately drives a steam turbine-generator.

Concentrating solar thermal plants that use steam turbines typically make use of a “working fluid” such as water, oil, or molten salt. Solar thermal plants that use a working fluid can make use of several optical geometries including: parabolic trough, power tower, and linear Fresnel. The characteristics described in this section can generally be applied to these geometric designs.

The mass of working fluid in concentrating solar thermal plants results in these types of plants having stored energy and thermal inertia. There are several important attributes of thermal inertia associated with solar thermal plants. First, the electric output can be predicted with a high degree of certainty on a minute-to-minute basis. Secondly, due to their energy storage capability, the electrical output ramps of a solar thermal plant can be less severe and more predictable than other forms of solar power and variable renewable sources. Third, a solar thermal plant will require some period of time after sunrise to begin electrical production as the working fluid heats up. A solar thermal plant can produce electrical output after sunset by drawing on the thermal energy stored in the working fluid. Figures 2.9 and 2.10 demonstrate the variation in output of a 64 MW solar thermal plant on sunny and partly-cloudy days, respectively.

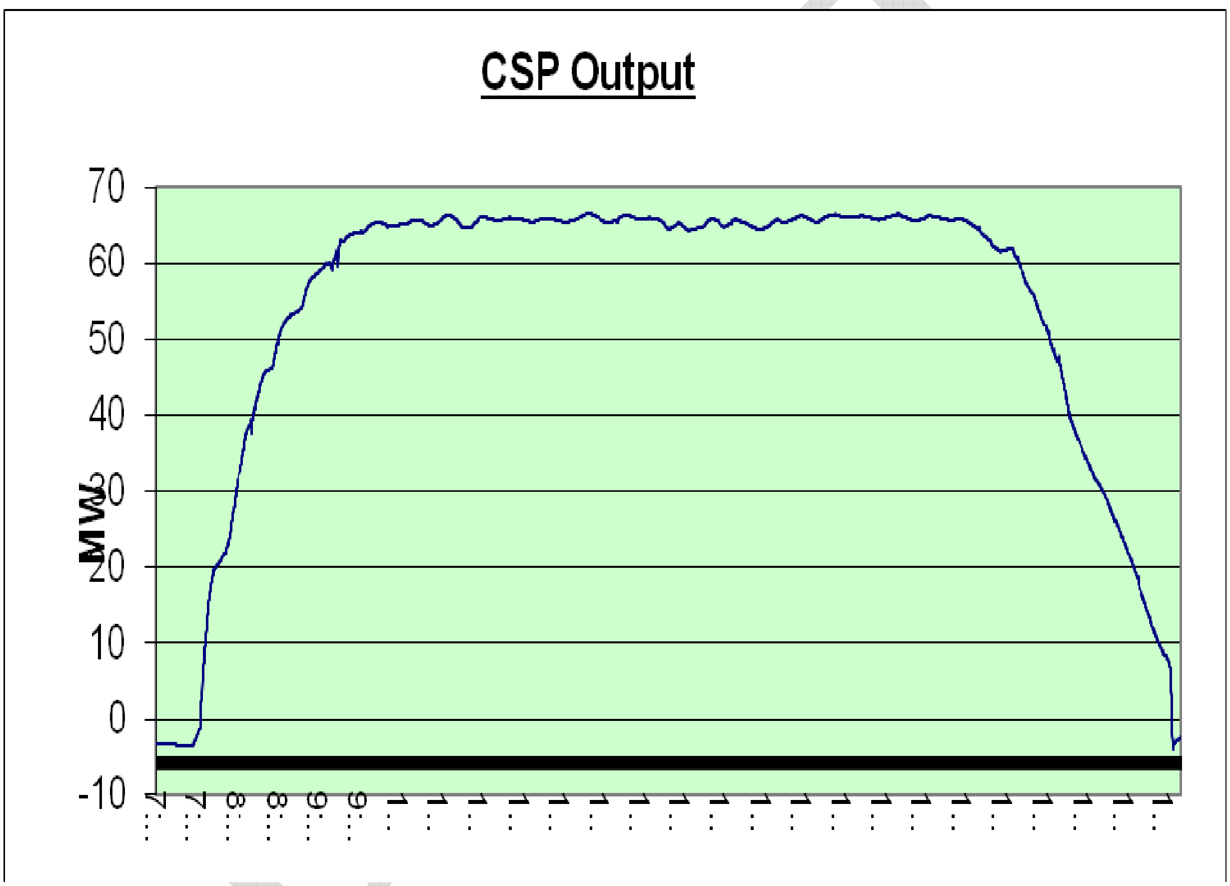


Figure 2.9: Output of a parabolic trough CSP plant on a sunny day.

Sampling time of 10 seconds

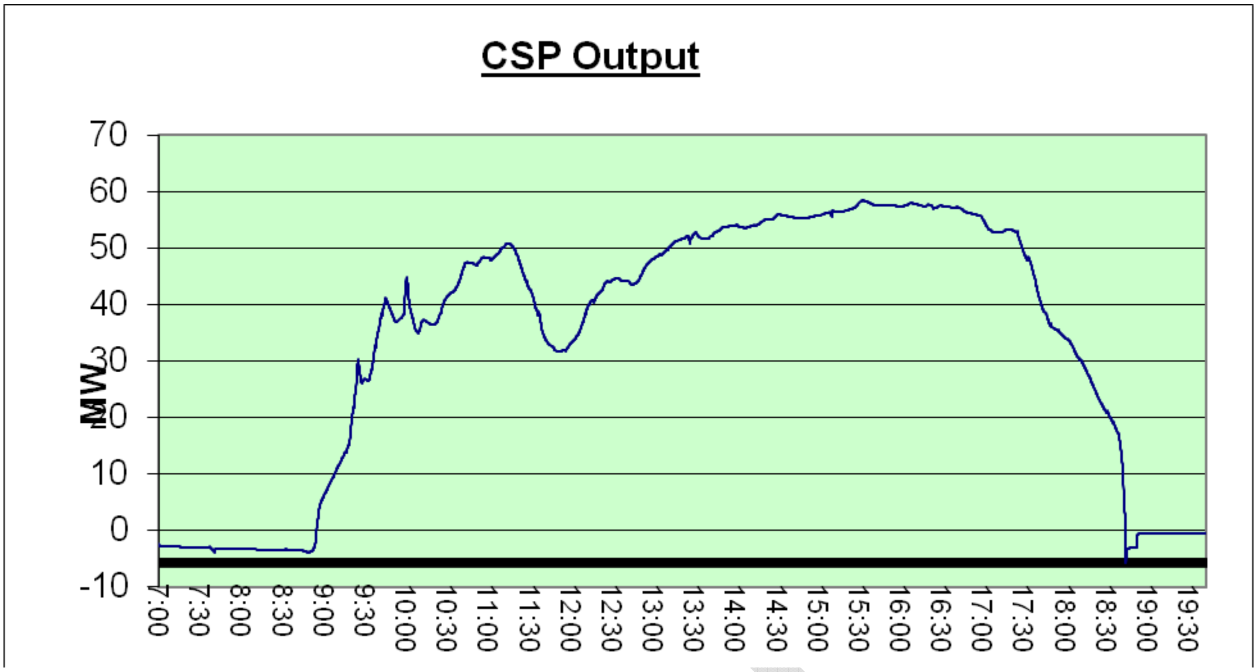


Figure 2.10: Parabolic trough CSP plant on a partly-cloudy day. Sampling time of 10 seconds.

The concentrating solar plants described in this section use existing steam-turbine generator designs. The performance of the steam-turbine generator is well known and understood from both a steady state and dynamic/transient perspective.

Solar thermal plants can be expected to be deployed as central stations with transmission (or sub-transmission) interconnections. Concentrating solar thermal plants achieve similar economies of scale as turbine-generator electrical output approaches 50 MW. However, CSPs reach practical limits, in terms of scale, for individual turbine-generator ratings of around 250 MW. There is little application for distributed concentrating solar thermal.

Solar thermal plants can be expected to be deployed as central stations with transmission (or sub-transmission) interconnections. Concentrating solar thermal plants may also achieve similar economies of scale as turbine-generator electrical output approaches 50 MW. However, CSPs reach practical limits, in terms of scale, for individual turbine-generator ratings of around 250 MW. There is little application for distributed concentrating solar thermal.

Two additional forms of solar thermal generation have been proposed for utility scale application. These others forms of solar technology are dish-Stirling and solar chimney. Specific characteristics of dish-Stirling plants have yet to be published. Generally speaking, proposed Dish-Stirling projects are a collection of thousands of individual turbine-generators with individual ratings from 10-50 kW. Dish-Stirling plants have been proposed for as large as 300

MW in terms of collective plant output. The ramping characteristics of Dish-Stirling plants are expected to be similar to those of PV as the inertia of an individual Stirling engine is considered nearly zero, though there is some energy stored in the rotating mass of multiple turbine generators. It is unknown whether the large geographic areas (one square mile or more) will reduce the ramp severity for the collective output of a fully deployed Stirling project. The solar chimney concept may yield a solar plant with a 75% capacity factor with essentially zero variability in minute-to-minute output. Turbine generators for solar chimney are being developed using existing designs for large hydro plants.

2.4.2.2. Photovoltaic (PV) Technology

PV technology converts the electromagnetic energy in sunlight directly into direct current (DC). PV (except for concentrating PV) can use both diffuse solar radiation and DNI. As a result, PV installations are deployed throughout North America and are not limited to regions with superior DNI resources such as the Southwestern US and northern Mexico. PV does not require larger plant sizes to achieve economies of scale and is often deployed as distributed generation.

In order to interconnect with the AC power system, a PV system must use a power electronic inverter (much like WTG types I & 2) to convert its DC output at the terminals of the PV panel into AC. As with solar thermal there are many forms of PV. This section describes technical characteristics that are applicable to all forms of PV.

In order to interconnect with the AC power system, a PV system must use a power electronic inverter (much like WTG types I & 2) to convert its DC output at the terminals of the PV panel into AC. As with solar thermal there are many forms of PV. This section describes the technical characteristics that are applicable to all forms of PV.

The nature of PV is such that PV does not involve a rotating mass and therefore does not have inertia. Therefore, PV can not directly provide inertial response.[26] PV systems can experience declines in output from 100% to 20% of rated output in less than five minutes if a cloud bank shades or disrupts all or portions of the PV array. Similarly, a PV array can ramp-up in output from 20% to 100% of rated output in less than five minutes, when a cloud bank retreats. This phenomenon has been observed on some of the largest PV arrays (ranging from 3-10 MW) deployed in the US located in Arizona and Nevada. Figures 2.11 and 2.12 demonstrate the potential for significant ramps in output from a PV plant located in Nevada.[27]

[26] This can be provided indirectly through local storage (i.e. battery, energy storage, etc. is available)

[27] Nevada Power Company, Renewable Energy Department

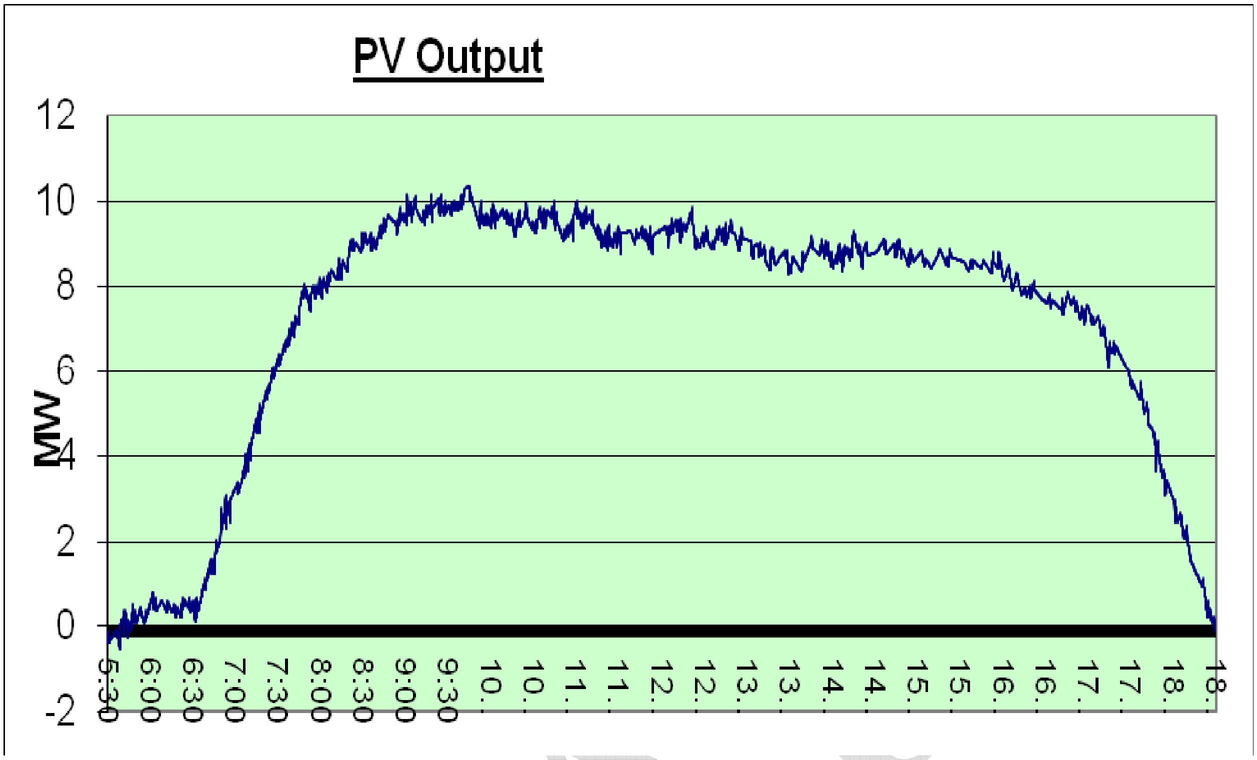


Figure 2.11: PV plant output on a sunny day.

Sampling time 10 seconds

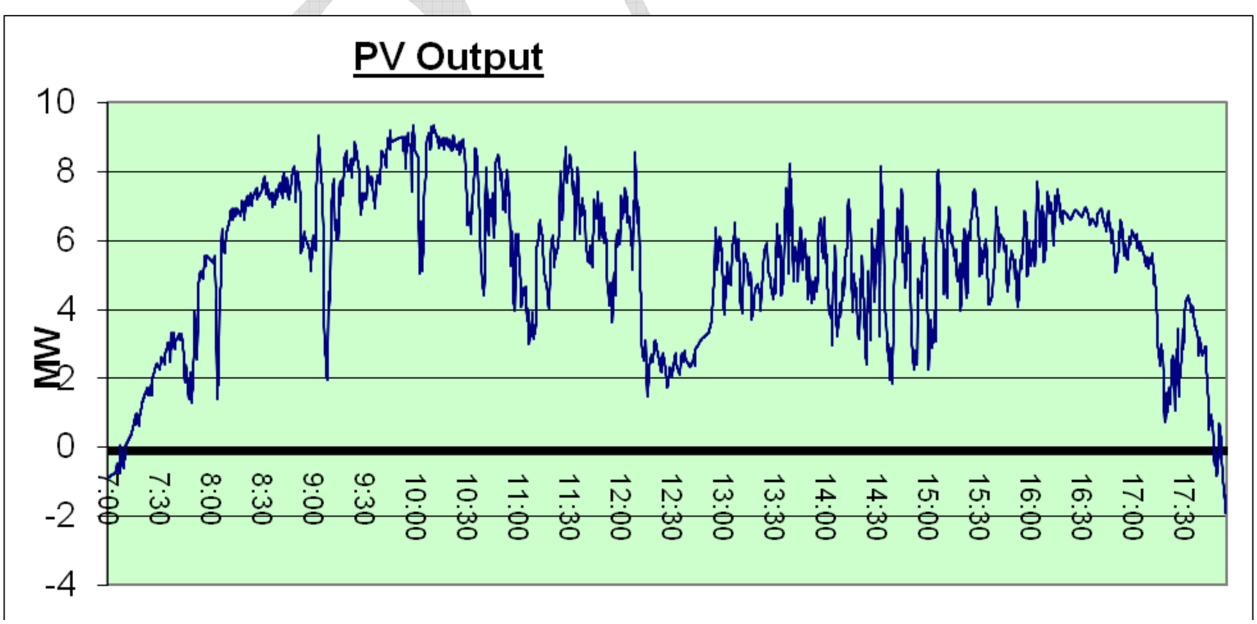


Figure 2.12: PV Plant output on a partly-cloudy day.

Sampling time 10 seconds

The use of an inverter makes PV similar to Type 4 Wind Turbine-Generators in that the inverter can provide real-time control of voltage, supporting both real and reactive power output. Given the absence of performance standards for PV inverter modules, it is likely that actual performance of PV inverter modules will vary from supplier to supplier.

PV plants with ratings on the order of 100s of MW are being proposed throughout the North America. It is unclear if the scale of these plants will limit the impact of ramping by virtue of significantly greater land coverage than the PV plants presented here. It should also be noted that the addition of energy storage in the form of batteries could offer a means of lessening the severity of minute-to-minute ramps associated with PV. However, the scale of energy storage required for a 100 MW PV system would require considerable improvements to currently available large-scale battery system technologies in terms of charging cycles and cost effectiveness.

2.5. Variable Generation Modeling

Existing NERC modeling standards require Reliability Entities (RE) to develop comprehensive steady-state data requirements and reporting procedures needed to model and analyze the steady-state and dynamic performance of the power system (MOD-011 and MOD-013). Equipment owners are required to provide steady state and dynamic models (MOD-012) to the RE. This information is required to build a reasonable representation of the interconnected system for planning purposes, as stated in MOD-014 and MOD-015.[28] Specifically models are required to perform load flow, short circuit, and stability studies necessary to ensure system reliability. There are also NERC standards which deal with periodic verification of the models, such as MOD-023, which deals with verification of reactive power limits. Again, with the lack of accepted models, this provision has in essence been ignored for existing variable generation plants.

[28] http://www.nerc.com/page.php?cid=2|20

Much work has been done, particularly in recent years,[29] to clearly define and explain the various variable generation technologies and how they should be modeled for system studies. International cooperation to develop generic wind turbine models initiated by the Western Electricity Coordinating Council (WECC) is a positive step. This WECC-led effort considered the four major turbine topologies in current commercial applications. In the very near term, best representations of specific commercial turbine models with the current generic structures must be developed. This effort will require significant collaboration between the power engineering community and the wind turbine vendors, since the measurement data or detailed simulation results that provide the best opportunities for validation of the behavior and adjusting the parameters of the generic models are held by the vendors and not generally available publicly.

The modeling of variable generation should continue to be advanced by the IEEE Power and Energy Society's Power System Dynamics Committee in order to provide a broader forum going forward for the needed work and refinements in this area. It is expected wind generators will be required to comply with existing modeling standards and this requirement should be clearly stated. There are challenges that need to be addressed over time to improve model standardization and industry experience similar to conventional generator models. Steps that should be taken in this regard include:

- It should clarified that variable generators must comply with standards, and a timetable should be set for compliance;
- Existing standards should be assessed to determine what modifications to modeling standards (if any) are necessary to properly consider the unique aspects of wind generation;
- Appropriate test procedures should be developed to comply with NERC model validation and performance verification requirements (such as reactive limits).

> ***NERC Action:*** The NERC Planning Committee should undertake a review of the Modeling, Data and Analysis Standards (MOD) with a view towards enforcement of

[29] WECC Wind Generator Power Flow Modeling Guide,

Nevada Power Company, Renewable Energy Department,

ESB National grid, "Dynamic modeling of wind generation in Ireland", January 2008

Coughlan, Y., Smith, P., Mullane, A. and O'Malley, M.J., "Wind turbine modelling for power system stability analysis - a system operator perspective", *IEEE Transactions on Power Systems*, Vol. 22, pp. 929 – 936, 2007.

CIGRE Technical Brochure 328, Modeling and Dynamic Behavior of Wind Generation as it Relates to Power System Control and Dynamic Performance, Prepared by CIGRE WG C4.601, August 2007 (available on-line at: www.e-cigre.org) existing standards and improvements required to simulate high levels of variable generation.

Industry Action: Variable generation vendors need to familiarize themselves with the Modeling, Data and Analysis Standards (MOD) and materials which explain their intent and purpose. Ongoing industry activities, in particular within the IEEE and WECC, should be supported.

In contrast to wind turbine generators, simulation models for CSP steam turbine generator sets are fully developed and for dish-Stirling engines are considered proprietary. However, it is not known if simulation models have been validated against performance of commercially-available PV inverter modules. Wind plants are often located in remote areas of the network where the short circuit level is weak and where problems such as over-voltages, harmonics or voltage unbalances may be observed. Furthermore, wind projects may be located near HVDC interconnections or near series compensation and may interact with such equipment.[30] Therefore, wind turbine manufacturer specific 3-phase equipment level models are also needed to support specialized studies under these and other circumstances.

Industry Action: The variable generation manufacturers should support the development of detailed models required for special system studies.

2.6. Summary

This Chapter has outlined power system planning and operation and the characteristics of variable generation with an emphasis on those attributes that may impact the reliable integration of these technologies onto the North American power system. Particular attention was given to the need for adequate grid codes and models for power system analysis. The following two Chapters further consider the characteristics described here and investigate what changes may be need in planning (Chapter 3) and operations (Chapter 4) to maintain the reliability of the bulk power system with increasing levels of variable generation.

[30] CIGRE Technical Brochure 328, Modeling and Dynamic Behavior of Wind Generation as it Relates to Power System Control and Dynamic Performance, Prepared by CIGRE WG C4.601, August 2007 (available on-line at: www.e-cigre.org)

3. Transmission Planning & Resource Adequacy

The goal of bulk power system planning is to ensure that sufficient energy resources and delivery capacity exists to interconnect new supply and ensure that demand requirements are met in a reliable and economic manner for the planning horizon. System planners use forecasts of future demand and generating technology to specify the resources and delivery infrastructure required to meet stated reliability targets, to ensure adequacy of supply and economic delivery of electricity. In addition to ensuring sufficient resources and capacity to meet demand under normal operating conditions, planners must also ensure adequate reserves and resources exist to reliably serve demand under credible contingencies such as the loss of a generating unit or transmission line facility.[31]

Traditionally, bulk system planning included generation planning and transmission planning. Generation planning is now more appropriately referred to as resource adequacy planning and assessment acknowledging the increased role of demand-side resources. Transmission planning and resource adequacy are inter-related as there must be adequate transmission to interconnect generation to reliably meet demand.

This section describes the critical role that transmission plays in the large scale integration of variable generation resources and the key considerations for planning a reliable bulk power system with high levels of variable generation. It also describes some of the necessary enhancements to existing practices and techniques for transmission and resource adequacy.

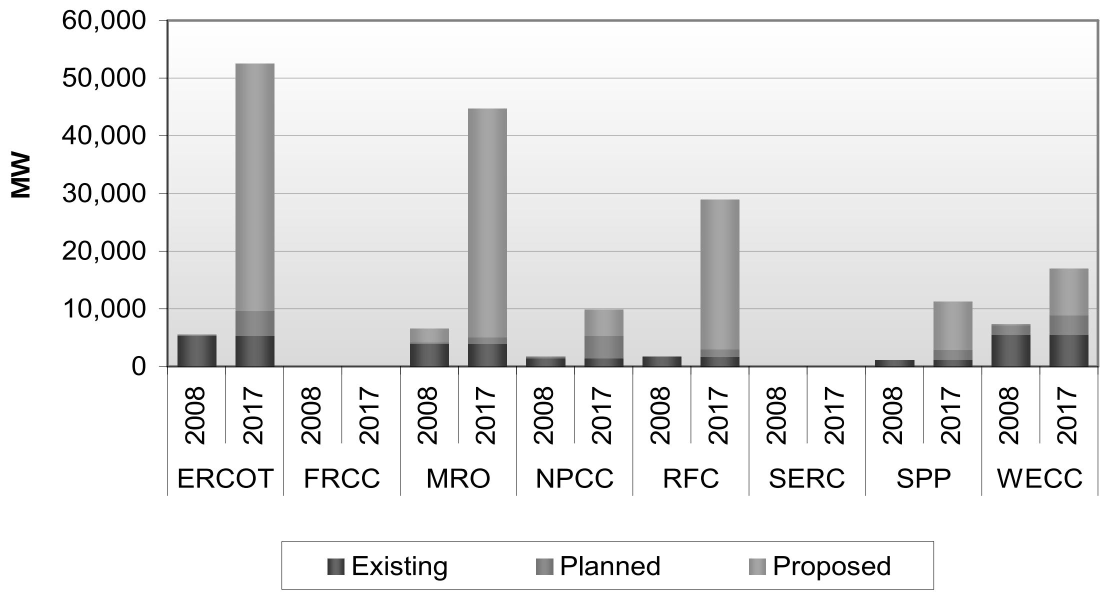
3.1. The Critical Need for Transmission

Many new variable generation plants interconnecting to the bulk power system will be located in remote areas away from the demand centers and existing transmission infrastructure. The *2008 Long-Term Reliability Assessment* estimates that more than 145 GW of wind generation is either Planned or Potential resources by the year 2017 in North America (See Figure 3.1*)*.[32] Figure 3.1 shows the projected increases in installed wind capacity in 2008 and 2017 in various regions.

[31] NERC, "Reliability Concepts, Version 1.0.2" December 2007.

[32] http://www.nerc.com/files/LTRA2008.pdf

Figure 3.1 Projected Increase in Summer Wind Nameplate/Installed Capacity



Additional transmission infrastructure is vital to accommodate large amounts of wind resources into the power grid:

1. Deliver wind energy out of remote regions
2. Smoothing the variable generation output across a broad geographical region.
3. Delivering the ramping and ancillary services to balance supply and demand.

Transmission expansion is a critical element for aggregating the output of variable generation resources to reduce variability and accessing flexible system resources to maintain reliability. System planners and operators are also seeking to increase the use of existing transmission assets, in part to allow increased penetration of variable generation.

Industry Actions: State, provincial, and federal government agencies should consider and factor the impact of variable generation integration on inter-state and international bulk power system reliability into their evaluations. These entities are encouraged to work together to remove obstacles, accelerate siting, and approve permits for transmission line construction. Customer education and outreach programs should be fostered by the electric power industry to improve the public's understanding of the critical need for transmission, the issues and trade-offs, its role in supporting the overall reliability of the bulk power system, and the need for new transmission lines to support variable generation resources.

3.2. Resource Adequacy Planning

The overarching goal of resource planning is to ensure that sufficient energy resources and delivery capacity exists to meet future demand requirements in a reliable and economic manner. All resource planners maintain some percentage reserve margin of capacity over and above their demand requirements to meet state regulatory and regional reliability entity requirements or resource adequacy metrics that are meant to maintain reliability of supply following unexpected system conditions. The reserve margins are determined by calculating the capacity of supply resources, discounted to reflect the potential unavailability of the resource at high risk times.

The analytical processes used by resource planners range from relatively simple calculations of planning reserve margins to very rigorous reliability simulations that calculate system Loss of Load Expectation (LOLE) or Loss of Load Probability (LOLP) values.[33] Most resource planners then periodically confirm the adequacy indicated by the calculated reserve margins through detailed reliability simulations that compare expected demand profiles with specific generating units forced outage rates and maintenance schedules to yield LOLE or LOLP values. The reliability simulations include probabilistic production cost simulations for meeting a specified demand curve from a specified generation fleet while incorporating the forced and unforced outage rates over the simulations.

Because the availability of variable generation energy sources is often weather dependent, which also impacts system demand requirements; there can be consistent correlations between system demand levels and variable generation output. For example, in some cases due to diurnal heating and cooling patterns, wind generation output tends to peak during daily off-peak periods. Also, many areas have experienced wind generation output falling off significantly during summer or winter high-pressure weather patterns that can correspond to system peak demand.[34]

For example, Figure 3.2 below shows the California Independent System Operator (CAISO) aggregate wind generation output over the ten-day July 2006 heat-wave.[35] Aggregate wind generation output during the peak demand hours of each day of the heat-wave ranged from 5 – 10% of nameplate capacity. Wind generation may tend to provide significantly higher output during shoulder months, however, which may be high risk hours for some balancing areas due to other resources being unavailable for maintenance.

---

[33] A traditional planning criterion used by some resource planners or demand-serving entities (LSEs) is maintaining system LOLE below one day in ten years.

[34] EoN Netz Wind Report 2005

[35] CAISO, "Integration of Renewable Resources", November 2007

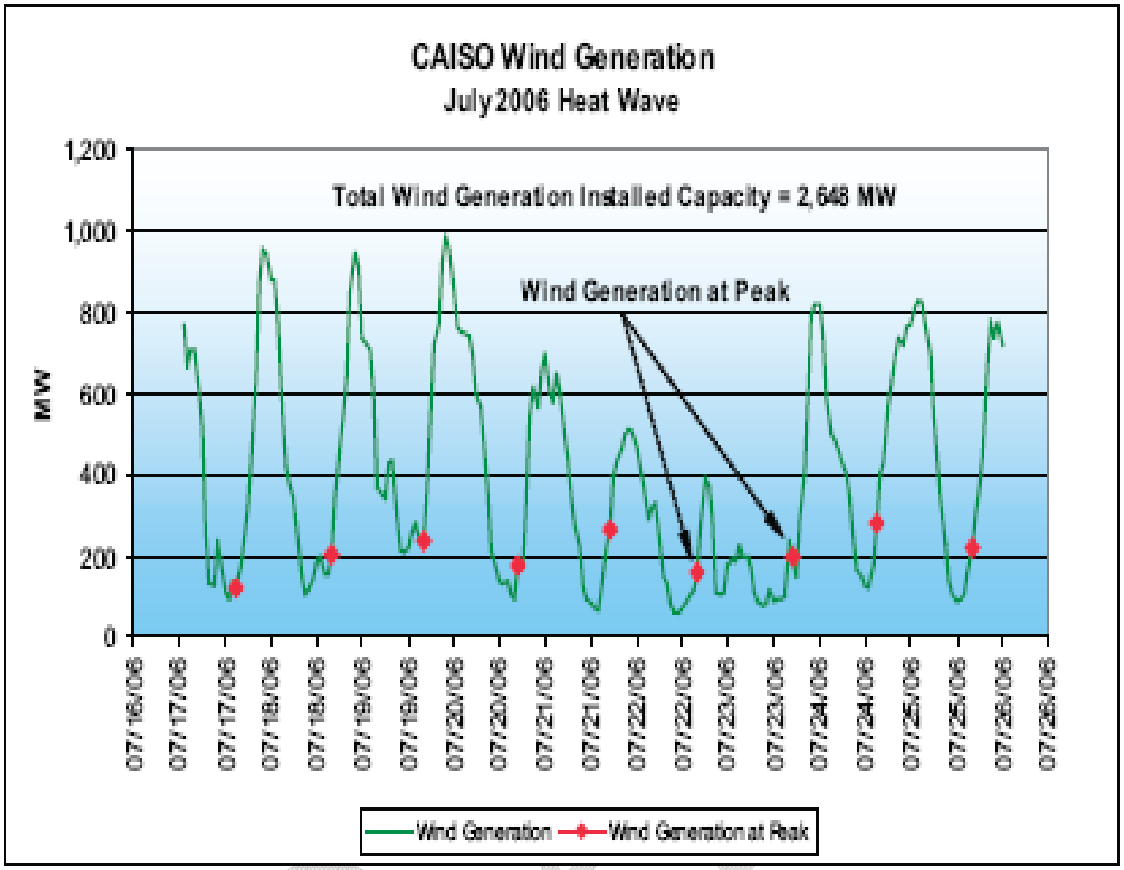


Figure 3.2: CAISO Wind Generation during the 2006 Heat Wave

While planners are accustomed to incorporating the fact that conventional generating units may be unavailable due to forced outage, with increased levels of variable generation, the planner must consider the additional uncertainty in available capacity from a large portion of the total supply portfolio. Traditionally, resource planning has been a capacity-focused process, however, with high penetrations of variable generation energy resources in the system, existing planning methods will have to adapt to ensure that adequate resources are available to maintain bulk power system reliability. The calculation of the capacity contribution of conventional generating units to reserve margins is somewhat straightforward based on the unit nameplate capacity, forced outage rate, and annual unforced maintenance cycle. However, the capacity contribution of variable generation is not as intuitive due to its variable and uncertain characteristics.

Current approaches used by resource planners[36] fall into two basic approaches:

[36] Load Serving Entities (LSEs), Independent System Operators (ISO) and Regional Transmission Operators (RTO)

- A rigorous LOLE/LOLP - based calculation of the Equivalent Load Carrying Capability (ELCC) of the variable generation relative to a benchmark conventional unit; and
- Calculation of the capacity factor (CF) of the variable generation during specified time periods that typically represent high-risk reliability periods (typically peak hours).

The ELCC approach considers all hours in a given year and the contribution of the variable generation output to capacity requirements during all periods. ELCC calculations are typically conducted through reliability simulations that consider conventional generating outage and maintenance characteristics and the hourly annual demand shape. In order to appropriately consider the capacity contribution of variable generation, the output of the variable generation should be represented by an hourly time series that correlates to the hourly demand series to ensure that correlations between the demand and variable generation behavior are properly represented. To perform this analysis, a significant amount of time-synchronized 8760 hourly wind generation data is required and this data is needed for wind generation plants in the specific geographic regions being studied. Further, in the near-term, this data will also be required for wind plants that are yet to be built. Currently, the best approach at obtaining such data is through large-scale numerical weather prediction models. While limited efforts at validating NWP models for specific regional studies have shown that these models can provide good representations of wind output and variability, work is on-going to validate these models for broader use.

Given that the hourly wind generation output will be different in any year based on wind simulations, planners must attempt to ensure accurate representation of the capacity values of the variable generation. Presently, the best approach is to explicitly represent the variable generation output as the historical 8,760 hourly wind generation output from measurements or NWP models that is time synchronized to the system demand 8,760 time series. Because the wind generation output varies from year to year, multiple years of 8,760 wind generation data must be used with the aggregate LOLE results across the multiple simulations considered. The concern with this approach is determining how many years of wind generation output data are required to accurately include the behavior of wind generation as a capacity resource. Future analysis techniques and tools may allow for a truer probabilistic representation of the variable generation output at each hour but the inherent correlations between demand and wind generation output levels must be retained. Thus, any probabilistic approach must not decouple the specific weather driven correlation of variable generation output and demand that characterizes the absolute system peak hours.

The simplified Capacity Factor (CF) approach attempts to approximate the more rigorous ELCC by assuming that the demonstrated output of the variable generation (from historical or synthesized data) during periods which may reflect typical high-risk reliability hours may represent the contribution of variable generation capacity to system reserve margins. The selection of specific time periods for the CF method will likely differ across the continent, and would depend on the specific characteristics of the region and the demand shape. Several entities in the United States use peak period definitions to calculate an approximate wind capacity value, as illustrated in Figure 3.3.[37] As the number of hours included in the time period increases, the results from the CF and ELCC approaches tend to converge. However the ELCC method is the most accurate method to calculate the capacity value of wind but requires much more data and computational resources than the CF approach.

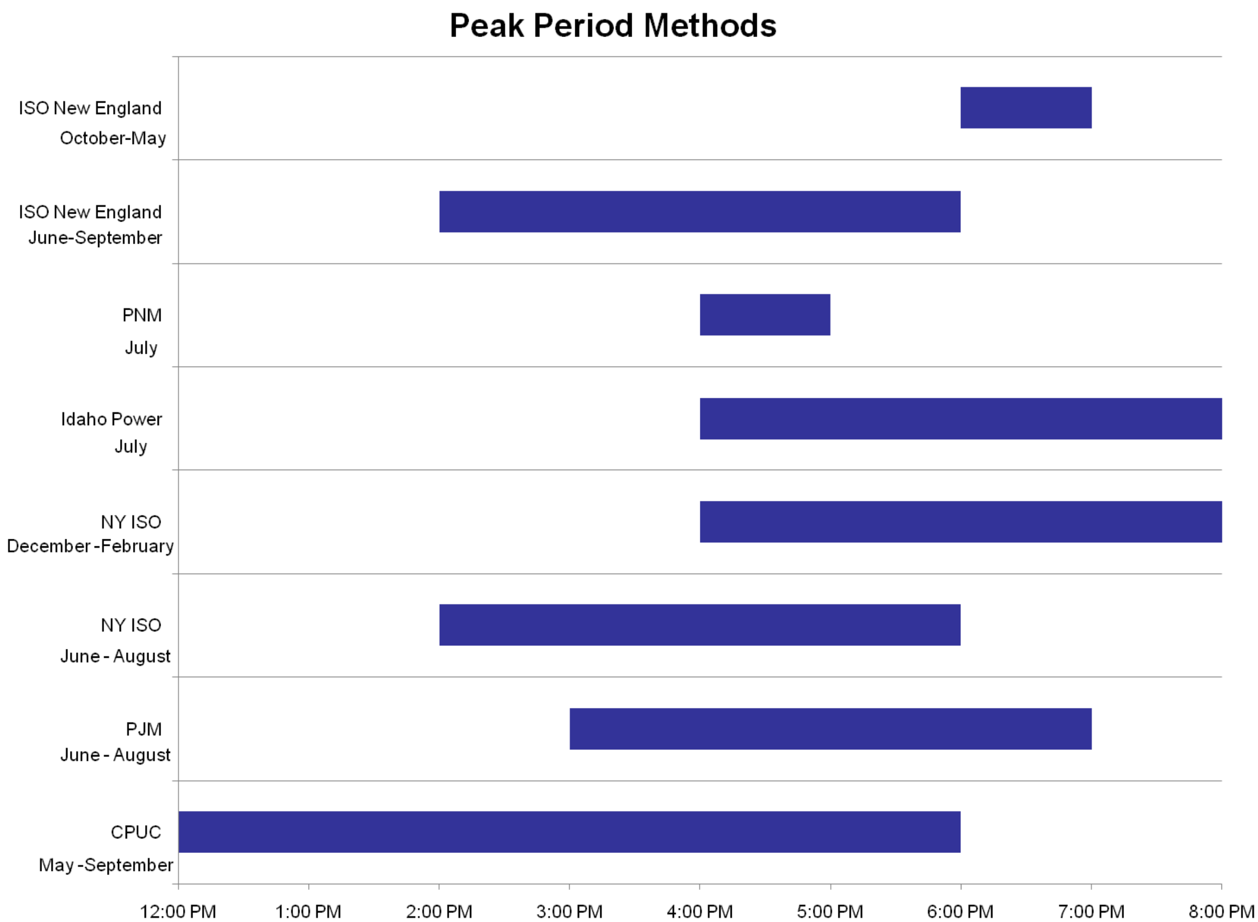
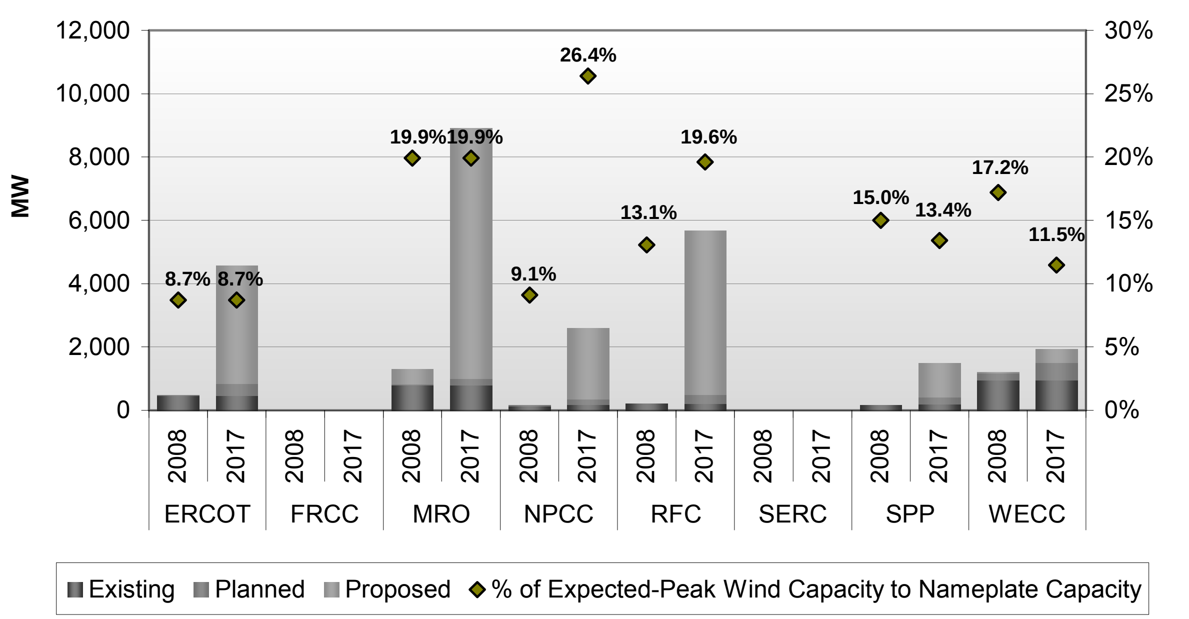


Figure 3.3: Alternative peak periods are used to assess wind capacity value in the U.S. *Note PNM does not have an official method for calculating Capacity Value.*

[37] M. Milligan and K. Porter, "Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation", Presented at Wind Power 2008, June 2008, Houston, Texas

Wind tends to be correlated across a region and the capacity value of wind in relative terms decreases as the penetration of wind increases. Figure 3.4 illustrates the range of capacity values that are currently being employed in North America for wind generation.[38]

Figure 3.4: Projected Increase in Existing, Planned & Proposed Summer On-Peak Wind Capacity



The correlation between the variable generation and the demand is an important factor in capacity value. In addition, the correlation (or lack of it) between different variable generation technologies (e.g. wind and solar) is also an important driver of capacity value. Wind will typically have patterns that are driven by seasonal and diurnal changes. Generation that depends on solar energy as its fuel, on the other hand, has higher outputs in the summer months and closer to midday. Unfortunately, because of differences in fuel availability, it is often hard to find geographic areas that have good resources for both fuel types. However, regions like California can benefit from this diversity of technology because of geographic and climatic diversity. California has both good wind resources in places, like the Tehachapi pass, as well as good solar resources in the sunnier southern portion of the state. Figure 3.5, below, shows California averages of wind output, solar output, demand, and net demand (demand – wind – solar) for July

[38] http://www.nerc.com/files/LTRA2008.pdf

of 2003.[39] Variability around these average values, especially for wind resources, can fluctuate significantly on a daily basis but it does illustrate that solar and wind profiles together on average can be a good match to the load profile and hence improve the composite capacity value for variable generation.

> ***NERC Action:*** The NERC Planning Committee should direct the Reliability Assessment Subcommittee and the Generating Availability Data System (GADS) to collect information related to the capacity value of variable generation based on its contribution to system capacity during high-risk hours when performing its seasonal and long-term reliability assessments. As additional data becomes available (i.e. involving multiple years of hourly-resolution variable generation output data from specific geographic locations and time-synchronized with system demand), NERC should consider adopting the Effective Load Carrying Capability (ELCC) approach.

3.3. Transmission Planning

Because the highest capacity factor wind resources can be remote from large load centers, a sequential evaluation of individual transmission lines needed for the next wind plant based solely on reliability may not justify the transmission needed to deliver the wind generation to the load centers. To satisfy policy objectives and take advantage of longer-term economic opportunities to deliver variable generation from high capacity areas to high cost energy areas may justify the development of more extensive transmission corridors. For example, wind generation development and the associated transmission required to deliver wind energy from the Midwest U. S. to the high energy price regions on the Eastern US coast might be justified by both reliability and economic benefits if the total wind generation in the region and sufficient time horizon is considered. Thus, the basic transmission planning process may have to be altered in order to consider these longer-term economic justifications to enable high variable generation penetration scenarios or to recognize government policy which mandates interconnection of renewable resources.

Furthermore, the appropriate planning process will likely vary depending on certain variables including:

- Whether government renewable policies or mandates exist
- Level of variable generation mandated or available variable generation in remote regions

---

[39] http://www.uwig.org/CEC-500-2007-081-APB.pdf on page 40

- Time horizon across which capital investments are evaluated
- Geographic footprint across which investments are evaluated

For low variable generation penetration levels, the traditional sequential expansion and managing wind variability in balancing areas may be satisfactory. However, identifying concentrated variable generation zones such as in ERCOT's Competitive Renewable Energy Zone (CREZ) process can improve the sequential planning process relative to the site selection of future wind generation and coordination of the transmission expansion.

The ability to manage wind variability and extreme events with the generation resources in the balancing area alone can limit the amount of variable generation that can be reliably integrated. As the level of variable generation increases, the wind variability and extreme events may not be manageable with the generation resources in the balancing area alone. Base load generation might have to be heavily cycled for the local generation to follow the wind variations, posing reliability concerns as well as economic consequences. To integrate higher levels of variable generation, balancing areas may need to be consolidated (see Chapter 4) to share ancillary services over a large generation base. While the traditional sequential reliability planning process may be sufficient to justify the needed transmission expansion in this mode, economic inter area planning methods may be required.

As the level of variable generation increases still further, the sequential planning process with expansion justified only by reliability will likely not provide for the needed transmission expansion. By considering these economic opportunities over a longer time horizon and larger geographic footprint, a high power transfer multiple line transmission overlay capable of delivering large amounts of variable generation energy to and across multiple jurisdictions may be justified. The Midwest Independent System Operator (MISO) has been leading a collaborative study of many of the Eastern Interconnection transmission companies (Joint Coordinated System Planning Study or JCSP)[40] to investigate this type of planning process for a 20% wind penetration level in the Eastern Interconnection.

Increasing the transfer capabilities between balancing areas will allow for greater sharing of resources that can provide the additional required flexibility. Planning/operating reserve levels, ramping and ancillary service requirements as well as the composite capacity value of wind resources are affected significantly when transmission is added (i.e. constraints are removed) for higher wind energy penetration levels. As such, the resource adequacy planning process should no longer be a function of planning the resource mix alone as the transmission system can

[40] www.jcspstudy.org

change the capacity available from wind generation to serve demand. Further, in those regions with a competitive generation marketplace, market participants, any Renewable Portfolio Standards and investors determine the type, location and timing of generation investments and the pace of wind development. In this respect, government Renewable Portfolio Standards and the policy framework and associated cost allocation (i.e. who pays for transmission and additional ancillary services) can be a key driver for variable generation capacity expansion in the US and Canada, again suggesting an iterative approach between transmission and generating resource planning is required to integrate resources.

Transmission expansion is a tool for aggregation and assists in the reduction of overall variability: Sufficient transmission capacity can blend and smooth the output variations of individual wind plants into the summation of the output of very large, aggregated wind power plants across a broad geographical region enabling energy delivery to the power system. For example, wind integration studies such as the New York, Minnesota,[41] California and Texas[42] show that there are significant reliability benefits from being able to obtain ramping and ancillary services from an adjacent large market.

> ***Industry Action:*** State, provincial and federal government agencies and policy makers should be informed of the potential importance of coordinated approach towards transmission and resource planning and assessment efforts.

High voltage transmission overlay expansions can assist in maintaining system reliability while enabling the integration of large amounts of variable generation. There are two alternatives along with a hybrid approach to achieve such integration: high voltage alternating current (HVAC) or high voltage direct current (HVDC) transmission. HVAC transmission is more accessible to tapping as the grid evolves, and thus allowing for the addition of intermediate substations for demand or other generation growth in the area. For very long, over ground distances (wind sites hundreds of miles from demand centers) dedicated HVDC may be a more suitable solution. Offshore applications also offer technical challenges that can preclude HVAC transmission as AC cables beyond distances of roughly 40 km are currently not technically feasible or practical. With the advent of voltage-source converter (VSC) technologies, there are additional HVDC benefits (e.g. reactive power control and black start capability) useful for offshore wind plants.[43]

---

[41] Zavadil et al, Minnesota Wind Integration Study Final Report - Volume I, prepared for the Minnesota Public Utilities Commission, November 2006.

[42] GE Energy, Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements, final report prepared for ERCOT, March 2008.

[43] www.abb.com and www.siemens.com.

3.4. Planning Tools and techniques

One vital goal of transmission planning is to identify and justify capital investments required to maintain power system reliability. The transmission planner is required to identify and advance new transmission facilities to maintain reliable system performance, supply new demand growth, manage transmission congestion, and integrate new generation including consideration of the size, location and technologies of new generation resources. Policy initiatives, such as Renewable Portfolio Standards, are also now significant drivers for reinforcement of transmission infrastructure. In North America today, the standard power flow, time-domain stability, small signal stability and short-circuit duty analyses required to produce such transmission plans are typically done in a deterministic way using verified simulation models of the power system.

With the advent of Renewable Portfolio Standards and increased use of demand response as an energy, ancillary and regulating resource, deterministic approaches to planning may need to be supplemented with more comprehensive analysis including probabilistic assessments to assess the reliability impacts of a variety of scenarios not studied in the past. Large penetration of variable generation, particularly wind generation, also accentuates this challenge. For example, planning studies have typically focused on peak load conditions however wind resources may be peaking or ramping or available at off-peak or during shoulder hours, and the actual performance of the power system (i.e. power flow, voltages, and system stability) may be dramatically different than what has been traditionally studied.

For conventional fossil-fuel, nuclear and hydro generation, the output level of the unit (notwithstanding market and maintenance factors) is highly predictable and dispatchable. Therefore typical unit interconnection analysis will commonly assess the impacts of generation at its peak output, during extreme system demand conditions (i.e. peak and minimum outputs) to assess reliability impacts – this would typically represent the most onerous conditions for identifying the necessary transmission reinforcements for interconnection.

However, this approach may not be adequate or suitable when accommodating large amounts of variable generation on the bulk power system. For instance, it is quite unlikely that wind generators would be at maximum installed output during these peak hours. Since the operational characteristics of wind generation are very different than conventional generation, it is not surprising that the methods used to assess reliability impacts and plan bulk power systems to maintain reliability might also require significant change from traditional methods.

Figure 3.5 illustrates an example of the total wind power distribution in Spain for the years of 2001 through 2005.[44] This figure illustrates that the total wind generation on a power system is rarely at its peak capacity. In this particular example, the median is around 27%. That is, the total wind generation is 50% of the time below 27% and 50% of the time above 27% of its capacity. Thus, it is clear that studying wind generation scenarios just at peak output for a variety of load forecasts scenarios will not be sufficient as it does not represent a very likely scenario.

Use of more probabilistic and risk-based planning methods can augment traditional methods to support reliability analysis. These methods potentially require extensive data sets (e.g. robust wind time series) that properly represent the overall characteristics of the power system with high levels of wind generation.

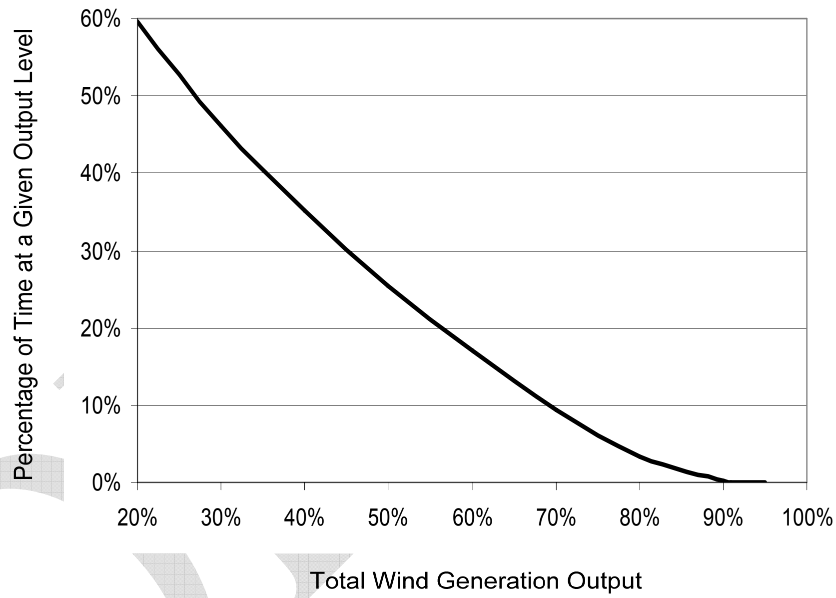


Figure 3.5: Wind power distribution for 2001 – 2005 in Spain.

Given there is limited industry experience in North America with high levels of wind penetration, the necessary detailed datasets are also limited. To ensure the validity of variable generation integration study results, high quality, high resolution (sub hourly if possible) its output data is a required. Historical variable generation data is very limited and difficult to obtain. As substantial amounts of wind generation is expected during the next ten years, industry must begin obtaining the data is required to design robust bulk power systems. To this point in

[44] CIGRE Technical Brochure 328, Modeling and Dynamic Behavior of Wind Generation as it Relates to Power System Control and Dynamic Performance, Prepared by CIGRE WG C4.601, August 2007 (www.e-cigre.org)

time, extensive modeling has been required to generate simulated data produced either directly or indirectly from historical weather data. The use of indirect data is far from ideal and, as real data becomes available, the validity of the original results should be reviewed. There is ample evidence, for example, that wind power outputs during high risk hours have been substantially overestimated.

> ***Industry Action:*** The use of probabilistic transmission expansion planning techniques should be encouraged for planning and designing power systems with high levels of variable generation. Additional research and development on probabilistic power system planning techniques is required.
>
> ***NERC Action:*** The NERC Planning Committee should identify necessary data requirements to conduct planning studies and should recommend that Planning Authorities and Reliability Coordinators collect and retain the data.

3.5. Flexibility in Resource Portfolio

From a planning perspective, the question is how does one ensure that adequate generation reserve, demand side resources or transmission transfer capability to neighboring regions is available to serve demand and maintain reliability during a greater range of operating conditions including severe wind ramping? If the underlying fuel is available, new variable generation technologies can readily contribute to the power system ancillary services and ramping needs, except for upward ramping and regulation beyond the maximum generation. However, unless these newer technologies are designed to provide inertial response, the planner must ensure other sources of inertia are available to meet bulk power system reliability requirements.

A comprehensive variable generation integration study should be conducted where high levels of penetration are expected, to assess the appropriate level of system flexibility to deal with this added variability. There are many different sources of system flexibility including; regulating and contingency reserves, ramping requirements, reactive power reserves, quick start capability, lower minimum generating levels and the ability to cycle conventional generation. Further, system planners must ensure that suitable system flexibility is accommodated into future designs of the bulk power system as it is necessary to deal with the additional variability and uncertainty introduced into power system operations. Variability/uncertainty increases on all time scales (seconds, minutes, hours), but appears to be greatest in the longer time frames.

Although relatively rare, many power systems[45] have experienced significant ramping events and rates that can transverse a large geographic area and can create significant operating challenges.[46] The results of variable generation integration studies must quantify the need for flexibility and the physical resources that the system operator needs to operate the system in light of greater uncertainty and variability.

Many areas also consider the overall system load factor of their system as an indicator of the amount of flexible generation required to operate between minimum daily demand and peak daily demand. For example, in a region with a very high load factor (e.g. Alberta has an annual load factor in excess of 80%) the generation resource mix may have developed with a large amount of baseload generation and will inherently have a lesser amount of dispatchable or flexible generation available to balance variable generation resources which can limit the wind penetration. In addition, the amount of regulating reserves and demand following capacity may also be as little as 1% of the total peak demand.[47] This also underlines the fact that wind integration studies are not generic and the results will be affected by the circumstances and characteristics of each area (i.e. interconnection capability, load factor, system resource mix, etc.).

Minimum standards and/or price signals in those areas with markets can be used to signal valued system characteristics (e.g. fast start, ramp rates, etc.) to both existing and new resources.[48] Wind plant aggregation across broad geographical regions can also significantly reduce output variability, decrease uncertainty and consequently reduce the need for additional flexibility.

> ***NERC Action:*** The NERC Planning Committee's Resource Issues Subcommittee should study changes required to the current resource adequacy assessment processes (e.g., ramping requirements, minimum generation levels, shorter scheduling intervals etc.) including incorporation of wind integration studies into planning processes.
>
> ***Industry Action:*** To the extent possible, minimum requirements and/or market mechanisms (i.e. price signals) should be provided to ensure that conventional generation has the desired characteristics (e.g., ramping requirements, minimum generation levels,

[45] http://www.ercot.com/meetings/ros/keydocs/2008/0313/07._ERCOT_OPERATIONS_REPORT_EECP022608_public.doc

[46] John Dumas, "ERCOT Feb 26, 2008 EECP Event", UWIG, Texas, April, 2008.

[47] EnerNex Corporation. 2006. Final Report: *2006 Minnesota Wind Integration Study*. Volumes I and II. Knoxville, TN: EnerNex. http://www.puc.state.mn.us/docs/#electric

[48] Doherty, R., Lalor, G. and O'Malley, M.J., "Frequency Control in Competitive Electricity Market Dispatch", *IEEE Transactions on Power Systems*", Vol. 20, pp. 1588 - 1596, 2005.

shorter scheduling intervals etc.) to accommodate large amounts of variable generation and foster the development of an appropriate resource mix that will maintain reliability.

3.6. Smart grid developments

There are several developments under the category of "smart grids" which may assist in the large scale integration of variable generation. This may include the deployment of smart meters which should facilitate more demand response, plug-in electric vehicles which are starting to appear on the roads and policies which encourage the installation of storage facilities and generation (much of it variable) on the distribution system. All of these technology developments need to be considered in the integration of variable generation.

Demand response has already been shown in some balancing areas to be a flexible tool for operators to use with wind generation[49] and is a potential source of flexibility equal to supply-side options. Demand response is an asset that can operate in every time frame of interest, from seasons to seconds, supporting with variable generation integration. Demand response programs can be designed to use a variety of demands to achieve response objectives. Different demands have different response capabilities, and different costs to respond. Work is required to identify demand response opportunities and to develop commercial arrangements to obtain significant aggregate response.

Electric vehicles (EVs), including Plug in Hybrid Electric Vehicles (PHEV), may prove to be a source of flexibility for the electric power system sometime in the future. The key technology which presently limits market penetration of electric vehicles is the current state of battery technology (i.e. cost and length of charge).[50] Lightweight, high power density batteries suitable for this application are not yet available at the necessary quantity and price point. As electric vehicles become available, they could also provide energy storage services that will benefit a bulk power system experiencing increasing levels of variability. However, many design hurdles need to be overcome, especially on distribution system where the storage most likely will be discharged, to fully capture the potential benefits of synergies between variable generation and electric vehicles.[51]

In a sense, energy storage may be thought of as bringing together in one location a dispatchable generator and demand. There are numerous storage technologies in various stages of

[49] J. Dumas, "ERCOT February 26, 2008 EECP Event," Presented at UWIG Spring Workshop, Fort Worth, TX, April 2008.

[50] Denholm, P. and Short, W. "An Evaluation of Utility System Impacts and Benefits of Optimally Dispatched Plug-In Hybrid Electric Vehicles" Technical Report NREL/TP-620-40293 Revised October 2006.

[51] Kempton, W and Tomic, J. "Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy", *Journal of Power Sources*, Vol. 144, pp. 280 – 294, 2005.

development and commercialization that can provide additional system flexibility. Pumped hydro comprises the vast majority of energy storage used in the bulk power system today, though applications of flywheels are growing. Another technology that shows promise is Compressed Air Energy Storage which is receiving a lot of attention recently.[52] There are currently two Compressed Air Energy Storage plants operational in world: one each in North America and Germany. The ability of storage to transform energy into capacity has many advantages depending on the technical capabilities and economics of the technology. However, the cost of storage devices compared to other methods of flexibility currently limits their applicability to specific and limited situations. The benefits of energy storage are most broadly realized and valuable when operated as a system resource for the benefit of the entire system, and not in a dedicated mode for any individual resource such as variable generation plant.[53] As a system resource, it may be linked to power system network controls and responsive to system operators to provide ancillary services such as regulation, demand following (ramping), capacity, etc. Since it is a network resource, it is available to balance variability of any combination of sources and demands.

Energy storage is beneficial in integrating variable generation but there are generally more cost effective means of providing the flexibility. The recent Department of Energy 20% by 2030 report indicates that at a 20% wind energy penetration level in the United States, there is no need for storage.[54] Other international studies[55] show that storage is not necessary for penetration levels of over 40% renewable (mainly wind). Deployment of storage can also have perverse results as illustrated by a recent study in the Netherlands where CO_2 emissions increased with increased storage and wind.[56] Energy storage is the subject of a significant amount of Research & Development.

[52] Greenblatt, J.B., Succar, S., Denkenberger, D.C., Williams, R.H., Socolow, R.H., "Baseload wind energy: modeling the competition between gas turbines and compressed air energy storage for supplemental generation", *Energy Policy*, Vol 35, pp. 1474 – 1492, 2007.

[53] Sullivan, P., Short, W and Blair, N. "Modeling the Benefits of Storage Technologies to Wind Power", American Wind Energy Association Wind Power Conference, Houston, Texas, June, 2008.

[54] '20% Wind Energy by 2030 – Increasing Wind Energy's Contribution to U.S. Electricity Supply', U.S. Department of Energy, May 2008.

[55] All Island Renewable Grid Study, Department of Communications Energy and Natural Resources, www.dcenr.gov.ie, 2008.

[56] Ummels, B.C., Pelgrum, E., Kling, W.L., "Integration of large-scale wind power and use of energy storage in the Netherlands electricity supply", *IET Renewable Power Generation*, Vol 2, pp. 34 – 46, 2008.

NERC Action: NERC Planning Committee should assess the influence on reliability of accommodating large amounts of electric vehicles (such as Plug-in Hybrid Electric Vehicles) and storage.

Industry Action: Research and development in demand side management and storage technologies should be encouraged and supported.

Another significant change to the planning process that should be considered is the influence of high levels of variable generation on the distribution system. As the penetration of these resources grows, their influence on bulk system supply and delivery planning cannot be ignored including their variable generation characteristics (e.g. ramping). For example, to maintain bulk power system reliability, distribution system designs may need to be enhanced to accommodate reactive power control requirements,[57] coordinated system restoration, controllability and visibility of variable resources by bulk power system operators and safety concerns. In addition, the NERC Functional Model may need to be enhanced to recognize owners and operators of distributed generation.

In some areas of North America, it is possible that very high penetrations of distribution system connected variable generation could be achieved in future, as has occurred in some regions of Denmark and Germany.[58] Under these circumstances, the requirement for bulk power system voltage ride through capability would be in conflict with the anti-islanding voltage drop-out requirements of distribution connected generation which comply with IEEE Standard 1547. At some point, an effort will need to be made to reconcile bulk power system voltage ride-through requirements and IEEE Standard 1547 to maintain the reliability of the bulk power system. For example, under conditions of high penetration of distributed generation in the network of Western Denmark (25% annual energy), a number of problems affecting bulk system reliability have arisen and are expected to worsen with increased variable generation penetration.

NERC Action: A joint NERC Operating and Planning Committee task force should review and study the impact of distributed generation on bulk power system reliability, and the possible need to recognize owners and operators of distributed generation in the functional model.

Industry Action: Research and development activities to measure the impact on reliability of distributed variable generators should be encouraged and supported.

---

[57] The Danish Cell Project - Part 1: Background and General Approach; Per Lund, Energinet.dk, Denmark. IEEE PES GM, Tampa, 2007

[58] Holttinen H., et al 2007, Design and Operation of Power Systems with Large Amounts of Wind Power: State of the Art Report, VTT Working Paper 82, IEA Wind.

NERC & Industry Action: The NERC Planning Committee and IEEE Power and Energy Society should reconcile bulk power system voltage ride-through requirements and distribution system anti-islanding voltage drop-out requirements of IEEE Standard 1547.

3.7. Summary

Power system planning is intended to ensure that a reliable and robust power system both in terms of generation resources and transmission is available to the power system operator. This Chapter has addressed the need for additional transmission and for the development of new planning methods and techniques that consider the characteristics of variable generation. Power system operations is distinct from power system planning as it is involves the actual real time operation of the system, including supply/demand balance The operational impacts resulting from the large scale integration of variable generation are discussed in the following Chapter.

4. Power System Operations

This chapter describes the key issues and considerations related to the operation of the bulk power system with integration of large scale variable generation, with a focus on wind resources. As discussed in Chapter 2, variable generation at times will produce no energy, produce peak energy during off-peak periods, and may ramp up or down based on the availability and characteristics of its primary fuel. The production, variability and ramping characteristics of variable generation may not correlate well with the system demand (See *Resource Adequacy Planning* in Chapter 3). This chapter first describes the nature of the operational challenges associated with high levels of variable generation on a power system. The chapter then provides a description of potential solutions within three related, but distinct domains: forecasting, commitment and dispatch, and the benefits associated with larger balancing areas.

4.1. Forecasting

Wind power forecasting is one of the key tools that can be used to increase operator awareness and assist the operator in managing wind plant output uncertainty in the future. Rapid developments are occurring in the field of wind plant output forecasting and its application to assisting the operator in managing the additional uncertainty introduced into the hour ahead and day-ahead operations planning processes.[59]

As described in Chapter 2, variable generation resources have a certain amount of inherent uncertainty and forecasting can help to address this uncertainty. It is important to note that in many areas where wind power has developed and not reached high penetration levels, the current uncertainty associated with the wind power may be less or equal to that of demand. Operating experience has been shown that as the amount of wind power increases, there is not an proportional increase in overall uncertainty. Consequently, power system operators have been able to accommodate current levels of wind integration (i.e. less than 5%) and uncertainty with little or no effort.

Power system operators are very familiar with demand forecasting and while there are similarities with forecasting variable generation there are some fundamental differences. The errors in demand forecasting are typically small (of the order of a few %) and are not very sensitive to time horizon i.e. the further out in time the more uncertainty and hence a bigger error. Variable generation forecasting (e.g. wind) is different in that it is very sensitive to horizon with forecast errors growing with the time horizon.

[59] Ahlstrom, M. et al., "The Future of Wind Forecasting and Utility Operations," IEEE Power and Energy Magazine, Nov-Dec 2005. Special Issue: Working With Wind; Integrating Wind into the Power System

Demand Example: On a system with a 10,000 MW peak demand, a 12 hour out forecast could be off by 300 MW (3%) and is unlikely to be off by 1,000 MW.

Wind Example: For a system with 10,000 MW of wind power, a 12 hour forecast could be off by 2,000 MW (20%) and has some chance of being off by 10,000 MW (i.e. no wind).

See for example Figure 4.1 where the standard deviation of the error grows with time horizon. Note that different regions can have different errors, however the errors are larger then demand forecasting and thus are not useful at long time horizons.

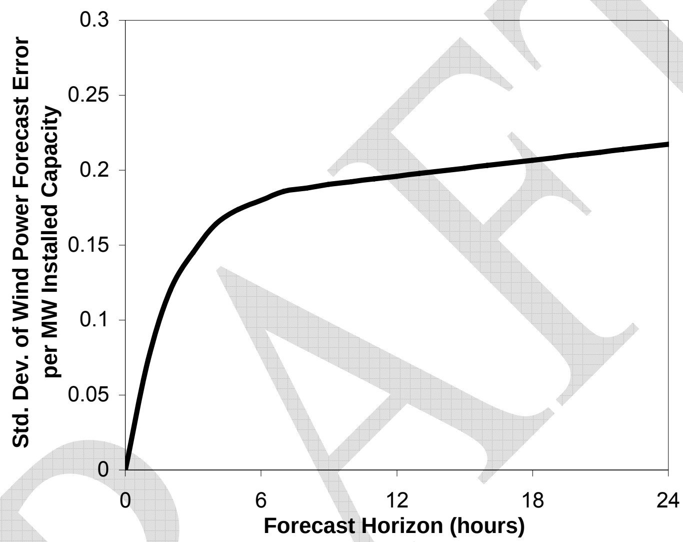


Figure 4.1: Forecast Error as a Function of Horizon[60]

The Alberta Electric System Operator (AESO), in conjunction with the Alberta Energy Research Institute and the Alberta Department of Energy, initiated a wind power forecasting pilot project in the summer of 2006 to trial three different forecasting vendors and methods over the course of a year to determine an effective approach for wind power forecasting in Alberta. As can be seen from the results of this study (see following Figure 4.2), there can be significant variations in the amplitude and phase (i.e. timing) between the actual wind and the aggregate wind forecast. Improvements to short term forecasting techniques, used for real time operation are necessary to provide the system operator with a valuable tool which should be integrated into existing

[60] Doherty, R. and O'Malley, M.J., "Establishing the role that wind generation may have in future generation portfolios", *IEEE Transactions on Power Systems*, Vol. 21, pp. 1415 – 1422, 2006.

platforms, systems and procedures. The project demonstrated forecasting over larger geographic areas improves accuracy[61]

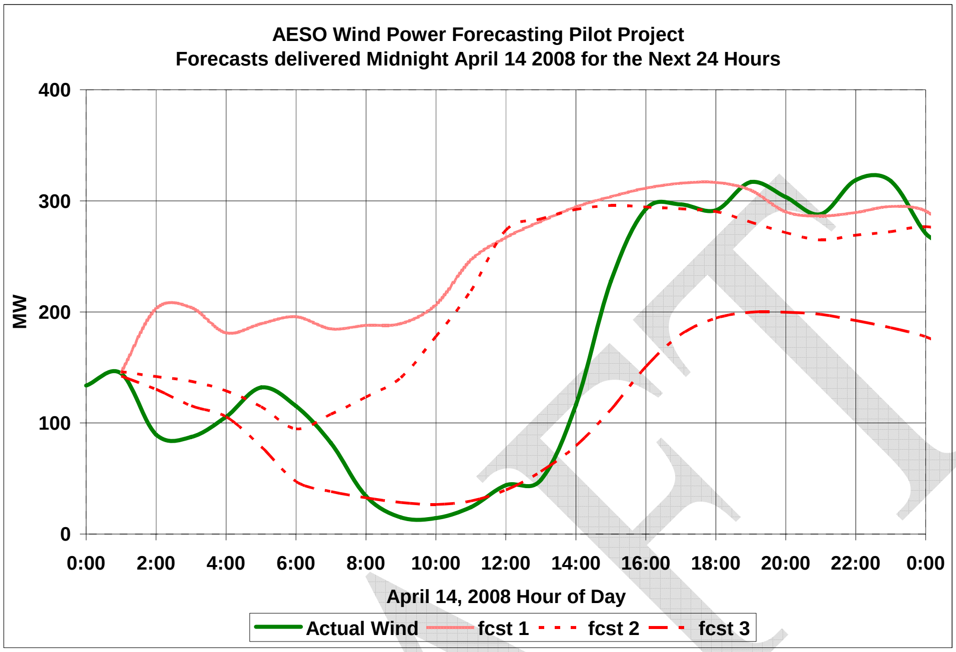


Figure 4.2 AESO Wind Forecasting Pilot

While a significant amount of effort has gone into developing relatively accurate wind plant output forecasts for real-time, hour ahead, and day-ahead operations planning purposes, a significant effort remains to integrate the forecasting products into the actual operations planning procedures and software systems. In fact, the major software vendors are just beginning to pay attention to this emerging need. There are significant efficiencies to be realized through the incorporation of a state-of-the-art wind plant output forecast into the day-ahead market planning and unit commitment procedures. Similarly, there are significant operations concerns and reliability impacts which can be mitigated through the incorporation of rapid-update hour-ahead forecasts into system operating procedures, as illustrated through the recent ERCOT event of February 26, 2008.[62] Actual experience from utilities using forecasting techniques indicates that there are generally four different forecasting products which are useful for improved power system operations and reliability.

- ***Severe Weather Alert*** to improve situational awareness in the control room. This is a real-time system which will enable operators to visualize and react to high wind events.

[61] http://www.aeso.ca/downloads/Work_Group_Paper_Final_(3).pdf

[62] John Dumas, "ERCOT Feb 26, 2008 EECP Event", UWIG, Texas, April, 2008.

An example is the high wind warning system based on a geographic information system platform being developed for Xcel Energy. It includes U.S. Storm Prediction Center watches, warnings, and convective outlooks in both graphical and text format. It also provides high wind forecasts for winds exceeding 20 m/s and real-time color-coded high wind observations.[63] This type of system allows operators to quickly identify the amount of wind generation that may be impacted by an extreme wind event. Power system operators may also be concerned about sudden loss of power from large wind plants under certain weather events due to turbine high speed cut-off.. In addition, cold temperatures can also cause turbine shut-down. These weather conditions can cause all the turbines to shut down after they have been operating at full capacity. Although such condition may be of great concern to the power system operator, data collected to date show little evidence of an event where high winds caused all turbines within a plant to simultaneously reach cut-off, as high wind cause turbines to shut down individually. Rather, experience with several high wind events in Texas show it can take one to two hours for a large wind event to ramp down a significant portion of the wind fleet. Furthermore, it expected that these type of conditions should be predictable events with sufficient lead time allowing for proper corrective actions.

- ***Day-Ahead Forecast*** provides hourly power values typically for an 84-96 hour time horizon and are typically updated every 6-12 hours. This forecast is used by system operators or generation owners in the unit commitment process and can be used for scheduling fuel purchases and deliveries for systems with significant natural gas generation. The uncertainty associated with the wind plant output forecast in this time frame is important to know, and is an area in which significant developments are occurring with using multiple forecasting techniques. Separate forecasts are also developed for delivery nodes.

- ***Hours-Ahead Forecast*** which provides finer time resolution for the next few hours. It is used by operators for next-hour planning, and as input for defensive operating strategies during large ramps in wind power production. The value of this forecast, and the measure of its accuracy, is its ability to identify the magnitude and phase of significant wind events in time for the operators to prepare for them and do something about them. Such actions might include curtailing the output under some scenarios, limiting the up-ramp in other scenarios, or procuring additional ramping and reserve capabilities.

[63] Smith, J. C., Oakleaf, B., Ahlstrom, M., Savage, D., Finley, C., Zavadil, R., and Reboul, J., The Role of Wind Forecasting in Utility System Operation, Paper C2-301, CIGRE, August 2008

- ***Nodal Injection Forecast*** for use in the transmission congestion planning process. Separate forecasts are generated for each delivery node in the transmission system on a day-ahead b*a*sis to help manage transmission congestion and losses.

Some wind forecasting techniques and products will require substantial amounts of data. The data needs can include on-site meteorological data from the wind power facility and electrical data such as real power production and wind power facility real power capability as the sum of turbine availability. This high quality data should be provided in a timely manner through the Energy Management System (EMS) and Supervisory Control and Data Acquisition (SCADA) systems.

The field of wind plant output forecasting has made significant strides in the past 10 years. The progress has been greatest in Europe, which has seen a much more rapid development of wind power than North America. However, the situation is now changing in North America and some control areas have already implemented forecasting systems, others are in the implementation process, and many more are in the information gathering and fact-finding stage.

NERC Action: NERC Operating Committee should ensure that state-of-the-art forecasting requirements are addressed in its review of FAC-001.

Industry Action: Research and development should be encouraged to improve forecasting methods and in particular in niche applications such as severe weather and ramp forecasting.

4.2. Unit Commitment and Dispatch

The unit commitment and dispatch process ensures that the bulk power system under normal conditions will operate with sufficient capacity on-line to serve demand, reserves and to respond to generator contingencies. The expected increase in variable generation on the bulk power system will significantly increase the amount of operational uncertainty that the system operator must factor into operating decisions. The system operator must also have the ability to dispatch the available supply resources including variable generation. In practical terms, the system operator may decide to commit additional capacity for ancillary services and/or energy, use demand side management, or use power management (i.e. ramp rate or power limiting) of the variable generation in anticipation of a forecast ramping event that may or may not actually occur. On the surface, this may seem inefficient but the system operator must make operating decisions based on the best available information in order to ensure system reliability. In this respect, it is critical that practices and procedures respecting wind forecasting, operating guidelines, unit commitment practices, reserve practices, use of demand side resources (see Chapter 3) and use of wind power management are reviewed and enhanced to assist the system operator in managing the increased uncertainty from variable generation. This may also include the consideration and use of probabilistic operating criteria and techniques.

Another operating challenge with variable generation is the possibility of over-generation during light load conditions when conventional generation is dispatched to its minimum operating level. The power system operator must have the ability to limit or reduce the output of variable generation, on an as needed basis to maintain system reliability during over-generation periods.

> **NERC Action:** The NERC Operating Committee should study operational tools that are suitable for large levels of variable generation, in particular, probabilistic methods to forecast uncertainty and should increase the awareness of these needs through established NERC programs and/or initiatives.

4.3. Larger Balancing Areas and Reduced Scheduling Intervals

Utilities have taken advantage of demand aggregation and interconnected system operation for decades. Since each balancing area only has to compensate for the variability of its own aggregate demand and since random variations in individual demands partially cancel each other out, larger balancing areas require relatively less system balancing through "regulation" and ramping services than smaller balancing areas to maintain reliable system performance such as the NERC Control Performance Standards. Larger balancing areas may also offer similar benefits as it relates to the large scale integration of variable generation.[64]

A larger balancing area can also lead to increased diversity of variable generation resources and also provide greater access to more dispatchable resources, thus increasing the ability of the bulk power system to accommodate variable generation.. Balancing authorities should evaluate the benefits of consolidation or participating in wider-area arrangements such as ACE sharing or Wide Area Energy Management systems.

More frequent or shorter scheduling intervals for energy transactions may also assist in the large scale integration of variable generation. Balancing areas that schedule the interconnections on an hourly basis must have sufficient balancing resources to maintain the schedule for the hour. If these scheduling intervals are reduced for example to 10 minutes, the interconnections between the BA's start to look like dispatchable generators which increases the flexibility of both BA's and increases the ability to manage large scale variable generations.

> ***NERC Action:*** The NERC Operating Committee should review and study the consequences of larger balancing areas or participation in wider-area balancing management like ACE sharing and/or shorter scheduling intervals within and between

[64] Report for the International Energy Agency by Holttinen et al in 2007

balancing areas so that variability of generation resources can be managed over a larger footprint. In addition or alternatively, new methods such as the proposed BAL standard (new BAL 007- BAL 011), should be given greater prominence and promotion by NERC. This can be viewed as a complementary route to achieve a comparable goal.

Industry Action: State, provincial and federal government agencies and policymakers should be informed of the potential benefits of larger balancing areas and the desirability of more frequent scheduling intervals, including sub-hourly schedules or regional dispatch optimization for those areas or transmission providers that do not yet permit this technique.

4.4. Summary

The expected increase in variable generation on the bulk power system will significantly increase the amount of operational uncertainty that the system operator must factor into operating decisions. To manage this increased uncertainty, the system operator must have access to advanced wind forecasting techniques and sufficient dispatchable resources to mitigate the variability associated with the large scale integration of variable generation. In this respect, operator tools, practices and procedures regarding wind forecasting, commitment, scheduling and balancing will need to be enhanced to assist operators in maintaining bulk power system reliability.

5. Conclusions & Recommended Actions

The addition of renewable variable generation is expected to grow considerably as policy and regulations on Greenhouse Gas emissions are being developed by individual states and provinces throughout the North America. This proposed level of commitment to renewable variable generation offers many benefits such as new generation resources, fuel diversification, and greenhouse gas reductions, as well as certain new and significant challenges.

As a major shift in resource allocation is underway, it is imperative that power system planners and operators understand the potential reliability impacts associated with large scale integration of variable generation and what techniques, options and resources may be used to reliably integrate variable generation resources into the bulk power system. This understanding should be accompanied by changes in bulk power system planning and operations to ensure reliability.

Following is a summary of the consolidated conclusions, recommended actions and observations developed by the IVGTF:

1. **Planners must consider the impacts of variable generation in power system planning and design and develop necessary practices and methodologies to maintain bulk power system reliability (NERC's Planning Committee)**

1.1. Consistent methods are needed to calculate energy and capacity values attributable to variable generation.

1.2. Probabilistic expansion analysis can support study of bulk power system designs to accommodate large amounts of variable generation.

1.3. Resource adequacy and transmission planning processes must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design.

1.4. Variable distributed resources can have a significant impact on reliability and must be accommodated in system design.

1.5. Integration of large amounts of plug-in hybrid electric vehicles; storage and demand response programs may provide additional resource flexibility and can positively influence bulk power system reliability.

1.6. Standard, generic, non-confidential power flow and stability models are required to enable planners to maintain bulk power system reliability.

2. **Operators may require new tools and enhanced NERC Standards to maintain bulk power system reliability (NERC's Operating Committee)**

2.1. Forecasting techniques should be incorporated into day-to-day operating routines/practices and unit commitment, dispatch and operations planning policies.
2.2. The influence of larger balancing areas on bulk power system reliability requires study..
2.3. Enhanced grid codes may be required to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response.
2.4. Balancing Authorities must have adequate communications and control of variable resources.

3. **Planners and Operators would benefit from a reference manual which describes the changes required to plan and operate a bulk power system accommodating large amounts of variable generation.**

3.1. Write a Reference Manual geared to educate bulk power system planners and operators on how to reliably integrate large amounts of variable generation.

In addition, a number of industry actions, which are not activities that fall under NERC are suggested by the IVGTF:

4. Industry Actions

4.1. Ongoing industry activities (e.g. Institute of Electrical and Electronic Engineers (IEEE) and Western Electric Coordinating Council (WECC)) assessing short circuit characteristics of variable generation should be supported and an increased awareness of the issues should be encouraged.
4.2. Variable generation manufacturers should provide access to the Modeling, Data and Analysis Standards (MOD) and materials. Variable generation manufacturers should be informed of the need for detailed models to support special system studies.
4.3. To the extent possible, practices, minimum requirements and/or market mechanisms (i.e. price signals) should be developed to ensure that conventional generation has the desired characteristics (e.g., ramping requirements, minimum generation levels, shorter scheduling intervals etc.) and also to foster the development of an appropriate resource mix that will support reliability.
4.4. State, provincial, and federal agencies and policy makers should consider:
   4.4.1. The impact of variable generation integration on inter-state and international bulk power system reliability into their oversight and evaluations.
   4.4.2. Collaborative efforts to remove obstacles, accelerate siting, and approve permits for transmission line construction.

4.4.3. The potential importance of coordinated approach towards transmission and resource planning and assessment efforts.

4.5.5. The potential benefits of larger balancing areas and the desirability of more frequent scheduling intervals, including sub-hourly schedules or regional dispatch optimization.

4.6. The following industry research and development activities should be encouraged:

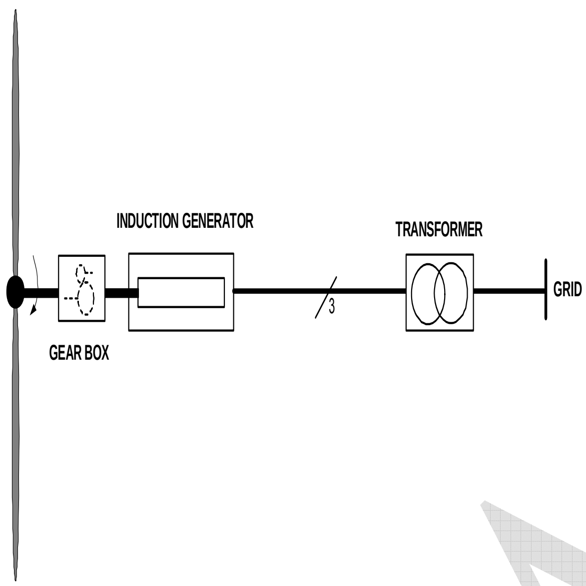
4.6.1. Development of demand side management and storage technologies

4.6.2. Ongoing monitoring of the impact on reliability of distributed variable generators.

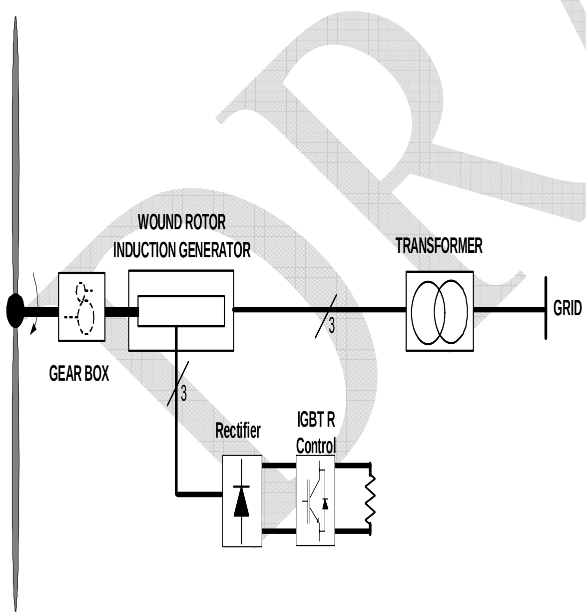
4.6.3. Ongoing improvements to forecasting methods, in particular, specific applications such as severe weather forecasting.

4.6.4. Adoption of probabilistic power system planning techniques.

Appendix I: Wind-Turbine Generation (WTG) Technologies

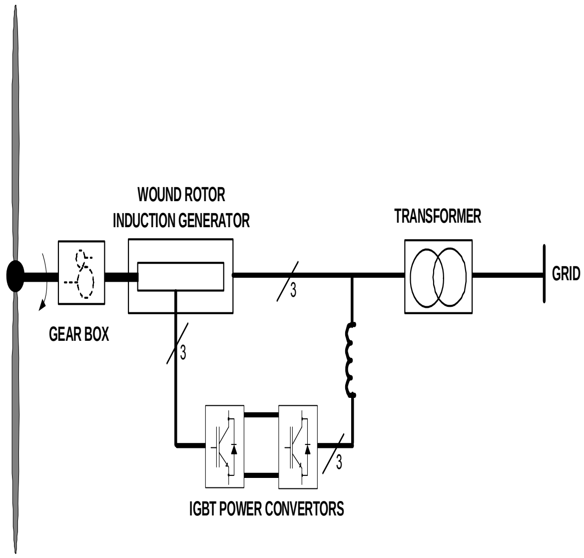


(a) Type 1 Wind Turbine-Generator: Fixed Speed Induction Generator

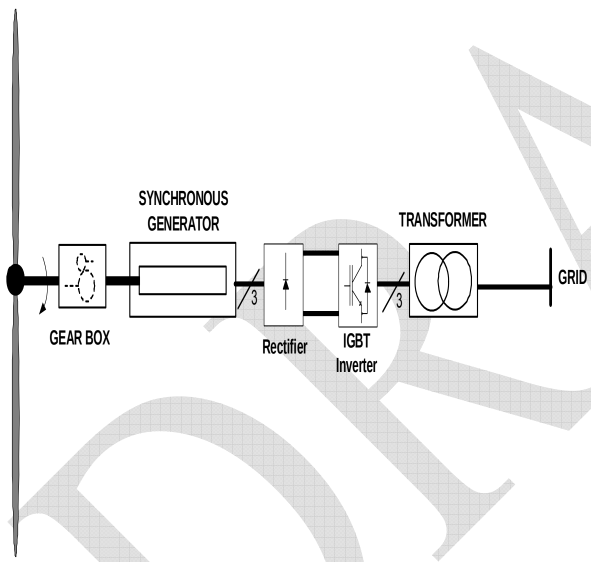


(b) Type 2 Wind Turbine-Generator: Variable Slip Induction Generator [65]

[65] IBGT R control= Isolated Gate Bi-Polar Transistor controlled by Resistor



(c) Type 3 Wind Turbine-Generator: Double-Fed Asynchronous Generator



(d) Type 4 Wind Turbine-Generator: Full Power Conversion

Appendix II: 2009-2011 NERC Objectives and Work Plan

To manage the uncertainty and variability associated with integrating large amounts of variable generation, changes are required to Planning and Operations to maintain bulk power system reliability. As part of the first phase of NERC's Integration of Variable generation Task Force (IVGTF) activities, it studied the gaps in industry's understanding and need for NERC Standards activities. The following objectives and work plan act as a guide for the next phase of the IVGTF activities:

Objectives

1. **Planners must design suitable systems to maintain bulk power system reliability (NERC's Planning Committee)**

    1.1. Consistent methods are needed to calculate variable resource energy and capacity

    1.2. Probabilistic expansion analysis can support study of bulk power system designs to accommodate larges amounts of variable generation

    1.3. Resource adequacy and transmission planning process must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design

    1.4. Variable distributed resources can have a significant impact on reliability and must be accommodated in system design

    1.5. Integrating large amounts of plug-in hybrid electric vehicles, storage and demand response designed to provide resource flexibility can influence bulk power system reliability.

    1.6. Standard, generic, non-confidential power flow and stability models are required to enable planners to maintain bulk power system reliability

2. **Operators may require new tools and enhanced NERC Standards to maintain bulk power system reliability (NERC's Operating Committee)**

    2.1. Integrate forecasting techniques into day-to-day operating routines/practices and change operating practices in unit commitment, dispatch and operations planning policies

    2.2. The influence of larger balancing areas on bulk power system reliability, useful in providing ancillary services for variable resources, requires study.

    2.3. Integrating forecasting techniques into day-to-day operating routines/practices and changing operating practices in unit commitment, dispatch and operations planning will be required

2.4. Enhanced grid codes may be required to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response.

2.5. Balancing areas need to have adequate communications and control of variable resources

3. **Planners and Operators may benefit from a reference manual to support the changes required to plan and operate a bulk power system accommodating large amounts of variable generation.**

   3.1. Write a Reference Manual geared to educate bulk power system planners and operators on how to reliably integration large amounts of variable generation.

2009-11 Work Plan Summary

Following are the proposed 2009-11 improvements and work plan recommended by the IVGTF to the OC/PC. The overall work plan and schedules can be found in the Appendix III.

1. ***Planners must design systems that maintain bulk power system reliability***
   The goal of this effort is to identify what bulk power system planners must do to accommodate large amounts of variable generation. The primary goal is to provide more consistency in reporting regional resource reliability assessment results, including but not limited to methods to calculate energy and capacity, probabilistic analysis, coordinated generation/transmission planning processes, study of distributed resources, impacts of integrating large amounts of storage and demand response, and wind plant modeling requirements.

1.1. Consistent methods are needed to calculate variable resource energy and capacity

- **Resource Issues Subcommittee (2009)**
  Investigate consistent approaches for calculating resource energy and capacity associated with variable generation for the following methods:
  - Effective Load Carrying Capability (ELCC) approach
  - Contribution of variable generation to system capacity for high-risk hours
  - Estimate resource contribution using historical data

1.2. Probabilistic expansion analysis can support study of bulk power system designs to accommodate larges amounts of variable generation

- **IVGTF (2009) – Planning sub-group**
  Define probabilistic techniques/criteria that can be used in expansion analysis with variable generation and transition road map for system planning. A guidebook on study methods will be produced.

1.3. Resource adequacy and transmission planning process must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design

- **IVGTF (2009) – Planning sub-group**
  - Study resource and transmission planning processes to include variable generation characteristics such as ramping, fuel mix, minimum generation levels, shorter scheduling intervals, etc.
  - Identify necessary data requirements to support resource adequacy assessment and which NERC entities should collect, retain and provide this data.

1.4. Variable distributed resources can have a significant impact on reliability and must be accommodated in system design

- **IVGTF (2009) – Planning sub-group**
  - Study the impact of distributed variable generation on bulk power system reliability. The task force should make recommendations about recognizing owners and operators of distributed generation into *NERC's Functional Model*.
  - Engage the Institute of Electrical and Electronic Engineers (IEEE) Standards Coordinating Committee #21 (SCC21) "Standards Coordinating Committee on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage" should reconcile voltage ride-through requirements for distributed resources and IEEE 1547 Standard for *Interconnecting Distributed Resources with Electric Power Systems*.

1.5. Integrating large amounts of plug-in hybrid electric vehicles, storage and demand response along with smart grid technology all designed to provide resource flexibility can influence bulk power system reliability.

- **IVGTF (2009) – Planning sub-group**
  Assess the influence on bulk power system reliability of accommodating large amounts of charging/discharging battery electric vehicles, storage and demand response along with smart grid technology, including integration on the distribution system.

1.6. Standard, generic, non-confidential power flow and stability models are required to enable planners to maintain bulk power system reliability

- **IVGTF (2009) – Planning sub-group**
  Review the Modeling, Data and Analysis Standards[66] (MOD) for improvements required to support simulation of high amounts of variable generation.

[66] http://www.nerc.com/page.php?cid=2|20

2. ***Operators may require new tools and enhanced NERC Standards to maintain bulk power system reliability***
The goal of this effort is to identify gaps and solutions required by operators to accommodate large amounts of variable generation. The primary goal is to study operator tool enhancements, balancing area capability/size, and Standards/Criteria required by system operators to maintain bulk power system reliability.

2.1. Integrate forecasting techniques into day-to-day operating routines/practices and change operating practices in unit commitment, dispatch and operations planning policies

- **IVGTF (2009) – Operations sub-group**
Study variable resource-forecast tool requirements suitable for large amounts of variable generation and identify any gaps.

2.2. The influence of larger balancing areas on bulk power system reliability, useful in providing ancillary services for variable resources, requires study.

- **IVGTF (2009) – Operations sub-group**
Study the influence on bulk power system reliability of enlarging balancing areas. Area Control Error (ACE) sharing and/or shorter scheduling intervals between and within areas should also be investigated.

2.3. Variable generation forecasts for multiple time frames are critical to reduce uncertainty and maintain system reliability.
2.4. Enhanced grid codes may be required to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response.
2.5. Balancing areas need to have adequate communications and control of variable resources

- **IVGTF (2009) – Operations sub-group**
Review NERC's Facilities Design, Connections, and Maintenance (FAC) Standard FAC-001-0[67] entitled, "Facility Connection Requirements," to ensure that the following are addressed:
    - State-of-the-art variable resource forecast requirements.
    - Appropriate grid codes are in place.
    - Along with COM-002-2[68] and registry criteria, ensure adequate communications and control

[67] http://www.nerc.com/files/FAC-001-0.pdf

[68] http://www.nerc.com/files/COM-002-2.pdf

If these Standards and criteria are found to be inadequate, action should be initiated to remedy (e.g. Standards Authorization Request, registry criteria enhancement, etc.).

3. ***Planners and Operators may benefit from a reference manual to support the changes required to plan and operate a bulk power system accommodating large amounts of variable generation.***
The goal of this effort is write a reference guide outlining the planning, design and operating considerations needed to integrate large amounts of variable generation.

.

3.1. Write an industry reference manual

- **IVGTF (2009)**
  From the materials provided as background to this report, develop a comprehensive reference manual useful for bulk power system planners and operators.

2009-2011 Plan & Time Table provide background this plan in Appendix III.

Appendix III: 2009–2011 Plan

1. ***Planners must design systems that maintain bulk power system reliability***
   The goal of this effort is to identify what bulk power system planners must do to accommodate large amounts of variable generation and provide more consistency in reporting regional resource reliability assessment results, including but not limited to methods to calculate energy and capacity, probabilistic analysis, coordinated generation/transmission planning processes, study of distributed resources, impacts of integrating large amounts of storage and demand response, and wind plant modeling.

2009 Action Plan

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.1	Consistent methods are needed to calculate variable resource energy and capacity	Collect variable generation capacity values based on their contribution to system capacity during high-risk hours. The Effective Load Carrying Capability (ELCC) approach to determine variable generation capacity values should be adopted.	Resource Issues Subcommittee	Investigation of consistent approaches for calculating resource energy and capacity associated with variable generation for the following methods: • Effective Load Carrying Capability (ELCC) approach • Contribution of variable generation to system capacity during high-risk hours • Estimate resource contribution with historical data	• October-November 2008 assessment data requests for 2009 to include new definitions

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.2	Probabilistic expansion analysis can support study of bulk power system designs to accommodate larges amounts of variable generation	Define probabilistic techniques/criteria that can be used in expansion analysis with variable generation and transition road map for system planning.	*Ad Hoc* group: Members from IVGTF - Planning	A guidebook on study methods will be produced.	• Draft guidebook ready by September 2009 PC meeting • Final sent to PC for endorsement in December 2009
1.3	Resource adequacy and transmission planning process must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design	- Study resource and transmission planning processes to include variable generation characteristics such as ramping, fuel mix, minimum generation levels, shorter scheduling intervals, etc. - Identify necessary data requirements to support resource adequacy assessment and which NERC entities should collect, retain and provide this data.	*Ad Hoc* group: Members from IVGTF - Planning	A report defining how to include variable generation into resource and transmission planning. Data needs identified/and recommendations responsible NERC entities	• Draft report ready by September 2009 PC meeting • Final sent to PC for endorsement in December 2009 • Based on report results, develop Data Authorization Request in 2009.
1.4	Variable distributed resources can have a significant impact on reliability and must be accommodated in system design	• Study the impact of distributed variable generation on bulk power system reliability. The task force should make recommendations about recognizing owners and operators of distributed generation into *NERC's Functional Model*. • Engage the IEEE Standards coordinating Committee # 21 (SCC21) on Fuel Cells, Photovoltaics, Dispersed Generation and Energy Storage to reconcile voltage ride-through requirements of distributed generation and the IEEE Standard 1547.	*Ad Hoc* group: Members from IVGTF - Planning	• Report on impacts of distributed generation on reliability and recommendations for *NERC's Functional Model.* • NERC stakeholder engagement to reconcile IEEE & NERC standards. Identify any gaps in NERC Standards	• Draft report ready by September 2009 PC meeting • Final sent to PC for endorsement in December 2009 • Begin NERC/IEEE joint activities to updated IEEE Standards. • Develop SAR with the Standards Committee if required.

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.5	Integrating large amounts of plug-in hybrid electric vehicles, storage and demand response along with smart grid technology, designed to provide flexibility can influence bulk power system reliability.	Assess the influence on bulk power system reliability of accommodating large amounts of charging/discharging battery electric vehicles, storage and demand response along with smart grid technology, including integration on the distribution system.	*Ad Hoc* group: Members from IVGTF - Planning	Report reviewing the impact on bulk power system reliability of integrating large amounts of distributed stationary and mobile storage along with smart grid technology. Gaps and next steps identified.	• Draft report ready by September 2009 PC meeting • Final sent to PC for endorsement in December 2009
1.6	Standard, generic, non-confidential power flow and stability models are required to enable planners to maintain bulk power system reliability	Review the Modeling, Data and Analysis Standards[69] (MOD) for improvements required to support simulation of high amounts of variable generation.	*Ad Hoc* group: Members from IVGTF - Planning	Make recommendations and identify changes needed to NERC's MOD Standards	• Draft report ready by June 2009 PC meeting • Final report sent with recommendations to PC for endorsement in September 2009 • Develop SAR with Standards Committee if required.

[69] http://www.nerc.com/page.php?cid=2|20

2010 Action Plan

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.1	Consistent methods are needed to calculate variable resource energy and capacity	- Collect variable generation capacity values based on their contribution to system capacity during high-risk hours. - The Effective Load Carrying Capability (ELCC) approach to determine variable generation capacity values should be adopted.	Resource Issues Subcommittee	Investigation of consistent approaches for calculating resource energy and capacity associated with variable generation for the following methods: • Effective Load Carrying Capability (ELCC) approach • Contribution of variable generation to system capacity during high-risk hours • Estimate resource contribution using historical data	• October-November 2009 assessment data requests for 2010 to include new definitions

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.3	Resource adequacy and transmission planning process must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design	- Study resource and transmission planning processes to include variable generation characteristics such as ramping, fuel mix, minimum generation levels, shorter scheduling intervals, etc. - Identify necessary data requirements to support resource adequacy assessment and which NERC entities should collect, retain and provide this data.	*Ad Hoc* group: Members from IVGTF - Planning	Data Authorization Request vetted by industry and added to *NERC's Rules of Procedures*.	• Completed by December 2010 PC meeting
1.4	Variable distributed resources can have a significant impact on reliability and must be accommodated in system design	• Study the impact of distributed variable generation on bulk power system reliability. The task force should make recommendations about recognizing owners and operators of distributed generation into *NERC's Functional Model*. • Engage the IEEE Standards coordinating Committee # 21 (SCC21) on Fuel Cells, Photovoltaics, Dispersed Generation and Energy Storage to reconcile voltage ride-through requirements of distributed generation and IEEE Standard 1547.	*Ad Hoc* group: Members from IVGTF - Planning	• NERC stakeholder engagement to reconcile IEEE & NERC standards. • Identify gaps in current NERC Standard and develop SAR.	• Fully reconcile IEEE Standards. • Add distributed generator owners and operators to NERC's Function Model • Ballot any NERC Standards.

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.5	Integrating large amounts of plug-in hybrid electric vehicles, storage and demand response designed to provide resource flexibility can influence bulk power system reliability.	Assess the influence on bulk power system reliability of accommodating large amounts of charging/discharging battery electric vehicles, storage and demand response along with smart grid technology, including integration on the distribution system.	*Ad Hoc* group: Members from IVGTF - Planning	Next steps developed in 2009 completed.	• Draft report ready by September 2010 PC meeting • Final sent to PC for endorsement in December 2010
1.6	Standard, generic, non-confidential power flow and stability models are required to enable planners to maintain bulk power system reliability	Review the Modeling, Data and Analysis Standards[70] (MOD) for improvements required to support simulation of high amounts of variable generation.	*Ad Hoc* group: Members from IVGTF - Planning	Make recommendations and write SAR to improve the MOD standards to support variable generation integration	• Ballot Standard.

[70] http://www.nerc.com/page.php?cid=2|20

2011 Action Plan

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.3	Resource adequacy and transmission planning process must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design	- Study resource and transmission planning processes to include variable generation characteristics such as ramping, fuel mix, minimum generation levels, shorter scheduling intervals, etc. - Identify necessary data requirements to support resource adequacy assessment and which NERC entities should collect, retain and provide this data.	*Ad Hoc* group: Members from IVGTF - Planning	Data collection to support industry efforts to study resource and transmission process including variable generation	• Data Collection system and initial report to PC at December 2011 meeting

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
1.4	Variable distributed resources can have a significant impact on reliability and must be accommodated in system design	• Study the impact of distributed variable generation on bulk power system reliability. The task force should make recommendations about recognizing owners and operators of distributed generation into *NERC's Functional Model*. • Engage the IEEE Standards coordinating Committee # 21 (SCC21) on Fuel Cells, Photovoltaics, Dispersed Generation and Energy Storage to reconcile voltage ride-through requirements of distributed generation and the current IEEE Standard 1547.	*Ad Hoc* group: Members from IVGTF - Planning	NERC Standard.	• Complete Standard by December 2011.
1.6	Standard, generic, non-confidential power flow and stability models are required to enable planners to maintain bulk power system reliability	Review the Modeling, Data and Analysis Standards[71] (MOD) for improvements required to support simulation of high amounts of variable generation.	*Ad Hoc* group: Members from IVGTF - Planning	Enhanced NERC MOD Standards.	• Complete Standards by December 2011

[71] http://www.nerc.com/page.php?cid=2|20

2. Operators may require new tools and enhanced NERC Standards to maintain bulk power system reliability

The goal of this effort is to identify gaps and solutions required by operators to accommodate large amounts of variable generation. The primary goal is to study operator tool enhancements, balancing area capability/size, and Standards/Criteria required by system operators to maintain bulk power system reliability.

2008 Action Plan

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
2.1	Integrate forecast techniques into day-to-day operating routines/practices and change operating practices in unit commitment, dispatch and operations planning policies	Study variable resource-forecast tool requirements suitable for large amounts of variable generation and identify any gaps.	*Ad Hoc* group: Members from IVGTF - Operations	Report outlining current state-of-the-art for variable forecasting and identification of gaps	• Draft report ready by September 2009 CC meeting • Final sent to PC for endorsement in December 2009
2.2	The influence of larger balancing areas on bulk power system reliability, useful in providing ancillary services for variable resources, requires study.	Study the influence on bulk power system reliability of enlarging balancing areas. Area Control Error (ACE) sharing and/or shorter scheduling intervals between and within areas should also be investigated.	*Ad Hoc* group: Members from IVGTF - Operations	Report outlining the impacts and benefits of balancing area enlargement and shorter scheduling intervals	• Draft report ready by September 2009 OC meeting • Final sent to OC for endorsement in December 2009

2009 Action Plan

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
2.3	Integrate forecasting techniques into day-to-day operating routines/practices and change operating practices in unit commitment, dispatch and operations planning	Review NERC's Facilities Design, Connections, and Maintenance (FAC) Standard FAC-001-0[72] entitled, "Facility Connection Requirements," to ensure that the following are addressed: • State-of-the-art variable resource forecast requirements. • Appropriate grid codes are in place. • Along with COM-002-2[73] and registry criteria, ensure adequate communications and control If these Standards and criteria are found to be inadequate, action should be initiated to remedy (e.g. Standards Authorization Request, registry criteria enhancement, etc.).	*Ad Hoc* group: Members from IVGTF - Operations	Report outlining the review of NERC standards, along with next steps. Action to remedy to gaps in the NERC Standards	• Draft report ready by June 2009 OC meeting • Final sent to OC for endorsement in September 2009 • Develop SAR with the Standards Committee by December.
2.4	Enhanced grid codes may be required to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response.				
2.5	Balancing areas need to have adequate communications and control of variable resources				

[72] http://www.nerc.com/files/FAC-001-0.pdf

[73] http://www.nerc.com/files/COM-002-2.pdf

2010 Action Plan

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
2.3	Integrate forecasting techniques into day-to-day operating routines/ practices and change operating practices in unit commitment, dispatch and operations planning	Review NERC's Facilities Design, Connections, and Maintenance (FAC) Standard FAC-001-0[74] entitled, "Facility Connection Requirements," to ensure that the following are addressed: • State-of-the-art variable resource forecast requirements. • Appropriate grid codes are in place. • Along with COM-002-2[75] and registry criteria, ensure adequate communications and control If these Standards and criteria are found to be inadequate, action should be initiated to remedy (e.g. Standards Authorization Request, registry criteria enhancement, etc.).	*Ad Hoc* group: Members from IVGTF - Operations	• Write SAR to improve NERC Standards to support variable generation integration	• Ballot NERC Standards by December 2010.
2.4	Enhanced grid codes may be required to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response.				
2.5	Balancing areas need to have adequate communications and control of variable resources				

[74] http://www.nerc.com/files/FAC-001-0.pdf

[75] http://www.nerc.com/files/COM-002-2.pdf

2011 Action Plan

Item #	Proposed Improvement	Abstract	Lead	Deliverables	Milestones
2.3	Integrate forecasting techniques into day-to-day operating routines/ practices and change operating practices in unit commitment, dispatch and operations planning	Review NERC's Facilities Design, Connections, and Maintenance (FAC) Standard FAC-001-0[76] entitled, "Facility Connection Requirements," to ensure that the following are addressed: • State-of-the-art variable resource forecast requirements. • Appropriate grid codes are in place. • Along with COM-002-2[77] and registry criteria, ensure adequate communications and control If these Standards and criteria are found to be inadequate, action should be initiated to remedy (e.g. Standards Authorization Request, registry criteria enhancement, etc.).	*Ad Hoc* group: Members from IVGTF - Operations	• Write SAR to improve NERC Standards to support variable generation integration	• Complete NERC Standard by December 2011.
2.4	Enhanced grid codes may be required to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response.				
2.5	Balancing areas need to have adequate communications and control of variable resources				

[76] http://www.nerc.com/files/FAC-001-0.pdf

[77] http://www.nerc.com/files/COM-002-2.pdf

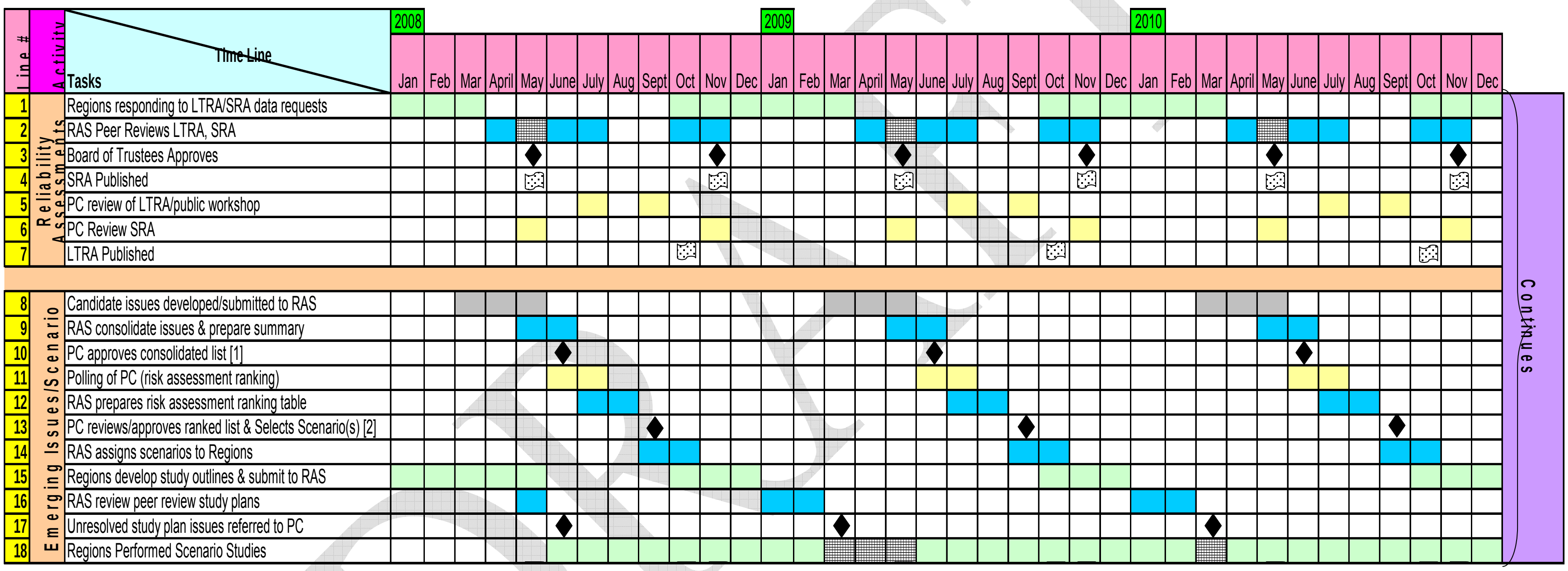
3. ***Planners and Operators may benefit from a reference manual to support the changes required to plan and operate a bulk power system accommodating large amounts of variable generation.***
4. *The goal of this effort is write a reference guide outlining the planning, design and operating considerations needed to integrate large amounts of variable generation.*

2009 Action Plan

Item #	Proposed Improvement	Abstract	*Lead*	Deliverables	Milestones
3.1	Planners and Operators require a reference manual for to support the changes required to plan and operate a bulk power system accommodating large amounts of variable generation	Planners and Operators will need to change their activities to ensure that large amounts of variable generation can be reliably integrated into the bulk power system	Members from IVGTF	Reference Manual	Completed by December 2009.

2009–2011 Time Table

NEED TO COMPLETE ONCE PLAN AGREED



[1] For 2008, the PC will be reviewing a list based on the emerging issues approved at the March meeting.

[2] Selection of scenarios is optional at the discretion of the PC

Planning Committee (PC)
Reliability Assessment Subcommittee (RAS)
Regional Entities
Subgroups (Transmission Issues Subcommittee (TIS), Resource Issues Subcommittee (RIS) and RAS)
Individual Task Overlap

LTRA = Long Term Reliability Assessment
SRA = Seasonal Reliability Assessment

Acronyms

ACE – Area Control Error

AESO – Alberta Electric System Operator

ANSI – American National Standards Institute

BAL – Balancing

CAISO – California Independent System Operator

COM – Communications

CF – Capacity Factor

CPS – Control Performance Standard

CSP – Concentrating Solar Power

CIGRE - International Council on Large Electric Systems

DCS – Disturbance Control Standard

DFAG – Doubly Fed Asynchronous Generator

DFIG - Doubly Fed Induction Generator;

DSO – Distribution System Operator

ELCC – Equivalent Load Carrying Capability

EMS – Energy Management System

ERCOT – Electricity Reliability Council of Texas

EV – Electric Vehicles

FAC – Facilities Design, Connections, and Maintenance

FERC – Federal Energy Regulatory Commission

HVDC – High-Voltage Direct-Current transmission

HVRT – High-Voltage Ride-Though

IEC – International Electrotechnical Commission

IEEE – Institute of Electrical and Electronic Engineers

ISO – Independent System Operator

LOLP – Loss of Demand Probability

LOLE – Loss of Demand Expectation

LSE- Demand Serving Entities

LVRT – Low-Voltage Ride-Through

MOD – Modeling, Data and Analysis Standards

NERC – North American Electric Reliability Corporation

NWP – Numerical Weather Prediction

DNI - Direct normal irradiance

PHEV – Plug-in Hybrid Electric Vehicle

PV – Photovoltaic

POI – Point of Interconnection (as define what it means)

RE – Reliability Entity

RPS – Renewable Portfolio Standard

RRO –Regional Reliability Organization

RTO – Regional Transmission Operator

SAR – Standards Authorization Request (NERC process)

SCADA - Supervisory Control and Data Acquisition

SOA – State-of-the-Art

STATCOM – Static Compensator (voltage source converter based technology)

SVC – Static Var Compensator (thyristor based technology)

TSO – Transmission System Operator

VG – Variable generation

VRT – Voltage Ride-Through

VSC – Voltage Source Converter

WTG – Wind Turbine Generator

WECC – Western Electricity Coordinating Council

IVGTF Roster

Chairman	Warren Frost Vice President Operations & Reliability	Alberta Electric System Operator 2500, 330 - 5 Avenue SW Calgary, Alberta T2P 0L4	(403) 539-2515 (403) 539-2612 Fx warren.frost@ aeso.ca
Leadership Team	Daniel Brooks Manager, Power Delivery System Studies	Electric Power Research Institute 942 Corridor Park Blvd. Knoxville, Tennessee 37932	(865) 218-8040 (865) 218-8001 Fx dbrooks@epri.com
Leadership Team	John Kehler Senior Technical Specialist	Alberta Electric System Operator 2500-330 5th Avenue S.W. Calgary, Alberta, T2P 0L4	(403) 539-2622 (403) 539-2612 Fx john.kehler@aeso.ca
Leadership Team	Mark O'Malley Professor of Electrical Engineering	University College Dublin R. 157A Engineering & Materials Science Centre University College Dublin, Belfield, Dublin 4, IRELAND	00353-1-716-1851 00353-1-283-0921 Fx mark.omalley@ucd.ie
Leadership Team	Dariush Shirmohammadi Consultant	Oak Creek Energy Systems, Inc. 10208 Cielo Drive Beverly Hills, California 90210	(310) 858-1174 (310) 858-8274 Fx dariush@shirconsultants.com
Leadership Team	J. Charles Smith Executive Director	Utility Wind Integration Group 2004 Lakebreeze Way Reston, Virginia 20191	(703) 860-5160 (703) 860-1544 Fx jcharlessmith@comcast.net
Leadership Team	Pouyan Pourbeik Technical Executive	EPRI 942 Corridor Park Boulevard Knoxville, Tennessee 37932	(919) 806-8126 ppourbeik@epri.com

Member	Jay Caspary Director, Engineering	Southwest Power Pool 415 North McKinley Suite 140 Little Rock, Arkansas 72205	(501) 614-3220 (501) 666-0376 Fx jcaspary@spp.org
Member	Lisa Dangelmaier Operations Superintendent	Hawaii Electric Light Company 54 Halekauila Street P.O. Box 1027 Hilo, Hawaii 96721	(808) 969-0427 (808) 969-0416 Fx lisa.dangelmaier@helcohi.com
Member	Abraham Ellis Transmission Operations	Public Service Company of New Mexico 414 Silver SE Albuquerque, New Mexico 87102	(505) 241-4595 (505) 241-4363 Fx aellis@pnm.com
Member	William Grant Manager, Transmission Control Center South	Xcel Energy, Inc. 6086 48th Amarillo, Texas 79109	(806) 640-6306 william.a.grant@xcelenergy.com
Member	David Jacobson Interconnection & Grid Supply Planning Engineer	Manitoba Hydro 12-1146 Waverly Street P.O. Box 815 Winnepeg, Manitoba R3C 2P4	(204) 474-3765 (204) 477-4606 Fx dajacobson@hydro.mb.ca
Member	Eric John Vice President, Project Development	SkyFuel Inc. 10701 Montgomery Boulevard, NE Albuquerque, New Mexico 87111	(505) 999-5823 (413) 228-5380 Fx eric.john@skyfuel.com

Member	Khaqan Khan Senior Engineer	Ontario, IESO Station A P.O. Box 4474 Toronto, Ontario M5W 4E5	(905) 855-6288 (905) 855-6372 Fx khaqan.khan@ieso.ca
Member	Clyde Loutan Senior Advisor - Planning and Infrastructure Development	California ISO 151 Blue Ravine Road Folsom, California 95630	(916) 608-5917 cloutan@caiso.com
Member	David Maggio Operations Engineer/Analyst I	Electric Reliability Council of Texas, Inc. 2705 West Lake Drive Taylor, Texas 76574	(512) 248-6998 (512) 248-6560 Fx dmaggio@ercot.com
Member	Michael McMullen Director, West Regional Operations	Midwest ISO, Inc. 1125 Energy Park Drive St. Paul, Minnesota 55108	(651) 632-8404 (612) 632-8417 Fx mmcmullen@midwestiso.org
Member	Thomas M. Moleski Senior Analyst	PJM Interconnection, L.L.C. 955 Jefferson Avenue Norristown, Pennsylvania 19403-2497	(610) 666-8826 (610) 666-4779 Fx moleski@pjm.com
Member	John R. Norden Manager, Renewable Resource Integration	ISO New England, Inc. One Sullivan Road Holyoke, Massachusetts 01040-2841	(413) 537-7699 (413) 535-4343 Fx jnorden@iso-ne.com

Member	Sophie Paquette Transmission Planning Engineer	Hydro-Quebec TransEnergie Complexe Desjardins, Tower East 10th Floor P.O. Box 10000 Montreal, Quebec H5B 1H7	(514) 289-2211 Ext. 2796 (514) 289-4459 Fx paquette.sophie@hydro.qc.ca
Member	Charles W. Rogers Principal Engineer	Consumers Energy System Planning and Protection 1945 W. Parnall Road Jackson, Michigan 49201	(517) 788-0027 (517) 788-0917 Fx cwrogers@cmsenergy.com
Member	David C. Schooley Sr. Engineer	Commonwealth Edison Co. 2 Lincoln Centre Oakbrook Terrace, Illinois 60181	(630) 437-2773 david.schooley@ exeloncorp.com
Member	Edward P. Weber Transmission System Planning Manager	Western Area Power Administration P.O. Box 35800 Billings, Montana 59107-5800	(406) 247-7433 (406) 247-7408 Fx weber@wapa.gov
Observer	John M. Adams Principle Electric System Planner	New York Independent System Operator 3890 Carman Road Schenectady, New York 12303	(518) 356-6139 jadams@nyiso.com
Observer	Vladimir Chadliev Development Manager	Nevada Power Co. 6226 W. Sahara Avenue P.O. Box 98910 MS 13 Las Vegas, Nevada 89151	(702) 227-2460 vchadliev@nevp.com

Observer	Douglas K. Faulkner Manager Resource Integration	Puget Sound Energy, Inc. 10885 NE 4th Street PSE-11S Bellevue, Washington 98004-5591	(425) 462-3352 (425) 462-3836 Fx doug.faulkner@pse.com
Observer	David Hawkins Lead Industry Relations Representative	California ISO 151 Blue Ravine Road P.O. Box 939014 Folsom, California 95630	(916) 351-4465 (916) 351-2373 Fx dhawkins@caiso.com
Observer	Sasan Jalali Electrical Engineer	Federal Energy Regulatory Commission 888 1st Street Washington, D.C. 20426	202.502.6223 (202) 208-0960 Fx sasan.jalali@ferc.gov
Observer	Yuriy Kazachkov Principal Consultant	Siemens Power Transmission & Distribution 1482 Erie Boulevard Schenectady, New York 12305	(518) 395-5132 (518) 346-2777 Fx yuriy.kazachkov@ siemens.com
Observer	Brendan Kirby Consultant	American Wind Energy Association 2307 Laurel Lake Road Knoxville, Tennessee 37932	(865) 250-0753 kirbybj@ieee.org
Observer	Warren Lasher Manager, System Assessment	Electric Reliability Council of Texas, Inc. 2705 West Lake Drive Taylor, Texas 76574	(512) 248-6379 (512) 248-4235 Fx wlasher@ercot.com

Observer	Michael Milligan Consultant	National Renewable Energy Laboratory NWTC 1617 Cole Boulevard Golden, Colorado 80401	(303) 384-6927 (303) 384-6901 Fx michael_milligan@ nrel.gov
Observer	Jay Morrison Senior Regulatory Counsel	National Rural Electric Cooperative Association 4301 Wilson Boulevard EP11-253 Arlington, Virginia 22203	(703) 907-5825 (703) 907-5517 Fx jay.morrison@nreca.coop
Observer	Bradley M. Nickell, PE, MBA Renewable Integration Director	Western Electricity Coordinating Council 615 Arapeen Drive Suite 210 Salt Lake City, Utah 84108	(202) 586-8508 bnickell@wecc.biz
Observer	Dale Osborn Transmission Technical Director	Midwest ISO, Inc. 1125 Energy Park Drive St. Paul, Minnesota 55108	(651) 632-8417 dosborn@midwestiso.org
Observer	Subbaiah Pasupulati Director of Technical Studies	Oak Creek Energy Systems, Inc. 14633 Willow Springs Road Mojave, California 93501	(909) 241-9197 (661) 822-5991 Fx subbaiah@oakcreekenergy.com
Observer	Matt Pawlowski Compliance Manager	FPL Energy 700 Universe Boulevard FEX/JB, Juno Beach, Florida 33408	(561) 304-5465 (561) 304-5161 Fx matt.pawlowski@fpl.com

Observer	Richard Piwko Director	GE Energy One River Road Bldg. 2-644 Schenectady, New York 12345	(518) 385-7610 richard.piwko@ge.com
Observer	Kevin Porter Senior Analyst	Exeter Associates 5565 Sterrett Place Suite 310 Columbia, Maryland 21044	(410) 992-7500 (410) 992-3445 Fx
Observer	Juan S. Santos Vice President, Market Integration	Wind Capital Group LLC 2923 Marketplace Drive, Suite 108 Madison , Wisconsin 53719	608-467-0987 jsantos@windcapitalgroup.com
Observer	Tom Schneider Managing Director of Planning and Standards	Western Electricity Coordinating Council 615 Arapeen Drive, Suite 210 Salt Lake City, Utah 84108	(801) 883-6871 (801) 582-3918 Fx tschneider@wecc.biz
Observer	Bob Stuart Senior Director - Transmission	BrightSource Energy, Inc. 1999 Harrison Street, Suite 2150 Oakland, California 94612	(510) 550-8905 (510) 550-8165 Fx bobstuart@iglide.net
Observer	Robert Zavadil Vice President	EnerNex Corp 170C Market Place Boulevard Knoxville, Tennessee 37922	(865) 691-5540 Ext. 149 (865) 691-5046 Fx bobz@enernex.com

NERC Staff	Mark G. Lauby Manager of Reliability Assessments	North American Electric Reliability Corporation 116-390 Village Boulevard Princeton, New Jersey 08540-5721	(609) 452-8060 (609) 452-9550 Fx mark.lauby@nerc.net
NERC Staff	John Moura Technical Analyst - Reliability Assessments	North American Electric Reliability Corporation 116-390 Village Boulevard Princeton, New Jersey 08540-5721	(609) 452-8060 (609) 452-9550 Fx john.moura@nerc.net
NERC Staff	Edward J. Dobrowolski Standards Development Coordinator	North American Electric Reliability Corporation 116-390 Village Boulevard Princeton, New Jersey 08540-5721	(609) 452-8060 (609) 452-9550 Fx ed.dobrowolski@nerc.net

Further Reading

[1] "Renewable Portfolio Standards in the United States", Lawrence Berkeley National Laboratory, April 2008.

[2] CIGRE Technical Brochure 293, Electric Power System Planning with the Uncertainty of Wind Generation, Prepared by CIGRE WG C1.3, April 2006 (available on-line at: www.e-cigre.org)

[3] WECC Wind Generator Power Flow Modeling Guide

[4] Nevada Power Company, Renewable Energy Department

[5] Lalor, G., Mullane, A., and O'Malley, M.J., "Frequency Control and Wind Turbine Technologies", IEEE Transactions on Power Systems, Vol. 20, pp. 1903-1913, 2005.

[6] Mullane, A. and O'Malley, M.J., "The inertial-response of induction-machine based wind-turbines", IEEE Transactions on Power Systems, Vol. 20, pp. 1496 – 1503, 2005.

[7] Reigh Walling, "Wind Plants of the Future", UWIG, Oct 2008.

[8] Hydro-Québec TransÉnergie, "Technical requirements for the connection of generation facilities to the Hydro-Québec transmission system", May 2006

[9] ESB National grid, "Dynamic modeling of wind generation in Ireland", January 2008

[10] Coughlan, Y., Smith, P., Mullane, A. and O'Malley, M.J., "Wind turbine modelling for power system stability analysis - a system operator perspective", IEEE Transactions on Power Systems, Vol. 22, pp. 929 – 936, 2007.

[11] NERC, "Reliability Concepts, Version 1.0.2" December 2007.

[12] Osborn and Zhou, IEEE Paper, "Transmission Plan Based on Economic Studies",

[13] CIGRE Technical Brochure 328, Modeling and Dynamic Behavior of Wind Generation as it Relates to Power System Control and Dynamic Performance, Prepared by CIGRE WG C4.601, August 2007 (available on-line at: www.e-cigre.org)

[14] CAISO, “Integration of Renewable Resources”, November 2007.

[15] EoN Netz Wind Report 2005

[16] M. Milligan and K. Porter, “Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation”, Presented at Wind Power 2008, June 2008, Houston, Texas.

[17] J. Dumas, “ERCOT February 26, 2008 EECP Event,” Presented at UWIG Spring Workshop, Fort Worth, TX, April 2008.

[18] L. Dangelmaier (HELCO) and L.Bryans presentations from UWIG 2008,

[19] GE Energy, Intermittency Analysis Project Final Report, Appendix B -Impact of Intermittent Generation on Operation of California Power Grid, prepared for the California Energy Commission Public Interest Energy Research Program, July, 2007.

[20] GE Energy 2005, The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations: Report on Phase 2, Prepared for The New York State Energy Research and Development Authority.

[21] Zavadil et al, Minnesota Wind Integration Study Final Report - Volume I, prepared for the Minnesota Public Utilities Commission, November 2006.

[22] GE Energy, Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements, final report prepared for ERCOT, March 2008.

[23] http://www.uwig.org/CEC-500-2007-081-APB.pdf on page 40

[24] Bryans, A.G., Fox, B., Crossley, P., O’Malley, M.J., “Impact of tidal generation on power system operation”, IEEE Transactions on Power Systems, Vol. 20, pp. 2034 - 2040, 2005.

[25] Doherty, R. and O’Malley, M.J., “Establishing the role that wind generation may have in future generation portfolios”, IEEE Transactions on Power Systems, Vol. 21, pp. 1415 – 1422, 2006.

[26] John Dumas, “ERCOT Feb 26, 2008 EECP Event”, UWIG, Texas, April, 2008.

[27] Doherty, R., Lalor, G. and O’Malley, M.J., “Frequency Control in Competitive Electricity Market Dispatch”, IEEE Transactions on Power Systems”, Vol. 20, pp. 1588 - 1596, 2005.

[28] Kempton, W and Tomic, J. “Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy”, Journal of Power Sources, Vol. 144, pp. 280 – 294, 2005.

[29] Denholm, P. and Short, W. “An Evaluation of Utility System Impacts and Benefits of Optimally Dispatched Plug-In Hybrid Electric Vehicles” Technical Report NREL/TP-620-40293 Revised October 2006.

[30] Greenblatt, J.B., Succar, S., Denkenberger, D.C., Williams, R.H., Socolow, R.H., “Baseload wind energy: modeling the competition between gas turbines and compressed air energy storage for supplemental generation”, Energy Policy, Vol 35, pp. 1474 – 1492, 2007.

[31] Sullivan, P., Short, W and Blair, N. “Modeling the Benefits of Storage Technologies to Wind Power”, American Wind Energy Association Wind Power Conference, Houston, Texas, June, 2008.

[32] Ummels, B.C., Pelgrum, E., Kling, W.L., “Integration of large-scale wind power and use of energy storage in the Netherlands electricity supply”, IET Renewable Power Generation, Vol 2, pp. 34 – 46, 2008.

[33] ‘20% Wind Energy by 2030 – Increasing Wind Energy’s Contribution to U.S. Electricity Supply’, U.S. Department of Energy, May 2008.

[34] All Island Renewable Grid Study, Department of Communications Energy and Natural Resources, www.dcenr.gov.ie, 2008.

[35] Lund, P., “The Danish Cell Project - Part 1: Background and General Approach”,

[36] 'Guide for selection of weather parameters for bare overhead conductor ratings', published by CIGRE working group B2.12.

[37] Miller, N.W and Jordan, G.A “Evaluating wind capacity value in New York and California”, IEEE PES Meeting Pittsburg, 2008.

[38] Ulrich Focken, Wind Power Forecast Experience in Germany, presented at UWIG Wind Forecasting Workshop, St Paul, MN, Feb 2008.

[39] Kirby, B. and M. Milligan, Facilitating Wind Development: The Importance of Electric Industry Structure, Electricity Journal, April 2008.

[40] Finley, C., Stinogel, J., Ahlstrom, M., Development and Implementation of an Integrated Utility-Wide Wind Forecast System, WindLogics Inc., February 22, 2008 at the UWIG Forecasting Workshop, St Paul, MN

[41] Miller, N.; Jordon, G. (2006), Impact of Control Areas Size on Viability of Wind Generation: A Case Study for New York, Windpower 2006, Pittsburgh, PA, American Wind Energy Association.

[42] Milligan, M.; Kirby, B. (2007). Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration: Preprint. 43 pp; NREL Report No. CP-500-41809. Presented at WindPower 2007, Los Angeles, CA.

[43] M. Milligan, B. Kirby, Sub-hourly Analysis of Ramping Requirements of Wind: Impact of Balancing Area Consolidated Operations, WindPower 2008, Houston, TX, American Wind Energy Association.

[44] Miller, N.; Jordon, G. (2006), Impact of Control Areas Size on Viability of Wind Generation: A Case Study for New York, WindPower 2006, Pittsburgh, PA, American Wind Energy Association.

[45] GE Energy 2005, The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations: Report on Phase 2, Prepared for The New York State Energy Research and Development Authority.

[46] Holttinen H., et al 2007, Design and Operation of Power Systems with Large Amounts of Wind Power: State of the Art Report, VTT Working Paper 82, IEA Wind.

[47] Kirby, B.; Milligan, M. (2005), Method and Case Study for Estimating the Ramping Capability of a Control Area or Balancing Authority and Implications for Moderate or High Wind Penetration: Preprint. 19 pp; NREL Report No. CP-500-38153.

[48] "Data Collection for Demand-Side Management," December 2007, ftp://ftp.nerc.com/pub/sys/all_updl/docs/pubs/NERC_DSMTF_Report_040308.pdf

[49] Brochure: "International Standard IEC 61400-25: Information and Information Exchange for Wind Power Plants", Version 4 (2660-02-20)

[50] H. Muller, M. Ppoller, A. Basteck, M. Tilshcher, J. Pfister, "Grid compatibility of variable speed wind turbines with directly coupled synchronous generator and hydro-dynamically controlled gearbox", Sixth Int'l Workshop on Large-scale integration of wind power and transmission networks for offshore wind farms, October 2006.

[51] A. Mullane, M. O'Malley, "Modifying the inertial response of power-converter based wind turbine generators", 2006

[52] Elkraft System and Eltra Regulation, "Wind turbines connected to grids with voltages above 100 kV – Technical regulation for the properties and the regulation of wind turbines", Regulation TF 3.2.5, December 2004

[53] Nordel, "Nordic grid code 2007 (Nordic collection of rules)", January 2007

[54] ESBNG, "Summary and discussion document for the review of frequency issues for wind turbine generators and wind farms", Version 2.7, April 2004

[55] Hydro-Québec TransEnergie, "Technical requirements for the connection of generation facilities to the Hydro-Québec transmission system", May 2006

[56] F.W. Koch, I. Erlich, F. Shewarega, U. Bachmann, "Dynamic interaction of large offshore wind farms with the electric power system", Bologna Power Tech IEEE conference, Italy, June 2003

[57] N.R. Ullah, T. Thiringer, D. Karlsson, "Temporary primary frequency control support by variable speed wind turbines – Potential and applications", IEEE, 2007

[58] Cigre Working Group 601 of Study Committee C4, "Modeling and dynamic behavior of wind generation as it relates to power system control and dynamic performance", January 2007

[59] A. Mullane, M. O'Malley, "The inertial response of induction-machine-based wind turbines", IEEE, 2005

[60] O. Anaya-Lara, F.M. Hughes, N. Jenkins, G. Strbac, "Contribution of DFAG-based wind farms to power system short-term frequency regulation", IEE Proc.-Gener. Transm. Distrib. Vol 153 No 2, March 2006

[61] J. Ekanayake, N. Jenkins, "Comparison of the response of doubly fed and fixed-speed induction generator wind turbines to changes in network frequency", IEEE, 2004

[62] G. Lalor, A. Mullane, M. O'Malley, "Frequency control and wind turbine technologies", IEEE, 2005

[63] Hydro-Québec TransÉnergie, Projets technologiques - Exploitation, "Spécification d'exigences - Acquisition des données éoliennes", November 2007

[64] The Danish Cell Project - Part 1: Background and General Approach; Per Lund, Energinet.dk, Denmark. IEEE PES GM, Tampa, 2007.

[65] The Danish Cell Project - Part 2: Verification of Control Approach via Modeling and Laboratory Tests; Sunil Cherian, Spirae, and Valerijs Knazkins, Energynautics. IEEE PES GM, Tampa, 2007.

[66] GE Energy, Intermittency Analysis Project Final Report, Appendix B -Impact of Intermittent Generation on Operation of California Power Grid, for California Energy Commission Public Interest Energy Research Program, July, 2007.

[67] Zavadil et al, Minnesota Wind Integration Study Final Report - Volume I, prepared for the Minnesota Public Utilities Commission, November 2006.

[68] GE Energy, Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements, final report prepared for ERCOT, March 2008.

[69] Ulrich Focken, Wind Power Forecast Experience in Germany, presented at UWIG Wind Forecasting Workshop, St Paul, MN, Feb 2008.

[70] Facilitating Wind Development: The Importance of Electric Industry Structure

[71] [33] B. Kirby and M. Milligan. NREL Technical Report NREL/TP-500-43251, May 2008. Available at http://www.nrel.gov/docs/fy08osti/43251.pdf

[72] Cardinal, M., and N. Miller. 2006. "Grid Friendly Wind Plant Controls: WindCONTROL – Field Test Results." Presented at WindPower 2006, June 4–7, Pittsburgh, PA.

[73] Deutsche Energie-Agentur GmbH (dena). 2005. Energy Management Planning for the Integration of Wind Energy into the Grid in Germany, Onshore and Offshore by 2020. Cologne, Germany: Deutsche Energie-Agentur GmbH. http://www.uwig.org/Dena-2005_English.pdf

[74] Eriksen, P., A. Orths, and V. Akhmatov. 2006. "Integrating Dispersed Generation into the Danish Power System – Present Situation and Future Prospects." Presented at the IEEE Power Engineering Society (PES) Meeting, June 20, Montreal.

[75] Erlich, I., W. Winter, and A. Dittrich. 2006. "Advanced Grid Requirements for the Integration of Wind Turbines into the German Transmission System," http://www.uni-duisburg.de/FB9/EAUN/downloads/papers/paper_030706-02.pdf Montreal: IEEE, Panel paper No. 060428.

[76] Gross, R., P. Heptonstall, D. Anderson, T. Green, M. Leach, and J. Skea. 2006. The Costs and Impacts of Intermittency: An Assessment of the Evidence on the Costs and Impacts of Intermittent Generation on the British Electricity Network. ISBN 1-90314-404-3. London, UK: Energy Research Centre. http://www.ukerc.ac.uk/ImportedResources/PDF/06/0604_Intermittency_report_final.pdf

[77] Holttinen, H. 2004. The Impact of Large Scale Wind Power Production on the Nordic Electricity System. ISBN 951-38-6426-X. Espoo, Finland: VTT Technical Research Centre of Finland. http://www.vtt.fi/inf/pdf/publications/2004/P554.pdf

[78] IEA (International Energy Agency). 2005. Variability of Wind Power and Other Renewables: Management Options and Strategies. Paris: IEA. http://www.iea.org/Textbase/Papers/2005/variability.pdf

[79] IEEE. 2005. IEEE Power and Energy Magazine Special Issue: Working with Wind; Integrating Wind into the Power System, November–December, 2005. Vol 3, No 6.

[80] Milligan, M. and K. Porter. 2006. "Capacity Value of Wind in the United States: Methods and Implementation," Electricity Journal, 19(2): 91–99.

[81] Milligan, M., B. Parsons, J.C. Smith, E. DeMeo, B. Oakleaf, K. Wolf, M. Schuerger, R. Zavadil, M. Ahlstrom, and D. Nakafuji. 2006. Grid Impacts of Wind Variability: Recent Assessments from a Variety of Utilities in the United States. Report No. NREL/CP-500-39955. Golden, CO: National Renewable Energy Laboratory (NREL). http://www.uwig.org/Ewec06gridpaper.pdf.

[82] Midwest ISO (Independent Transmission System Operator). 2007. Midwest ISO Transmission Expansion Plan 2007. http://www.midwestmarket.org/publish/Folder/193f68_1118e81057f_-7f900a48324a

[83] Northwest Power and Conservation Council. 2007. Northwest Wind Integration Action Plan. Portland, OR: Northwest Power and Conservation Council, Northwest Wind Integration Action Plan Steering Committee. http://www.nwcouncil.org/energy/Wind/library/2007-1.htm

[84] Pedersen, J. 2005. System and Market Changes in a Scenario of Increased Wind Power Production. Report No. 238389. Fredericia, Denmark: Energinet.dk.

[85] Saylors, S. 2006. “Wind Park Solutions to Meet Expectations of Grid System Planners and Operators.” Presented at WindPower 2006, June 4–7, Pittsburgh, PA.

[86] UWIG (Utility Wind Integration Group). 2006. Utility Wind Integration State of the Art. Reston, VA: UWIG. http://www.uwig.org/UWIGWindIntegration052006.pdf.

[87] Van Hulle, F. 2005. Large Scale Integration of Wind Energy in the European Power Supply: Analysis, Issues, and Recommendations. Brussels, Belgium: EWEA. http://www.ewea.org/fileadmin/ewea_documents/documents/publications/grid/051215_Grid_report.pdf.

[88] Wan, Y. 2005. Primer on Wind Power for Utility Applications. Report No. TP-500-36230.Golden, CO: NREL. http://nrelpubs.nrel.gov/Webtop/ws/nich/www/public/SearchForm

[89] Zavadil, R., J. King., L. Xiadon, M. Ahlstron, B. Lee, D. Moon, C. Finley, et al. 2004. Wind Integration Study – Final Report. Prepared for Xcel Energy and the Minnesota Department of Commerce. Knoxville, TN: EnerNex and WindLogics.

[90] B. Parsons, M. Milligan, J. C. Smith, E. DeMeo, B. Oakleaf, K. Wolf, M. Schuerger, R. Zavadil, M. Ahlstrom, and D. Yen Nakafuji, Grid impacts of wind power variability: recent assessments from a variety of utilities in the United States, presented at the European Wind Energy Conference, Athens, Greece. March 2006. Preprint available at http://www.nrel.gov/docs/fy06osti/39955.pdf. Accessed Aug 10, 2006.

[91] DeMeo, E. et al., “Wind Plant Integration,” IEEE” IEEE Power and Energy Magazine, Nov-Dec 2005. Special Issue: Working With Wind; Integrating Wind into the Power System.

[92] H. Holttinen et. al, “Design and Operation of Power Systems with Large Amounts of Wind Power Production: IEA Collaboration,” European Wind Energy Conference, Athens, Greece, February 2006. http://www.ieawind.org/AnnexXXV.html. Accessed November 17, 2006.

[93] M. Milligan, and K. Porter, “Determining the capacity value of wind: A survey of methods and implementation,” Presented at Windpower 2005, Denver, CO, May

2005. Preprint available at www.nrel.gov/docs/fy05osti/38062.pdf. Accessed August 10, 2006.

[94] Y. Wan, “Wind power plant behaviors: analysis of long-term wind power data,” National Renewable Energy Laboratory, Golden, CO, Tech. Rep. NREL/TP-500-36651, 2004. Available at www.nrel.gov/docs/fy04osti/36551.pdf. Accessed Aug 10, 2006.

[95] D. Brooks, E. Lo, R. Zavadil, S. Santoso, J. Smith, “Characterizing the Impacts of Significant Wind Generation Facilities on Bulk Power System Operation Planning,” prepared for Utility Wind Integration Group, Arlington, VA. May 2003. http://www.uwig.org/UWIGOpImpactsFinal7-15-03.pdf. Accessed Nov 17, 2006.

[96] H. Shiu, M. Milligan, B. Kirby, K. Jackson, “California Renewables Portfolio Standard, Renewable Generation Cost Analysis: Multi-Year Analysis Results and Recommendations,” California Wind Energy Collaborative for the California Energy Commission, Sacramento, CA. June 2006. http://www.energy.ca.gov/2006publications/CEC-500-2006-064/CEC-500-2006-064.PDF, Accessed Nov 17, 2006.

[97] Piwko, R.et al., “Wind Energy Delivery Issues,” IEEE Power and Energy Magazine, Nov-Dec 2005. Special Issue: Working With Wind; Integrating Wind into the Power System.

[98] Ahlstrom, M. et al., “The Future of Wind Forecasting and Utility Operations,” IEEE Power and Energy Magazine, Nov-Dec 2005. Special Issue: Working With Wind; Integrating Wind into the Power System.

[99] N. Miller, “Performance and economics of utility control areas with wind generation,” presented at Windpower 2006, Pittsburgh, PA. June, 2006. American Wind Energy Conference Proceedings for Windpower 2006, to appear.

[100] Smith, J. C., Milligan, M., DeMeo, E., and Parsons, B., Utility Wind Integration and Operating Impact State of the Art, IEEE Transactions on Power Systems, Vol. 22, No. 3, August 2007.

[101] Smith, J. C., Oakleaf, B., Ahlstrom, M., Savage, D., Finley, C., Zavadil, R., and Reboul, J., The Role of Wind Forecasting in Utility System Operation, Paper C2-301, CIGRE, August 2008.