STATE OF MINNESOTA

OFFICE OF ADMINISTRATIVE HEARINGS

FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION

IN THE MATTER OF THE PETITION OF NORTHERN STATES POWER COMPANY TO INITIATE A COMPETITIVE RESOURCE ACQUISITION PROCESS

OAH DOCKET NO. 8-2500-30760, MPUC DOCKET NO. E002/CN-12-1240

DIRECT TESTIMONY

OF

R. THOMAS BEACH

PRINCIPAL,

CROSSBORDER ENERGY

ON BEHALF OF

GERONIMO ENERGY, LLC

SEPTEMBER 27, 2013

Exhibit ____

DIRECT TESTIMONY OF R. THOMAS BEACH

TABLE OF CONTENTS

SCHEDULES

I. INTRODUCTION AND QUALIFICATIONS

Q: Please state your name and occupation.

A: My name is R. Thomas Beach. I am principal consultant of the consulting firm Crossborder Energy.

Q: On whose behalf are you submitting testimony?

A: I am submitting testimony on behalf of Geronimo Energy, LLC.

Q: Please describe your qualifications and experience in the energy and utility industries.

A: I have over 30 years of experience in the energy industry. I began my career in 1981 as a staff engineer at the California Public Utilities Commission (CPUC), where I worked on the implementation in California of the Public Utilities Regulatory Policy Act of 1978 (PURPA) and served as a policy advisor to three CPUC commissioners. Since entering private practice as a consultant in 1989, I have provided expert witness testimony in a wide range of utility regulatory proceedings in seven states.

Prior to this experience, I earned an undergraduate degree in Physics and English from Dartmouth College and a Masters in Mechanical Engineering from the University of California, Berkeley. My curriculum vita (CV) is attached to this testimony as Schedule RTB-1.

Q: Please describe Crossborder Energy's activities in the energy and utility industries, including, in particular, the firm's experience on issues involving the solar industry.

A: Crossborder Energy provides economic analysis and strategic advice on market and regulatory issues involving the natural gas and electricity industries. We have particular experience on issues involving independent power producers, and have worked extensively with individual generation projects and trade associations representing both combined heat and power projects as well as generators using the full range of renewable technologies. For example, we have represented the Solar Energy Industries Association and the California Wind Energy Association before the CPUC on issues concerning the capacity value of solar and wind projects in California. We have worked on the continuing implementation of renewable portfolio standard (RPS) programs in California and New Mexico, on the design of the community solar program in Colorado, and on electric rate design issues that impact customers who install distributed solar generation. My colleague Patrick McGuire and I recently authored a major cost/benefit study of net energy metering in California.

Q: What is the purpose of your testimony in this proceeding?

A: The purpose of my testimony is to provide support for Section 5.0 (Distributed Solar Project), in particular, Section 5.5 (Annual Capacity Accreditation), of Geronimo Energy's Distributed Solar Energy Proposal. My testimony discusses the technical qualities of solar energy, the methodology used to calculate the Project's accredited capacity, and how solar energy can be used reliably to meet Xcel's identified need.

II. DESCRIPTION OF SOLAR TECHNOLOGY

Q: What type of solar energy generating equipment is Geronimo proposing to use for its Project?

A: Geronimo is proposing to use nominal 300 watt solar photovoltaic (PV) modules mounted on linear axis tracking systems, with centralized inverters.

Q: Please briefly describe how the proposed technology produces electricity.

A: PV panels consist of a series of cells made of high-purity semiconductor material, typically silicon. When sunlight hits a cell, the solar photons excite electrons in the semiconductor material into higher energy levels. The high-energy electrons produce a voltage difference across the cell, and electrons can be drawn off to produce a current. This direct conversion of sunlight into electricity is known as the "photovoltaic effect." The efficiency of this conversion is typically 14% - 19%, that is, 14% to 19% of the available solar energy falling on the PV panel is converted into electricity. PV cells produce direct current (DC) electricity, which must be converted into standard, 60-cycles-per-second alternating current (AC) in a piece of power electronics called an inverter. PV cells produce electricity without moving parts, without combusting fossil fuels, and without emissions or waste products of any kind.

Q: We know that wind turbines only operate above and below certain wind speeds. Are there similar operational restrictions for solar facilities based on the availability of sunshine?

A: Yes. The output of a PV panel depends on the amount of sunlight hitting it, also known as the solar insolation. However, unlike wind turbines that do not operate below a certain wind speed, PV panels do produce small amounts of power in the low light of early morning and late evening, or when a cloud shades the panel. The output from a PV system is greatest in the middle of the day when the sun is overhead and when the panel is perpendicular to the incoming solar radiation, such that the maximum amount of sunlight is striking the panel. **Figure 1** below shows typical profiles for the electric output from several types of PV arrays over the course of a sunny summer day in Minnesota. Two of the profiles are the simulated outputs for solar arrays in Minneapolis and use the National Renewable Energy Lab's (NREL) PVWATTS calculator,[1] a standard on-line tool used to simulate the output of a PV array at selected locations in the United States. The third profile is actual metered data on July 2, 2012 from the Saint John's Solar Farm 400 kW linear axis tracking solar system located in Collegeville, Minnesota.

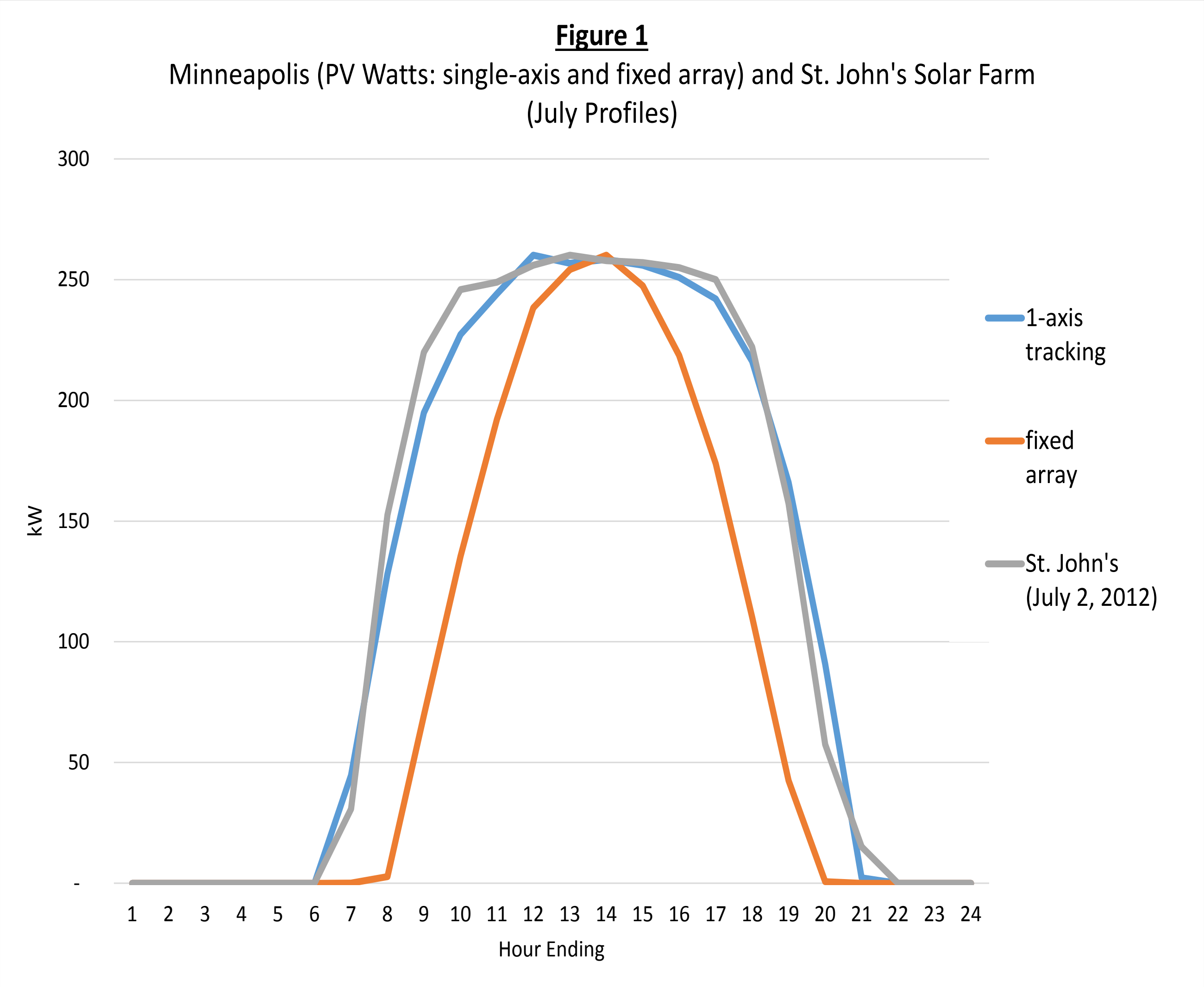

Figure 1

Minneapolis (PV Watts: single-axis and fixed array) and St. John's Solar Farm (July Profiles)

Q: If a cloud shadows a portion of a solar array, is the output of the entire array reduced as though all of the panels were shaded?

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[1] See http://rredc.nrel.gov/solar/calculators/pvwatts/version1/ .

A: No. A large solar array typically is divided into many groups or "strings" of panels that are wired in parallel, which means that a reduction in power in one string of panels does not have a major impact on production from other strings. Thus, for example, if one string of the array is shadowed by a cloud, power production will be reduced substantially only in the particular string that is shadowed.

Q: Geronimo is proposing to construct approximately 20 distributed solar facilities. Do each of the facilities need to be operational for the Project to produce electricity?

A: No. Each of Geronimo's approximately 20 sites will produce power for the grid independent of all of the other sites, depending only on the amount of sunlight available at that moment at its location. If one of Geronimo's units suffers an outage, none of the other units will be impacted. The geographic and operational diversity of Geronimo's units will increase the reliability and reduce the variability of the output of the Project as a whole. For example, on a partly cloudy day, at any one time a portion of the Project's units will be shaded while the remainder will be in full sunshine. This geographic diversity will result in much more stable output for the Project as a whole than for any one site in the Project.

Q: What is the function of the linear axis tracking system?

A: Geronimo's linear axis tracking system will adjust the tilt of the array such that the rays of the sun remain perpendicular to the solar panels in at least one dimension throughout the day. Tracking significantly increases the amount of solar energy that is incident on the panels – and thus increases their output – compared to an array that is fixed at a tilt that does not change.

Q: Are photovoltaic systems always built on tracking systems?

A: No. Most PV systems are fixed – for example, the typical small PV system installed on the roof of a home is fixed.

Q: Please explain how using the tracking system impacts the Project's energy production.

A: A tracking system typically increases the annual output of a solar PV system by 20% to 25%. For example, a fixed, south-facing array will have an annual "capacity factor" of 14% to 19%, while a tracking array can attain capacity factors of 20% to 25%. The capacity factor is the actual output of a generator divided by what the output would be if the generator operated at its full "nameplate" capacity in all 8,760 hours of the year. For example, **Figure 1** compares the output of fixed and tracking arrays in Minneapolis on a sunny July day. The figure shows that tracking allows a PV array to increase its output more quickly in the morning, and to sustain its output at a higher level longer into the late afternoon. Essentially, the output of the tracking system is steadier and more consistent over the course of the day. This characteristic is particularly important given that the demand for electricity on the Xcel system typically peaks in the summer in the mid- to late-afternoon hours. **Table 1** below shows the dates and times of Xcel's annual system peaks in 2010-2012, from FERC Form 1 data.

Table 1: *Dates, Times, and Magnitude of Xcel's Annual System Peaks*

Year	**Date**	**Time** *(Hour)*	**Peak** *(MW)*
2010	August 12, 2010	1600	9,950
2011	July 20, 2011	1700	10,561
2012	July 2, 2012	1700	10,420

Source: FERC Form 1, page 400, Monthly Transmission System Peak Load

III. ACCREDITED CAPACITY

Q: What is "accredited capacity"?

A: Accredited capacity is the electric generating capacity which the Midcontinent Independent System Operator (MISO) has verified as eligible to provide capacity that can be counted toward meeting the Resource Adequacy requirements of the MISO tariff. A load-serving entity (LSE, i.e. a utility such as Xcel's Northern States Power) that purchases accredited capacity can use that capacity to satisfy its resource adequacy obligations under the MISO tariff.[2]

Q: Please explain why the issue of accredited capacity is relevant to determining if the Project can meet Xcel Energy's identified need.

A: Xcel has an identified need for additional generating capacity in 2017. The capacity that Xcel acquires to meet that need should be accredited by MISO so that Xcel can count the new capacity toward meeting its peak capacity obligations in MISO's Planning Reserve Sharing Pool. Otherwise, if Xcel cannot provide enough accredited capacity, Xcel could be assessed a capacity deficiency charge to remedy the shortfall. This charge could be several times the cost of new capacity.

Q: Please provide a general description of the methodologies used in the energy industry to assign accredited capacity to renewable energy facilities.

A: There are two types of methodologies used to establish the accredited capacity of renewable energy facilities such as Geronimo's proposed solar project.

The ELCC Method. The most rigorous and complex approach is the Effective Load Carrying Capacity (ELCC) method. This methodology uses a production simulation model of the electric system in question, a computer model which can calculate the

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[2] Accredited capacity should not be confused with the Project's "AC" rating. In the latter case, AC is an abbreviation for alternating current. Alternating current generally refers to the time-varying voltage of the standard electric power supplied in the U.S.

probability in each of the 8,760 hours of the year that electric resources will be inadequate to serve demand – the loss-of-load probability (LOLP). The model is set up to include the resource whose capacity is being studied – for example, a solar resource with a nameplate of 100 MW. The model is calibrated to produce the desired level of system reliability – for example, a LOLP equivalent to one day of outage every ten years. Then the solar resource is removed and replaced by a reference resource, such as a combustion turbine (CT), whose capacity is increased until it provides the same LOLP as the case with the solar resource. The ELCC of the solar resource is equal to the ratio of the reference CT capacity to the solar resource's capacity, expressed as a percentage. Thus, for example, if 70 MW of CT capacity provides the same level of reliability as 100 MW of solar generation, the ELCC of the solar resource is 70 MW / 100 MW = 70%. In essence, the ELCC analysis showed that 100 MW of solar capacity can "effectively carry" the same amount of load as 70 MW of CT capacity, while maintaining the same level of reliability.

The Capacity Factor Approach. ELCC analyses require production simulation models which are complex and expensive to license and run, and which are not transparent except to the analysts who run them. Accurate ELCC analyses of the capacity value of intermittent resources also require that the data used for loads and for the output of the variable resource must be correlated in time. For example, hourly data on loads and on solar output from the same years should be used in the model. As a result of the limitations and complexities of ELCC analyses, most control area operators in the U.S. use the simpler and more transparent "capacity factor" approach to setting the capacity value of intermittent renewable resources. This method sets the capacity value of the renewable resource based on its demonstrated capacity factor during certain critical hours of peak demand. For example, as discussed in more detail below, MISO uses the critical hours ending 1500-1700 Eastern Standard Time [EST] on weekdays in the summer months of June to August. For example, if a 100 MW solar facility operates at a 75% capacity factor during the designated critical peak hours, the accredited capacity of that unit would be 75 MW.

Q: Can you provide an authoritative description of these two approaches, including a review of how control area operators have implemented the capacity factor method?

A: Yes. In April 2009, the North American Electric Reliability Corporation (NERC) issued a special report on "Accommodating High Levels of Variable Generation."[3] NERC is the organization charged with developing and enforcing the standards needed to assure the reliable operation of the electric grid in the U.S. and Canada. NERC's Integration of Variable Generation Task Force (IVGTF) prepared this report, which includes a section on Resource Adequacy Planning describing the two approaches I have summarized above for assessing the capacity value of intermittent renewable resources. I include the NERC IVGTF Report as Schedule RTB-2 to this testimony. In particular, Figure 3.3 on page 40 shows the details of the capacity factor methods used by a number of the major independent system operators in the U.S.

Q: Which of these methodologies does MISO use for calculating the accredited capacity of solar facilities?

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[3] Available at http://www.nerc.com/files/IVGTF_Report_041609.pdf.

A: Like most other system operators in the U.S., MISO uses the capacity factor methodology for calculating the accredited capacity for "non-wind variable generation," which applies to solar facilities. This methodology can be found in Section 4.2.2.1 of MISO's Resource Adequacy Business Practice Manual No. 011-r12 (RA BPM).[4]

Q: Please describe MISO's accredited capacity calculation methodology for solar facilities.

A: MISO determines the accredited capacity of a non-wind intermittent resource based on the most recent consecutive 3-year historical average output of the resource for hours ending 1500-1700 EST in the summer months of June, July, and August.[5]

Q: Is MISO's methodology for calculating accredited capacity for solar facilities consistent with industry best practices?

A: Yes. The ELCC approach sometimes is considered to be a "gold standard" in determining capacity values for solar facilities, and indeed the NERC IVGTF Report recommends that NERC "consider adopting" the ELCC method "[a]s 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)."[6] Conceptually, ELCC studies are more rigorous than capacity factor methodologies. However, as the NERC IVGTF Report notes, ELCC studies require time-correlated load and generation output data over multiple years, data which are difficult to obtain. ELCC analyses use computer models that are complex to build, can

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[4] Available at: https://www.misoenergy.org/Library/BusinessPracticesManuals/Pages/BusinessPracticesManuals.aspx

[5] MISO RA BPM, at 33-34. MISO's RA BPM was updated effective August 1, 2013; in this update, the accredited capacity calculation methodology for non-wind variable generation has not materially changed.

[6] NERC IVGTF Report, at 41.

be expensive to run, involve many input assumptions about which opinions may differ, and are not transparent except to the parties which run them. As a result, most system operators and their regulators, including MISO, CAISO,[7] NYISO,[8] New England ISO,[9] and PJM,[10] continue to use the capacity factor approach, presumably because it is fair and transparent to all participants.

Q: Please describe why you characterize the capacity factor approach as "fair and transparent to all participants"?

A: The capacity factor approach is fair and transparent to all participants because all potential market participants, regardless of size, can determine the likely capacity value of a proposed project, without the need to undertake a complex and uncertain modeling exercise that may be within the means and capabilities of only a few parties. It is also easy for regulators and utilities to verify calculations of accredited capacity.

Q: Did you review Geronimo's calculation of accredited capacity for the Project?

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[7] The CPUC establishes the resource adequacy rules for intermittent generation in California and on the CAISO-operated grid. In CPUC Decision No. 09-06-028, the CPUC adopted a modified version of the capacity factor method to determine the capacity value of intermittent solar and wind resources. This rule sets the capacity value for these resources based on the output of such a resource in certain summer peak hours (hours from 1 to 6 p.m. on summer days) that is exceeded in 70% of those hours. For comparison, a method based on the "average" capacity factor would use the output that is exceeded in about 50% of peak hours. This project-specific capacity value is then adjusted upward based on the 70% exceedance value for the aggregate output of all such intermittent generators, in recognition that, as a result of the temporal and geographic diversity of solar and wind resources, the capacity value of the aggregate of all such generators is greater than the sum of their individual capacities. For a description of this approach, see http://www.cpuc.ca.gov/PUC/energy/Procurement/RA/ra_history.htm , "Qualifying Capacity calculation methodologies."

[8] New York ISO, Installed Capacity Manual, Section 4.5, at 4-17 and Section 4.5.1. the NY ISO bases the Unforced Capacity from an Intermittent Power Resource for the summer capability period on "the average production during the 14:00 to 18:00 hours for the months of June, July and August" of the prior year. See http://www.nyiso.com/public/webdocs/markets_operations/documents/Manuals_and_Guides/Manuals/Operations/icap_mnl.pdf .

[9] New England ISO tariff, Section III. 13 – Forward Capacity Market of Market Rule 1, located at: http://www.iso-ne.com/regulatory/tariff/sect_3/index.html . In particular, see Section III.13.1.2.2.2.1. The New England ISO uses average output over the previous five years during the Summer Intermittent Reliability Hours, which are the hours ending 1400 through 1800 on each day of the summer period (June through September).

[10] Appendix B of PJM's Manual 21 specifies that the capacity value of a solar resource should be calculated based on its summer (June-August) capacity factor during the hours ending 3-6 p.m. local time, using three years of data. *See* http://www.pjm.com/documents/manuals.aspx .

A: Yes, I have.

Q: Please describe the data Geronimo used in its calculations.

A: Geronimo used a TMY3 (typical meteorological-year, version 3) data set produced by the National Renewable Energy Laboratory (NREL) as input to the PVSyst solar simulation model, as well as three years of actual energy production data from the Saint John's Solar Farm linear axis tracker.

Q: What data is included in the TMY3 data set?

A: The TMY3 data sets include hourly values of solar radiation for a 1-year period. The TMY3 data are derived from the 1961-1990 and 1991-2005 National Solar Radiation Data Base (NSRDB) archives. The TMY3 data sets use more recent and accurate data than the prior TMY1 and TMY2 data sets, and contain data for 1020 locations, compared with 239 locations for the TMY2 data set. The TMY3 data sets are used widely for computer simulations of the output of solar energy facilities throughout the U.S.[11]

Q: Why was the TMY3 data used?

A: The TMY3 data sets are a standard source for data on solar insolation at a broad range of locations in the U.S. The data is normalized to typical, i.e. long-term average, meteorological conditions, and thus provide a means to assess accurately the average output of solar facilities that will have useful lives of 20 – 30 years.

Q: Please explain why Geronimo also used energy production data from the Saint John's Solar Farm.

A: The Saint John's Solar Farm is an operating facility with several years of output data available, is centrally located among the DEGZs Geronimo is proposing, and is on Xcel

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[11] See http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/ .

Energy's system. Moreover, the Saint John's Solar Farm utilizes technology similar to that being proposed for the Project, so it is good proxy for the generation characteristics of the proposed facilities.

Q: Were any other proxies used to ensure that energy production data from Saint John's Solar Farm is representative of the energy production that can be expected from the Project?

A: As illustrated in Figure 1, the Saint John's Solar Farm output data was compared to the comparable output data for a single-axis tracking array from the NREL's widely-used PVWATTS solar simulation tool.

Q: Please walk us through how Geronimo applied this data to MISO's calculation methodology.

A: Geronimo used the NREL TMY3 data, plus the design characteristics of its proposed solar system, in a standard solar output simulation tool (PVSyst) to estimate the hourly production from the Project in a typical meteorological year. Geronimo then isolated the PV output in the hours on which MISO capacity accreditation is based (the hours ending 3 p.m., 4 p.m., and 5 p.m. EST, or the hours ending 2 p.m., 3 p.m., and 4 p.m. Central Standard Time [CST]), and calculated the Project's expected capacity factor in those critical hours. The capacity factor is the ratio of the Project's average output in those hours divided by its AC capacity rating. Geronimo also performed the same calculation using the actual operating data from 2010-2012 for the Saint John's solar project.

Q: Based on your review, was Geronimo's calculation of the 71 MW of accredited capacity for the Project consistent with MISO's methodology?

A: Yes, it was.

IV. RELIABILITY OF DISTRIBUTED SOLAR ENERGY TO SERVE PEAK DEMANDS

Q: What is “peak demand”?

A: A utility’s peak demand is the maximum demand served by the utility, typically the maximum demand served in any hour over the course of a year.

Q: What is a “peak capacity resource”?

A: A peak capacity resource is one which generates a significant portion of its energy at the time of a utility’s peak demand and in other high-demand hours.

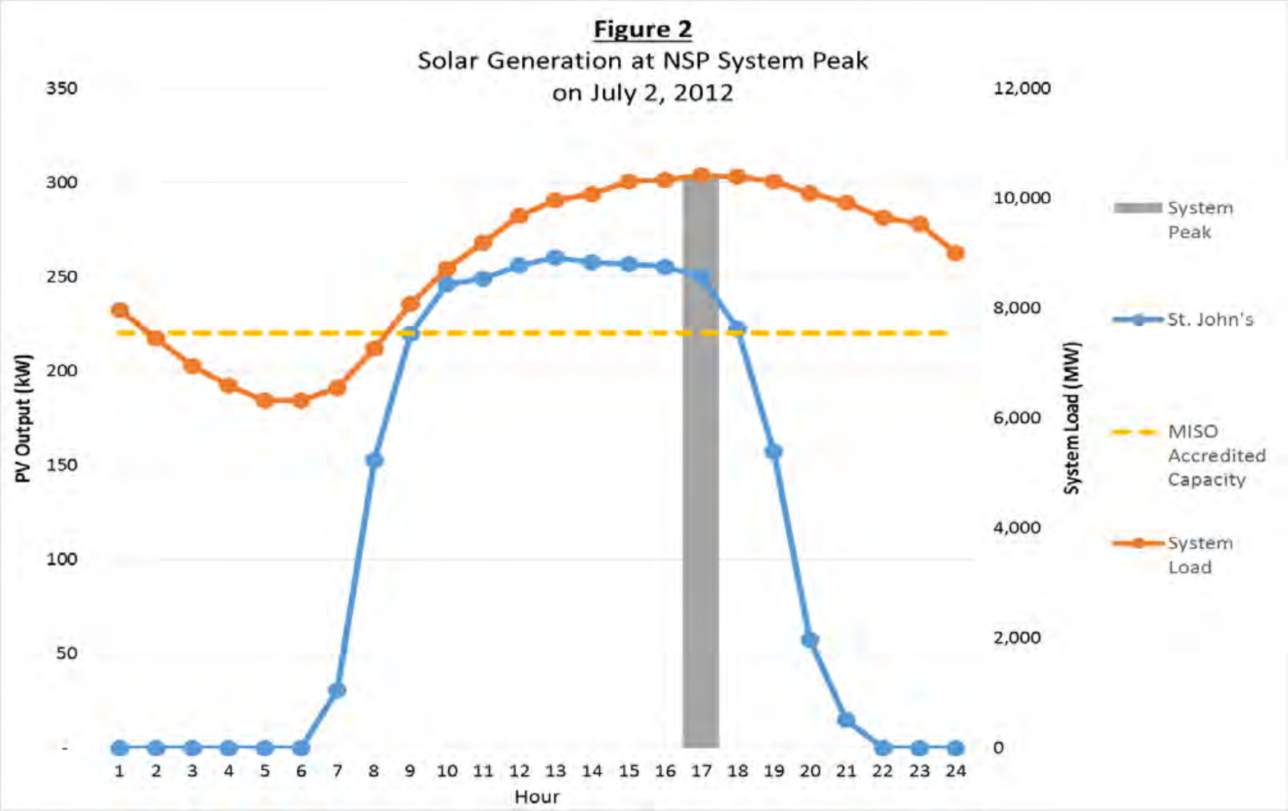
Q: Please explain how typical solar energy production compares to peak demand periods in the Midwest.

A: Peak demand generally occurs on summer weekdays between 2 p.m. and 6 p.m. EST (or Central Daylight Time [CDT]). Peak solar energy production generally occurs close to or during the hours of peak demand; exactly when solar production peaks depends on the orientation of the array and whether the array is fixed or tracks the sun. A south-facing fixed array will reach its maximum output at solar noon (i.e. 1 p.m. CDT), while a west-facing array will peak later in the afternoon, at about 3 p.m. EST/CDT.

Q: What impacts will use of the tracking systems have on the Project’s ability to meet peak demand periods?

A: A solar array with single-axis tracking, such as those which Geronimo proposes to use in the Project, is able to sustain its output close to the maximum through the afternoon hours when peak demand typically occurs, as shown in Figure 1. To illustrate this fact using actual PV output data, **Figures 2, 3, and 4** show the output of the Saint John’s Solar

Farm on the days in 2010 – 2012 when Xcel's annual peak hourly demand occurred.[12] The shaded hours show these peak demand hours. The figures also demonstrate that the output of the Saint John's project <u>exceeded</u> the MISO accredited capacity of this unit (220 kW) in all but one hour between 2 p.m. and 5 p.m. EST on each of these three system peak days, and averaged 252 kW (over 80% of the project's AC capacity) during these critical peak hours. This is not surprising – it makes sense that Xcel's annual peak demand would tend to occur on hot, sunny, summer days when solar output is also high.



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[12] The system load shapes shown in Figures 2-4 are based on the typical peak day load shape included in Xcel Energy's May 2013 Solar ELCC Study, scaled to the actual 2010-2012 system peak demands, and thus are representative only.

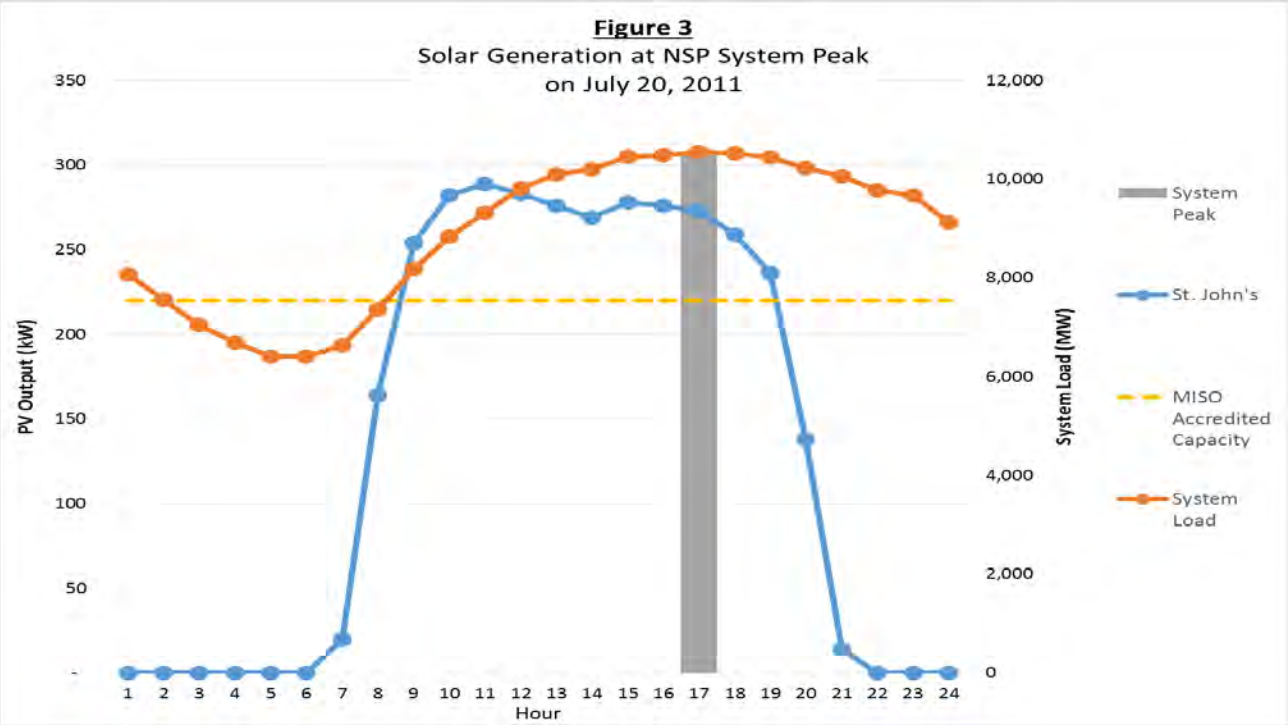

Figure 3
Solar Generation at NSP System Peak
on July 20, 2011

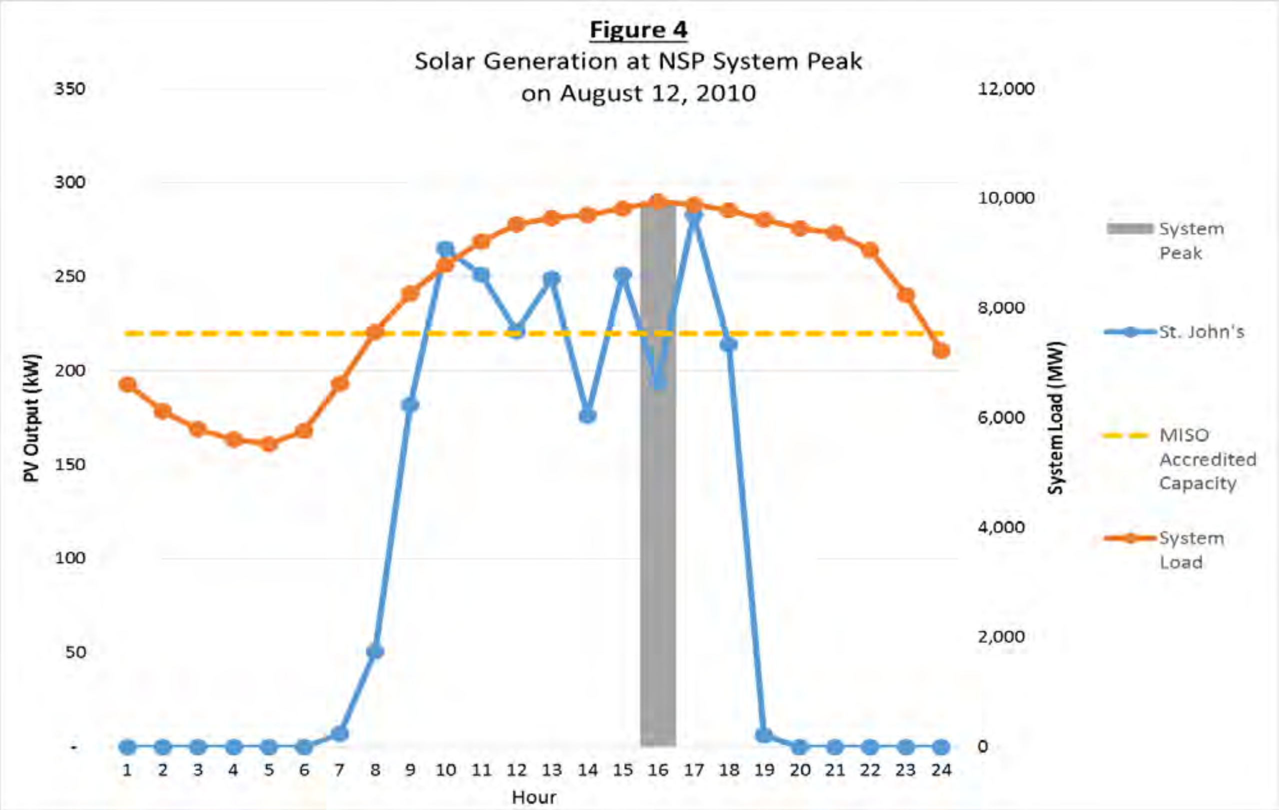

Figure 4
Solar Generation at NSP System Peak
on August 12, 2010

Q: How will constructing approximately 20 distributed sites impact the Project's ability to meet peak demand periods?

A: The geographic diversity of approximately 20 sites in the Project will reduce significantly the potential for fluctuations in the Project's total output due to momentary shading from passing cloud cover. The use of a large number of sites also ensures that any operational issues, constraints on the transmission or distribution (T&D) systems, or forced outages at one site will have only a minor impact on the Project's total output.[13] The result of the geographic diversity of 20 - 30 sites will be that the Project's output will be steadier and more reliable than if the Project were located at a single site.

Q: How will normal maintenance activities impact the Project's ability to meet peak demand periods?

A: Normal maintenance can be scheduled for times when the Project's output is zero, such as night-time hours.

Q: Are you familiar with examples where a utility has used solar energy as a peak capacity resource?

A: Many utilities across the U.S. now use solar energy as a peaking resource, and count the capacity from solar generating plants toward meeting their needs for firm electric capacity to serve peak demands. Utilities count the capacity both of demand-side solar installed by individual customers behind their meters and of larger wholesale solar projects, such as Geronimo's proposed Project, whose output the utilities purchase

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[13] For example, assume an individual solar site has a 5% chance of being forced out of service or unable to deliver its power as a result of T&D constraints. If the entire 100 MW is located at one site, there is a 5% chance that the full 100 MW of capacity will be lost during an hour of peak demand. However, if the 100 MW is sited at 20 different sites of 5 MW each, the likelihood that the entire 100 MW would be unavailable in the peak hour becomes $(0.05)^{20}$, i.e. essentially zero.

directly. In the last several years, I have reviewed integrated resource plans for utilities in Arizona, California, Colorado, New Mexico, and Nevada who count capacity from solar facilities as contributing to meeting their future peak capacity needs.

Q: Please compare how solar energy plants compare to natural gas peaking plants in terms of meeting peak capacity needs.

A: Both solar and gas-fired plants can meet peak capacity needs with a high degree of reliability. A gas-fired plant can supply 100% of its capacity toward meeting peak demand, while a tracking solar project such as the Project will supply about 70% of its capacity with a reliability equal to that of the gas-fired plant. If the solar capacity is located at multiple distributed sites, this geographic diversity will enhance the consistency and reliability of the solar output, compared to locating all of this capacity at a single site. The solar project differs most significantly from the gas peaker in that the solar facility provides 100% renewable generation with no consumption of fossil fuels and no emissions of greenhouse gases or criteria air pollutants.

V. CONCLUSION

Q: Please summarize your testimony.

A: Geronimo's solar Project will provide 71 MW of MISO-accredited capacity to Xcel Energy's system. This conclusion is based on the MISO accreditation rule and the expected hourly output of the Project using an industry-standard simulation of the Project's expected hourly output, and is confirmed by the estimated MISO-accredited capacity of a comparable, operating solar project located in Xcel's service territory that uses similar linear-axis tracking technology. The MISO accreditation rule is based on a capacity factor methodology that is used by many independent system operators in the

U.S. The Project's ability to supply this level of capacity is reinforced by Geronimo's proposal to site the Project at approximately 20 different locations across Xcel's service territory. Such geographic diversity will increase the stability and reliability of the Project's output, compared to a comparable peaking plant that is sited at one location. The power provided by the Project will be 100% renewable, with no carbon or other air emissions and minimal water usage and environmental impacts, and will make a significant and ground-breaking contribution to a cleaner, more reliable, and more resilient electric grid in Minnesota.

Q: Does this conclude your testimony?

A: Yes, it does.

R. THOMAS BEACH

Principal Consultant

Mr. Beach is principal consultant with the consulting firm Crossborder Energy. Crossborder Energy provides economic consulting services and strategic advice on market and regulatory issues concerning the natural gas and electric industries. The firm is based in Berkeley, California, and its practice focuses on the energy markets in California, the western U.S., Canada, and Mexico.

Since 1989, Mr. Beach has participated actively in most of the major energy policy debates in California, including renewable energy development, the restructuring of the state's gas and electric industries, the addition of new natural gas pipeline and storage capacity, and a wide range of issues concerning California's large independent power community. From 1981 through 1989 he served at the California Public Utilities Commission, including five years as an advisor to three CPUC commissioners. While at the CPUC, he was a key advisor on the CPUC's restructuring of the natural gas industry in California, and worked extensively on the state's implementation of PURPA.

AREAS OF EXPERTISE

- *Renewable Energy Issues:* extensive experience assisting clients with issues concerning California’s Renewable Portfolio Standard program, including the calculation of the state’s Market Price Referent for new renewable generation. He has also worked for the solar industry on the creation of the California Solar Initiative (the Million Solar Roofs), as well as on a wide range of solar issues in other states.
- *Restructuring the Natural Gas and Electric Industries:* consulting and expert testimony on numerous issues involving the restructuring of the electric industry, including the 2000 - 2001 Western energy crisis.
- *Energy Markets:* studies and consultation on the dynamics of natural gas and electric markets, including the impacts of new pipeline capacity on natural gas prices and of electric restructuring on wholesale electric prices.
- *Qualifying Facility Issues:* consulting with QF clients on a broad range of issues involving independent power facilities in the Western U.S. He is one of the leading experts in California on the calculation of avoided cost prices. Other QF issues on which he has worked include complex QF contract restructurings, electric transmission and interconnection issues, property tax matters, standby rates, QF efficiency standards, and natural gas rates for cogenerators. Crossborder Energy's QF clients include the full range of QF technologies, both fossil-fueled and renewable.
- *Pricing Policy in Regulated Industries:* consulting and expert testimony on natural gas pipeline rates and on marginal cost-based rates for natural gas and electric utilities.

EDUCATION

Mr. Beach holds a B.A. in English and physics from Dartmouth College, and an M.E. in mechanical engineering from the University of California at Berkeley.

ACADEMIC HONORS

Graduated from Dartmouth with high honors in physics and honors in English.
Chevron Fellowship, U.C. Berkeley, 1978-79

PROFESSIONAL ACCREDITATION

Registered professional engineer in the state of California.

EXPERT WITNESS TESTIMONY BEFORE THE CPUC

1. Prepared Direct Testimony on Behalf of **Pacific Gas & Electric Company/Pacific Gas Transmission** (I. 88-12-027 — July 15, 1989)

    - *Competitive and environmental benefits of new natural gas pipeline capacity to California.*

2. a. Prepared Direct Testimony on Behalf of the **Canadian Producer Group** (A. 89-08-024 — November 10, 1989)
    b. Prepared Rebuttal Testimony on Behalf of the **Canadian Producer Group** (A. 89-08-024 — November 30, 1989)

    - *Natural gas procurement policy; gas cost forecasting.*

3. Prepared Direct Testimony on Behalf of the **Canadian Producer Group** (R. 88-08-018 — December 7, 1989)

    - *Brokering of interstate pipeline capacity.*

4. Prepared Direct Testimony on Behalf of the **Canadian Producer Group** (A. 90-08-029 — November 1, 1990)

    - *Natural gas procurement policy; gas cost forecasting; brokerage fees.*

5. Prepared Direct Testimony on Behalf of the **Alberta Petroleum Marketing Commission and the Canadian Producer Group** (I. 86-06-005 — December 21, 1990)

    - *Firm and interruptible rates for noncore natural gas users*

6. a. Prepared Direct Testimony on Behalf of the **Alberta Petroleum Marketing Commission** (R. 88-08-018 — January 25, 1991)
   b. Prepared Responsive Testimony on Behalf of the **Alberta Petroleum Marketing Commission** (R. 88-08-018 — March 29, 1991)

   - *Brokering of interstate pipeline capacity; intrastate transportation policies.*

7. Prepared Direct Testimony on Behalf of the **Canadian Producer Group** (A. 90-08-029/Phase II — April 17, 1991)

   - *Natural gas brokerage and transport fees.*

8. Prepared Direct Testimony on Behalf of **LUZ Partnership Management** (A. 91-01-027 — July 15, 1991)

   - *Natural gas parity rates for cogenerators and solar power plants.*

9. Prepared Joint Testimony of R. Thomas Beach and Dr. Robert B. Weisenmiller on Behalf of the **California Cogeneration Council** (I. 89-07-004 — July 15, 1991)

   - *Avoided cost pricing; use of published natural gas price indices to set avoided cost prices for qualifying facilities.*

10. a. Prepared Direct Testimony on Behalf of the **Indicated Expansion Shippers** (A. 89-04-033 — October 28, 1991)
    b. Prepared Rebuttal Testimony on Behalf of the **Indicated Expansion Shippers** (A. 89-04-0033 — November 26,1991)

    - *Natural gas pipeline rate design; cost/benefit analysis of rolled-in rates.*

11. Prepared Direct Testimony on Behalf of the **Independent Petroleum Association of Canada** (A. 91-04-003 — January 17, 1992)

    - *Natural gas procurement policy; prudence of past gas purchases.*

12. a. Prepared Direct Testimony on Behalf of the **California Cogeneration Council** (I.86-06-005/Phase II — June 18, 1992)
    b. Prepared Rebuttal Testimony on Behalf of the **California Cogeneration Council** (I. 86-06-005/Phase II — July 2, 1992)

    - *Long-Run Marginal Cost (LRMC) rate design for natural gas utilities.*

13. Prepared Direct Testimony on Behalf of the **California Cogeneration Council** (A. 92-10-017 — February 19, 1993)

    - *Performance-based ratemaking for electric utilities.*

14. Prepared Direct Testimony on Behalf of the **SEGS Projects** (C. 93-02-014/A. 93-03-053 — May 21, 1993)

    - *Natural gas transportation service for wholesale customers.*

15 a. Prepared Direct Testimony on Behalf of the **Canadian Association of Petroleum Producers** (A. 92-12-043/A. 93-03-038 — June 28, 1993)
   b. Prepared Rebuttal Testimony of Behalf of the **Canadian Association of Petroleum Producers** (A. 92-12-043/A. 93-03-038 — July 8, 1993)

    - *Natural gas pipeline rate design issues.*

16. a. Prepared Direct Testimony on Behalf of the **SEGS Projects** (C. 93-05-023 — November 10, 1993)
    b. Prepared Rebuttal Testimony on Behalf of the **SEGS Projects** (C. 93-05-023 — January 10, 1994)

    - *Utility overcharges for natural gas service; cogeneration parity issues.*

17. Prepared Direct Testimony on Behalf of the **City of Vernon** (A. 93-09-006/A. 93-08-022/A. 93-09-048 — June 17, 1994)

    - *Natural gas rate design for wholesale customers; retail competition issues.*

18. Prepared Direct Testimony of R. Thomas Beach on Behalf of the **SEGS Projects** (A. 94-01-021 — August 5, 1994)

    - *Natural gas rate design issues; rate parity for solar power plants.*

19. Prepared Direct Testimony on Transition Cost Issues on Behalf of **Watson Cogeneration Company** (R. 94-04-031/I. 94-04-032 — December 5, 1994)

    - *Policy issues concerning the calculation, allocation, and recovery of transition costs associated with electric industry restructuring.*

20. Prepared Direct Testimony on Nuclear Cost Recovery Issues on Behalf of the **California Cogeneration Council** (A. 93-12-025/I. 94-02-002 — February 14, 1995)

    - *Recovery of above-market nuclear plant costs under electric restructuring.*

21. Prepared Direct Testimony on Behalf of the **Sacramento Municipal Utility District** (A. 94-11-015 — June 16, 1995)

    - *Natural gas rate design; unbundled mainline transportation rates.*

22. Prepared Direct Testimony on Behalf of **Watson Cogeneration Company** (A. 95-05-049 — September 11, 1995)

    - *Incremental Energy Rates; air quality compliance costs.*

23. a. Prepared Direct Testimony on Behalf of the **Canadian Association of Petroleum Producers** (A. 92-12-043/A. 93-03-038/A. 94-05-035/A. 94-06-034/A. 94-09-056/A. 94-06-044 — January 30, 1996)
    b. Prepared Rebuttal Testimony on Behalf of the **Canadian Association of Petroleum Producers** (A. 92-12-043/A. 93-03-038/A. 94-05-035/A. 94-06-034/A. 94-09-056/A. 94-06-044 — February 28, 1996)

    - *Natural gas market dynamics; gas pipeline rate design.*

24. Prepared Direct Testimony on Behalf of the **California Cogeneration Council and Watson Cogeneration Company** (A. 96-03-031 — July 12, 1996)

    - *Natural gas rate design: parity rates for cogenerators.*

25. Prepared Direct Testimony on Behalf of the **City of Vernon** (A. 96-10-038 — August 6, 1997)

    - *Impacts of a major utility merger on competition in natural gas and electric markets.*

26. a. Prepared Direct Testimony on Behalf of the **Electricity Generation Coalition** (A. 97-03-002 — December 18, 1997)
    b. Prepared Rebuttal Testimony on Behalf of the **Electricity Generation Coalition** (A. 97-03-002 — January 9, 1998)

    - *Natural gas rate design for gas-fired electric generators.*

27. Prepared Direct Testimony on Behalf of the **City of Vernon** (A. 97-03-015 — January 16, 1998)

    - *Natural gas service to Baja, California, Mexico.*

28.
a. Prepared Direct Testimony on Behalf of the **California Cogeneration Council and Watson Cogeneration Company** (A. 98-10-012/A. 98-10-031/A. 98-07-005 — March 4, 1999).
b. Prepared Direct Testimony on Behalf of the **California Cogeneration Council** (A. 98-10-012/A. 98-01-031/A. 98-07-005 — March 15, 1999).
c. Prepared Direct Testimony on Behalf of the **California Cogeneration Council** (A. 98-10-012/A. 98-01-031/A. 98-07-005 — June 25, 1999).

- *Natural gas cost allocation and rate design for gas-fired electric generators.*

29.
a. Prepared Direct Testimony on Behalf of the **California Cogeneration Council and Watson Cogeneration Company** (R. 99-11-022 — February 11, 2000).
b. Prepared Rebuttal Testimony on Behalf of the **California Cogeneration Council and Watson Cogeneration Company** (R. 99-11-022 — March 6, 2000).
c. Prepared Direct Testimony on Line Loss Issues of behalf of the **California Cogeneration Council** (R. 99-11-022 — April 28, 2000).
d. Supplemental Direct Testimony in Response to ALJ Cooke's Request on behalf of the **California Cogeneration Council and Watson Cogeneration Company** (R. 99-11-022 — April 28, 2000).
e. Prepared Rebuttal Testimony on Line Loss Issues on behalf of the **California Cogeneration Council** (R. 99-11-022 — May 8, 2000).

- *Market-based, avoided cost pricing for the electric output of gas-fired cogeneration facilities in the California market; electric line losses.*

30.
a. Direct Testimony on behalf of the **Indicated Electric Generators** in Support of the Comprehensive Gas OII Settlement Agreement for Southern California Gas Company and San Diego Gas & Electric Company (I. 99-07-003 — May 5, 2000).
b. Rebuttal Testimony in Support of the Comprehensive Settlement Agreement on behalf of the **Indicated Electric Generators** (I. 99-07-003 — May 19, 2000).

- *Testimony in support of a comprehensive restructuring of natural gas rates and services on the Southern California Gas Company system. Natural gas cost allocation and rate design for gas-fired electric generators.*

31.
a. Prepared Direct Testimony on the Cogeneration Gas Allowance on behalf of the **California Cogeneration Council** (A. 00-04-002 — September 1, 2000).
b. Prepared Direct Testimony on behalf of **Southern Energy California** (A. 00-04-002 — September 1, 2000).

- *Natural gas cost allocation and rate design for gas-fired electric generators.*

32. a. Prepared Direct Testimony on behalf of **Watson Cogeneration Company** (A. 00-06-032 — September 18, 2000).
    b. Prepared Rebuttal Testimony on behalf of **Watson Cogeneration Company** (A. 00-06-032 — October 6, 2000).

    - *Rate design for a natural gas "peaking service."*

33. a. Prepared Direct Testimony on behalf of **PG&E National Energy Group & Calpine Corporation** (I. 00-11-002—April 25, 2001).
    b. Prepared Rebuttal Testimony on behalf of **PG&E National Energy Group & Calpine Corporation** (I. 00-11-002—May 15, 2001).

    - *Terms and conditions of natural gas service to electric generators; gas curtailment policies.*

34. a. Prepared Direct Testimony on behalf of the **California Cogeneration Council** (R. 99-11-022—May 7, 2001).
    b. Prepared Rebuttal Testimony on behalf of the **California Cogeneration Council** (R. 99-11-022—May 30, 2001).

    - *Avoided cost pricing for alternative energy producers in California.*

35. a. Prepared Direct Testimony of R. Thomas Beach in Support of the Application of **Wild Goose Storage Inc.** (A. 01-06-029—June 18, 2001).
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of **Wild Goose Storage** (A. 01-06-029—November 2, 2001)

    - *Consumer benefits from expanded natural gas storage capacity in California.*

36. Prepared Direct Testimony of R. Thomas Beach on behalf of the **County of San Bernardino** (I. 01-06-047—December 14, 2001)

    - *Reasonableness review of a natural gas utility's procurement practices and storage operations.*

37. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 01-10-024—May 31, 2002)
    b. Prepared Supplemental Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 01-10-024—May 31, 2002)

    - *Electric procurement policies for California's electric utilities in the aftermath of the California energy crisis.*

38. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Manufacturers & Technology Association** (R. 02-01-011—June 6, 2002)

    - *"Exit fees" for direct access customers in California.*

39. Prepared Direct Testimony of R. Thomas Beach on behalf of the **County of San Bernardino** (A. 02-02-012 — August 5, 2002)

    - *General rate case issues for a natural gas utility; reasonableness review of a natural gas utility's procurement practices.*

40. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Manufacturers and Technology Association** (A. 98-07-003 — February 7, 2003)

    - *Recovery of past utility procurement costs from direct access customers.*

41. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council, the California Manufacturers & Technology Association, Calpine Corporation, and Mirant Americas, Inc.** (A 01-10-011 — February 28, 2003)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council, the California Manufacturers & Technology Association, Calpine Corporation, and Mirant Americas, Inc.** (A 01-10-011 — March 24, 2003)

    - *Rate design issues for Pacific Gas & Electric's gas transmission system (Gas Accord II).*

42. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Manufacturers & Technology Association; Calpine Corporation; Duke Energy North America; Mirant Americas, Inc.; Watson Cogeneration Company; and West Coast Power, Inc.** (R. 02-06-041 — March 21, 2003)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **California Manufacturers & Technology Association; Calpine Corporation; Duke Energy North America; Mirant Americas, Inc.; Watson Cogeneration Company; and West Coast Power, Inc.** (R. 02-06-041 — April 4, 2003)

    - *Cost allocation of above-market interstate pipeline costs for the California natural gas utilities.*

43. Prepared Direct Testimony of R. Thomas Beach and Nancy Rader on behalf of the **California Wind Energy Association** (R. 01-10-024 — April 1, 2003)

    - *Design and implementation of a Renewable Portfolio Standard in California.*

44. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 01-10-024 — June 23, 2003)
    b. Prepared Supplemental Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 01-10-024 — June 29, 2003)

    - *Power procurement policies for electric utilities in California.*

45. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Indicated Commercial Parties** (02-05-004 — August 29, 2003)

    - *Electric revenue allocation and rate design for commercial customers in southern California.*

46. a. Prepared Direct Testimony of R. Thomas Beach on behalf of **Calpine Corporation and the California Cogeneration Council** (A. 04-03-021 — July 16, 2004)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of **Calpine Corporation and the California Cogeneration Council** (A. 04-03-021 — July 26, 2004)

    - *Policy and rate design issues for Pacific Gas & Electric's gas transmission system (Gas Accord III).*

47. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (A. 04-04-003 — August 6, 2004)

    - *Policy and contract issues concerning cogeneration QFs in California.*

48. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council and the California Manufacturers and Technology Association** (A. 04-07-044 — January 11, 2005)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council and the California Manufacturers and Technology Association** (A. 04-07-044 — January 28, 2005)

    - *Natural gas cost allocation and rate design for large transportation customers in northern California.*

49. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Manufacturers and Technology Association and the Indicated Commercial Parties** (A. 04-06-024 — March 7, 2005)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **California Manufacturers and Technology Association and the Indicated Commercial Parties** (A. 04-06-024 — April 26, 2005)

    - *Electric marginal costs, revenue allocation, and rate design for commercial and industrial electric customers in northern California.*

50. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Solar Energy Industries Association** (R. 04-03-017 — April 28, 2005)

    - *Cost-effectiveness of the Million Solar Roofs Program.*

51. Prepared Direct Testimony of R. Thomas Beach on behalf of **Watson Cogeneration Company, the Indicated Producers, and the California Manufacturing and Technology Association** (A. 04-12-004 — July 29, 2005)

    - *Natural gas rate design policy; integration of gas utility systems.*

52. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 04-04-003/R. 04-04-025 — August 31, 2005)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 04-04-003/R. 04-04-025 — October 28, 2005)

    - *Avoided cost rates and contracting policies for QFs in California*

53. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Manufacturers and Technology Association and the Indicated Commercial Parties** (A. 05-05-023 — January 20, 2006)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **California Manufacturers and Technology Association and the Indicated Commercial Parties** (A. 05-05-023 — February 24, 2006)

    - *Electric marginal costs, revenue allocation, and rate design for commercial and industrial electric customers in southern California.*

54. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Producers** (R. 04-08-018 – January 30, 2006)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **California Producers** (R. 04-08-018 – February 21, 2006)

    - *Transportation and balancing issues concerning California gas production.*

55. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Manufacturers and Technology Association and the Indicated Commercial Parties** (A. 06-03-005 — October 27, 2006)

    - *Electric marginal costs, revenue allocation, and rate design for commercial and industrial electric customers in northern California.*

56. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (A. 05-12-030 — March 29, 2006)

    - *Review and approval of a new contract with a gas-fired cogeneration project.*

57. a. Prepared Direct Testimony of R. Thomas Beach on behalf of **Watson Cogeneration, Indicated Producers, the California Cogeneration Council, and the California Manufacturers and Technology Association** (A. 04-12-004 — July 14, 2006)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of **Watson Cogeneration, Indicated Producers, the California Cogeneration Council, and the California Manufacturers and Technology Association** (A. 04-12-004 — July 31, 2006)

    - *Restructuring of the natural gas system in southern California to include firm capacity rights; unbundling of natural gas services; risk/reward issues for natural gas utilities.*

58. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 06-02-013 — March 2, 2007)

    - *Utility procurement policies concerning gas-fired cogeneration facilities.*

59. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Solar Alliance** (A. 07-01-047 — August 10, 2007)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **Solar Alliance** (A. 07-01-047 — September 24, 2007)

    - *Electric rate design issues that impact customers installing solar photovoltaic systems.*

60. a. Prepared Direct Testimony of R,. Thomas Beach on Behalf of **Gas Transmission Northwest Corporation** (A. 07-12-021 — May 15, 2008)
    b. Prepared Rebuttal Testimony of R,. Thomas Beach on Behalf of **Gas Transmission Northwest Corporation** (A. 07-12-021 — June 13, 2008)

    - *Utility subscription to new natural gas pipeline capacity serving California.*

61. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Solar Alliance** (A. 08-03-015 — September 12, 2008)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **Solar Alliance** (A. 08-03-015 — October 3, 2008)

    - *Issues concerning the design of a utility-sponsored program to install 500 MW of utility- and independently-owned solar photovoltaic systems.*

62. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Solar Alliance** (A. 08-03-002 — October 31, 2008)

    - *Electric rate design issues that impact customers installing solar photovoltaic systems.*

63. a. Phase II Direct Testimony of R. Thomas Beach on behalf of **Indicated Producers, the California Cogeneration Council, California Manufacturers and Technology Association, and Watson Cogeneration Company** (A. 08-02-001 — December 23, 2008)
    b. Phase II Rebuttal Testimony of R. Thomas Beach on behalf of **Indicated Producers, the California Cogeneration Council, California Manufacturers and Technology Association, and Watson Cogeneration Company** (A. 08-02-001 — January 27, 2009)

    - *Natural gas cost allocation and rate design issues for large customers.*

64. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (A. 09-05-026 — November 4, 2009)

    - *Natural gas cost allocation and rate design issues for large customers.*

65. a. Prepared Direct Testimony of R. Thomas Beach on behalf of **Indicated Producers and Watson Cogeneration Company** (A. 10-03-028 — October 5, 2010)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of **Indicated Producers and Watson Cogeneration Company** (A. 10-03-028 — October 26, 2010)

    - *Revisions to a program of firm backbone capacity rights on natural gas pipelines.*

66. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Solar Alliance** (A. 10-03-014 — October 6, 2010)

    - *Electric rate design issues that impact customers installing solar photovoltaic systems.*

67. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **Indicated Settling Parties** (A. 09-09-013 — October 11, 2010)

    - *Testimony on proposed modifications to a broad-based settlement of rate-related issues on the Pacific Gas & Electric natural gas pipeline system.*

68. a. Supplemental Prepared Direct Testimony of R. Thomas Beach on behalf of **Sacramento Natural Gas Storage, LLC** (A. 07-04-013 — December 6, 2010)
    b. Supplemental Prepared Rebuttal Testimony of R. Thomas Beach on behalf of **Sacramento Natural Gas Storage, LLC** (A. 07-04-013 — December 13, 2010)
    c. Supplemental Prepared Reply Testimony of R. Thomas Beach on behalf of **Sacramento Natural Gas Storage, LLC** (A. 07-04-013 — December 20, 2010)

    - *Local reliability benefits of a new natural gas storage facility.*

69. Prepared Direct Testimony of R. Thomas Beach on behalf of **The Vote Solar Initiative** (A. 10-11-015—June 1, 2011)

    - *Distributed generation policies; utility distribution planning.*

70. Prepared Reply Testimony of R. Thomas Beach on behalf of the **Solar Alliance** (A. 10-03-014—August 5, 2011)

    - *Electric rate design for commercial & industrial solar customers.*

71. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Solar Energy Industries Association** (A. 11-06-007—February 6, 2012)

    - *Electric rate design for solar customers; marginal costs.*

72. a. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Northern California Indicated Producers** (R.11-02-019—January 31, 2012)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **Northern California Indicated Producers** (R. 11-02-019—February 28, 2012)

    - *Natural gas pipeline safety policies and costs*

73. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Solar Energy Industries Association** (A. 11-10-002—June 12, 2012)

    - *Electric rate design for solar customers; marginal costs.*

74. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Southern California Indicated Producers** and **Watson Cogeneration Company** (A. 11-11-002—June 19, 2012)

    - *Natural gas pipeline safety policies and costs*

75. a. Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 12-03-014—June 25, 2012)
    b. Reply Testimony of R. Thomas Beach on behalf of the **California Cogeneration Council** (R. 12-03-014—July 23, 2012)

    - *Ability of combined heat and power resources to serve local reliability needs in southern California.*

76. a. Prepared Testimony of R. Thomas Beach on behalf of the **Southern California Indicated Producers** and **Watson Cogeneration Company** (A. 11-11-002, Phase 2—November 16, 2012)
    b. Prepared Rebuttal Testimony of R. Thomas Beach on behalf of the **Southern California Indicated Producers** and **Watson Cogeneration Company** (A. 11-11-002, Phase 2—December 14, 2012)

    - *Allocation and recovery of natural gas pipeline safety costs.*

77. Prepared Direct Testimony of R. Thomas Beach on behalf of the **Solar Energy Industries Association** (A. 12-12-002—May 10, 2013)

    - *Electric rate design for commercial & industrial solar customers.*

EXPERT WITNESS TESTIMONY BEFORE THE COLORADO PUBLIC UTILITIES COMMISSION

1. Direct Testimony and Exhibits of R. Thomas Beach on behalf of the Colorado Solar Energy Industries Association and the Solar Alliance, (Docket No. 09AL-299E – October 2, 2009).

   - *Electric rate design policies to encourage the use of distributed solar generation.*

2. Direct Testimony and Exhibits of R. Thomas Beach on behalf of the Vote Solar Initiative and the Interstate Renewable Energy Council, (Docket No. 11A-418E – September 21, 2011).

   - *Development of a community solar program for Xcel Energy.*

EXPERT WITNESS TESTIMONY BEFORE THE IDAHO PUBLIC UTILITIES COMMISSION

1. Direct Testimony of R. Thomas Beach on behalf of the **Idaho Conservation League** (Case No. IPC-E-12-27—May 10, 2013)

   - *Costs and benefits of net energy metering in Idaho.*

EXPERT WITNESS TESTIMONY BEFORE THE PUBLIC SERVICE COMMISSION OF NEVADA

1. Pre-filed Direct Testimony on Behalf of the **Nevada Geothermal Industry Council** (Docket No. 97-2001—May 28, 1997)

   - *Avoided cost pricing for the electric output of geothermal generation facilities in Nevada.*

2. Pre-filed Direct Testimony on Behalf of **Nevada Sun-Peak Limited Partnership** (Docket No. 97-6008—September 5, 1997)

3. Pre-filed Direct Testimony on Behalf of the **Nevada Geothermal Industry Council** (Docket No. 98-2002 — June 18, 1998)

   - *Market-based, avoided cost pricing for the electric output of geothermal generation facilities in Nevada.*

EXPERT WITNESS TESTIMONY BEFORE THE NEW MEXICO PUBLIC REGULATION COMMISSION

1. Direct Testimony of R. Thomas Beach on Behalf of the **Interstate Renewable Energy Council** (Case No. 10-00086-UT—February 28, 2011)

   - *Testimony on proposed standby rates for new distributed generation projects; cost-effectiveness of DG in New Mexico.*

2. Direct Testimony and Exhibits of R. Thomas Beach on behalf of the **New Mexico Independent Power Producers** (Case No. 11-00265-UT, October 3, 2011)

   - *Cost cap for the Renewable Portfolio Standard program in New Mexico*

EXPERT WITNESS TESTIMONY BEFORE THE PUBLIC UTILITIES COMMISSION OF OREGON

1. a. Direct Testimony of Behalf of **Weyerhaeuser Company** (UM 1129 — August 3, 2004)
   b. Surrebuttal Testimony of Behalf of **Weyerhaeuser Company** (UM 1129 — October 14, 2004)

2. a. Direct Testimony of Behalf of **Weyerhaeuser Company and the Industrial Customers of Northwest Utilities** (UM 1129 / Phase II — February 27, 2006)
   b. Rebuttal Testimony of Behalf of **Weyerhaeuser Company and the Industrial Customers of Northwest Utilities** (UM 1129 / Phase II — April 7, 2006)

   - *Policies to promote the development of cogeneration and other qualifying facilities in Oregon.*

EXPERT WITNESS TESTIMONY BEFORE THE VIRGINIA CORPORATION COMMISSION

1. Direct Testimony and Exhibits of R. Thomas Beach on Behalf of the Maryland – District of Columbia – Virginia Solar Energy Industries Association, (Case No. PUE-2011-00088, October 11, 2011)

   - *Standby rates for net-metered solar customers, and the cost-effectiveness of net energy metering.*

LITIGATION EXPERIENCE

Mr. Beach has been retained as an expert in a variety of civil litigation matters. His work has included the preparation of reports on the following topics:

- The calculation of damages in disputes over the pricing terms of natural gas sales contracts (2 separate cases).
- The valuation of a contract for the purchase of power produced from wind generators.
- The compliance of cogeneration facilities with the policies and regulations applicable to Qualifying Facilities (QFs) under PURPA in California.
- Audit reports on the obligations of buyers and sellers under direct access electric contracts in the California market (2 separate cases).
- The valuation of interstate pipeline capacity contracts (3 separate cases).

In several of these matters, Mr. Beach was deposed by opposing counsel. Mr. Beach has also testified at trial in the bankruptcy of a major U.S. energy company, and has been retained as a consultant in anti-trust litigation concerning the California natural gas market in the period prior to and during the 2000-2001 California energy crisis.

Schedule RTB-2 to Beach Direct
MPUC Docket No. E002/CN-12-1240
OAH Docket No. 8-2500-30760

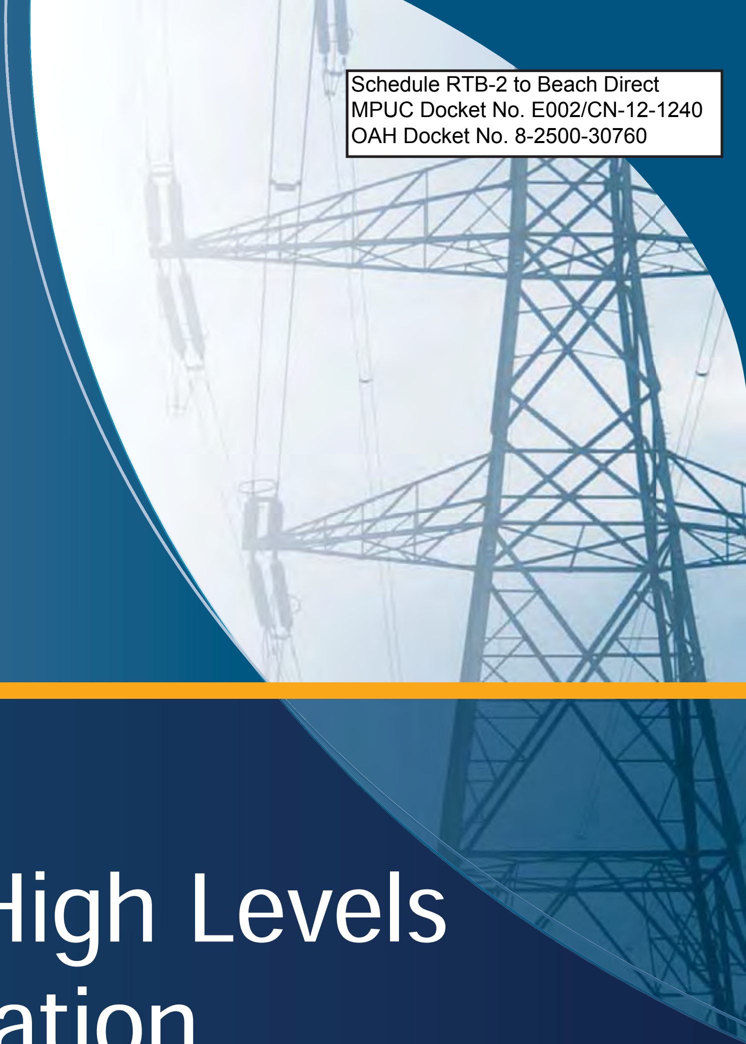

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Table of Contents

Executive Summary

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

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

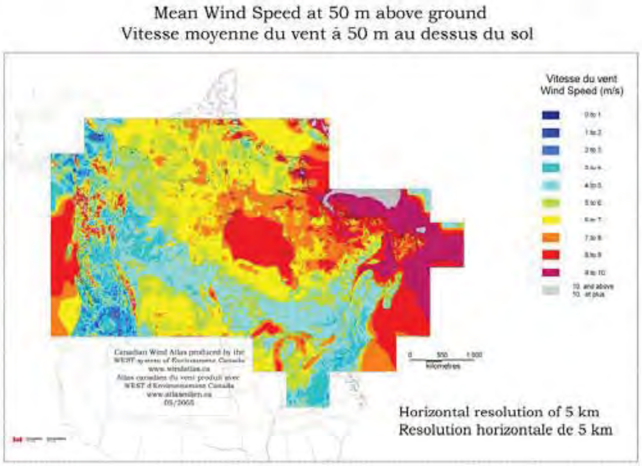

Figure A: Wind Availability in Canada

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

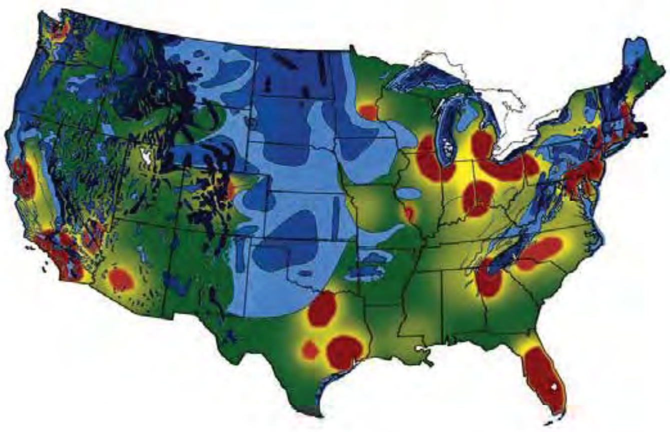

Figure B: Wind Availability and Demand Centers in the U.S.

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

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

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

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

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

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

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

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

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

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

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

1. Introduction

Fossil-fired generation produced nearly 70% of the total electrical energy in the United States in 2006, with nuclear producing 19% and existing renewable generation approximately 8%.[1] Natural gas-fired generation produced 21% of the electrical energy 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-fired capacity is negligible and total oil generation comprised less than 2% of the electrical energy produced in 2006.[2] Fossil fuels are non-renewable: that is, they draw on finite resources. In addition, they contribute to the production of greenhouse gases and particulates. In contrast, renewable energy resources, such as wind, solar, ocean, biomass, hydro, etc., can be replenished at a generally predictable rate and have no direct greenhouse gas or particulate emissions.

Government policy has been 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 and provinces with mandatory Renewable Portfolio Standards (RPS)[3] or equivalent policies (see Figure 1.1[4]). Other significant motivators include federal, provincial and state tax incentives, renewable energy investment funds, economic competitiveness, voluntary green power markets, public support, and hedging against fuel price increases and carbon regulation. Figure 1.1, shows a province-by-province and state-by-state breakdown of North

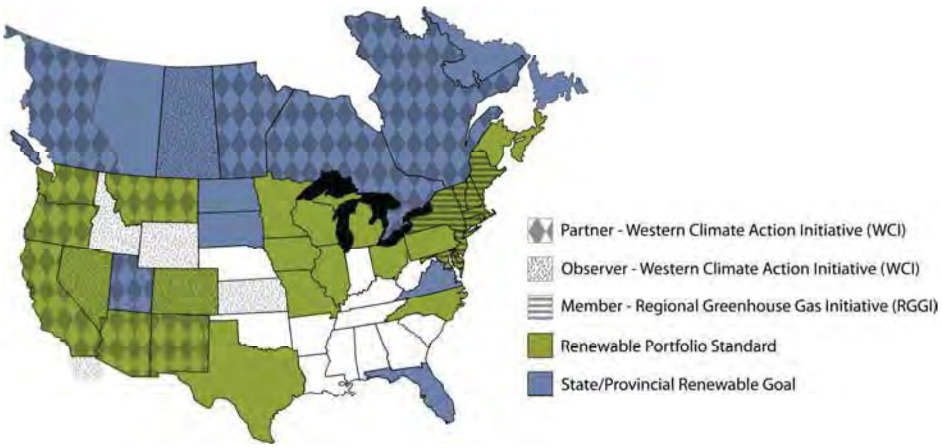

Figure 1.1: Snapshot of North American Climate Initiatives

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[1] http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf

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

[3] 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

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

American Climate Change Initiatives.[5] The Canadian government has set an overall goal of a 20% reduction in greenhouse gas emissions by 2020 using a 2006 baseline, with specific energy policies and greenhouse gas emission and renewable energy targets under development by each province.

Most of these North American targets are expected to be met by wind and solar[6] resources. In fact, based on the powerful economic and policy drivers mentioned above, wind resources are expected to constitute a significant portion of all new generation being added to the bulk power system in many parts of North America.[7]

This proposed level of commitment to renewables offers many benefits, as well as certain challenges, to the reliability of the bulk power system in North America. Unlike conventional resources, output of wind, solar, ocean and some hydro[8] generation resources varies according to the availability of a primary fuel that cannot be stored. Therefore, the key differences between variable generation and conventional power plants are that variable generation exhibits greater variability and uncertainty in its output on all time scales. Some amount of variability and uncertainty already exists on the bulk power system with regard to the demand for electricity in particular, and, to a lesser extent, to generation. To accommodate higher penetration of variable generation, changes will be required to traditional methods used by system planners and operators in order to maintain the reliability of the bulk power system on an ongoing basis. Making these significant changes will be challenging for the industry, however they will be needed to continue maintaining bulk power system reliability while integrating large amounts of variable generation.

The North American Electric Reliability Corporation's (NERC) mission is *to ensure the bulk power system in North America is reliable*. To achieve this objective, NERC develops and enforces reliability standards; assesses adequacy annually via a 10-year forecast and winter and summer forecasts; monitors the bulk power system; and educates, trains, and certifies industry personnel. NERC is a self-regulatory organization, subject to oversight by the U.S. Federal Energy Regulatory Commission and governmental authorities in Canada.

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

[6] During the time period this report was being prepared, solar development activity (as measured by interconnection requests for large solar plants) has dramatically increased. In the California ISO generation interconnection queue, interconnection requests for solar resources (all types) increased from 51 applications representing 17,600 MW in January 2008 to 91 applications representing nearly 30,000 MW (Source: California ISO website). In Arizona, the number of (non-California ISO) interconnection applications for large solar increased from four interconnection requests representing 920 MW in November 2007 to 33 requests representing 8,013 MW in December 2008 (Source: SWAT Renewable Transmission Task Force Presentation, January 2009)

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

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

Mindful of NERC's mission, this report does not address market, regulatory or policy issues and is neutral to the market environment in which the variable generation interconnects. Further, NERC does not advocate a particular resource mix, weigh cost allocation approaches or recommend specific technology solutions to address identified reliability concerns.

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 its physical capabilities; and
- Industry standards and criteria must be fair, transparent and performance-based.

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

Appreciating how today's bulk power system is planned and operated 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-scale hydro and fossil-fueled internal-combustion resources. Industry experience with these generating technologies is based on many years of accumulated knowledge, expertise and experience. Fundamentally, conventional generation resources have relatively predictable operating performance, their characteristics are well understood, and these resources are fully integrated into the long-term and short-term planning and operations of the electric power system in a highly reliable manner.

Planning entities develop long- and short- term plans for transmission reinforcements required to reliably interconnect generators, serve demand, and ensure the resulting system meets NERC and regional reliability standards. NERC's Regional Entities and Planning Coordinators assess the reliability of the bulk power system by forecasting the long-term supply and demand as well as 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 proactive manner.

Reliable power system operation requires ongoing balancing of supply and demand in accordance with established operating criteria such as maintaining system voltages and frequency within acceptable limits. 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 sufficient supply capacity 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.

There are two major attributes of variable generation that notably 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 fluctuations in the plant[9] output on all time scales.

- **Uncertainty:** The magnitude and 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 each of these are different. When accommodating large amounts of variable generation, these two attributes can have significant impact, requiring changes to the practices and tools used for both bulk power system planning and operations.

Power system planners and operators are already familiar with designing a system which can be operated reliably while containing a certain amount of variability and uncertainty, particularly as it relates to system demand and, to a lesser extent, to 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 Committees 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 Balancing Area (i.e. typically less than 5% of annual energy). Integration of this level of variable generation typically has not appreciably impacted the reliability of the bulk power system. Future projections, however, forecast a substantial increase in variable generation additions across North America, particularly wind resources (i.e. up to 145 GW of wind generation over the next 10 years).[10] Bulk power systems can accommodate the large-scale integration of variable generation energy in a variety of ways; therefore a complete understanding of reliability considerations is vital.

In addition to forecasts for significant wind resource additions, it is also worth noting that during the time period during which this report was prepared, activity (as measured by interconnection requests) for large solar plants increased dramatically. For example, in the California ISO generation connection queue, requests for solar (all types) increased from 51 applications representing 17,600 MW in January 2008 to 91 applications representing nearly 30,000 MW.[11]

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[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.

[10] http://www.nerc.com/files/LTRA2008%20v1.1.pdf

[11] Source: California ISO website

In Arizona, the number of (non-California ISO) interconnection applications for large solar increased from four interconnection requests representing 920 MW in November 2007 to 33 requests representing 8,013 MW in December 2008.[12]

Anticipating substantial growth of variable generation, in December 2007, NERC's Planning and Operating Committees created the Integration of Variable Generation Task Force (IVGTF) charged with preparing a report to: 1) Raise industry awareness and understanding of variable generation characteristics as well as system planning and operational 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 primary focus of this report is on bulk power system reliability considerations and approaches to deal with the integration of wind and solar generation, the conclusions and recommended actions should also apply to the integration of all types of variable generation technologies. The report is organized into a series of Chapters:

> **Characteristics of Power Systems and Variable Generation:** Chapter 2 provides an overview of power systems and operations along with a discussion of the technical characteristics of variable generation technologies. In addition, it addresses variable generation's capability, through power management, to support the reliable operation of the bulk power system.
>
> **Transmission Planning and Resource Adequacy:** Chapter 3 provides an overview of power system planning practices, techniques and tools along with potential enhancements. Further, it explores the critical role of transmission and necessary flexible system resources to enable the integration of large amounts of variable generation. Finally, this Chapter identifies key considerations for planning a reliable bulk power system with high penetrations of variable generation.
>
> **Power System Operations:** Chapter 4, after providing an overview of the critical components of power system operation, addresses 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 IVGTF conclusions and recommended actions are consolidated in the final Chapter, 5.

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[12] Source: SWAT Renewable Transmission Task Force Presentation, January 2009

2. Characteristics of Power Systems & Variable Generation

This chapter provides an overview of the inherent characteristics of variable generation, along with the power system modeling and analysis needed to accommodate large-scale integration of variable generation resources. Although there are many varieties of variable generation, this chapter focuses on wind and solar generation technologies, which currently have 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 in accordance with the prevailing operating criteria and standards, such as those established by NERC. Operating power grids are almost always in a changing state due to fluctuations in demand, generation, and power flow over transmission lines, maintenance schedules, unexpected outages and changing interconnection schedules. The characteristics of the installed power system equipment and its controls and the actions of system operators play a critical role in ensuring that the bulk power system performs acceptably after disturbances and can be restored to a balanced state of power flow, frequency and voltage.

The impacts of 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, sometimes up to 30 years, for both transmission and resource adequacy assessments.

In the seconds-to-minutes timeframe, bulk power system reliability is almost entirely controlled by automatic equipment and control systems such as Automatic Generation Control (AGC) systems, generator governor and excitation systems, power system stabilizers, automatic voltage regulators (AVRs), protective relaying and special protection and remedial action schemes, and fault ride-through capability of the generation resources. From the minutes through one week timeframe, system operators and operational planners must be able to commit and/or dispatch needed facilities to re-balance, restore and position the bulk power system to maintain reliability through normal load variations as well as contingencies and disturbances. For longer timeframes, power system planners must ensure that adequate transmission and generation facilities with proper characteristics are built and maintained so that operation of the system remains reliable throughout a range of operating conditions.

Figure 2.1 illustrates the planning and operations processes and the associated technology issues for the shorter timeframes mentioned above.[13] For operations closer to a day or days ahead of the real time, the reliability of the bulk power system is secured by ensuring that there is adequate generation supply with proper characteristics available to meet the forecast demand and its expected variation while maintaining bulk power system reliability. As time moves closer to a few minutes to a few hours ahead of real time, the operator requires a forecast of demand and generation at much higher accuracy and will also more closely consider the ramp rate capability of the resource fleet within or outside its Balancing Area to ensure that these resources are available and can be dispatched or maneuvered to ensure supply-demand balance while maintaining bulk power system reliability.

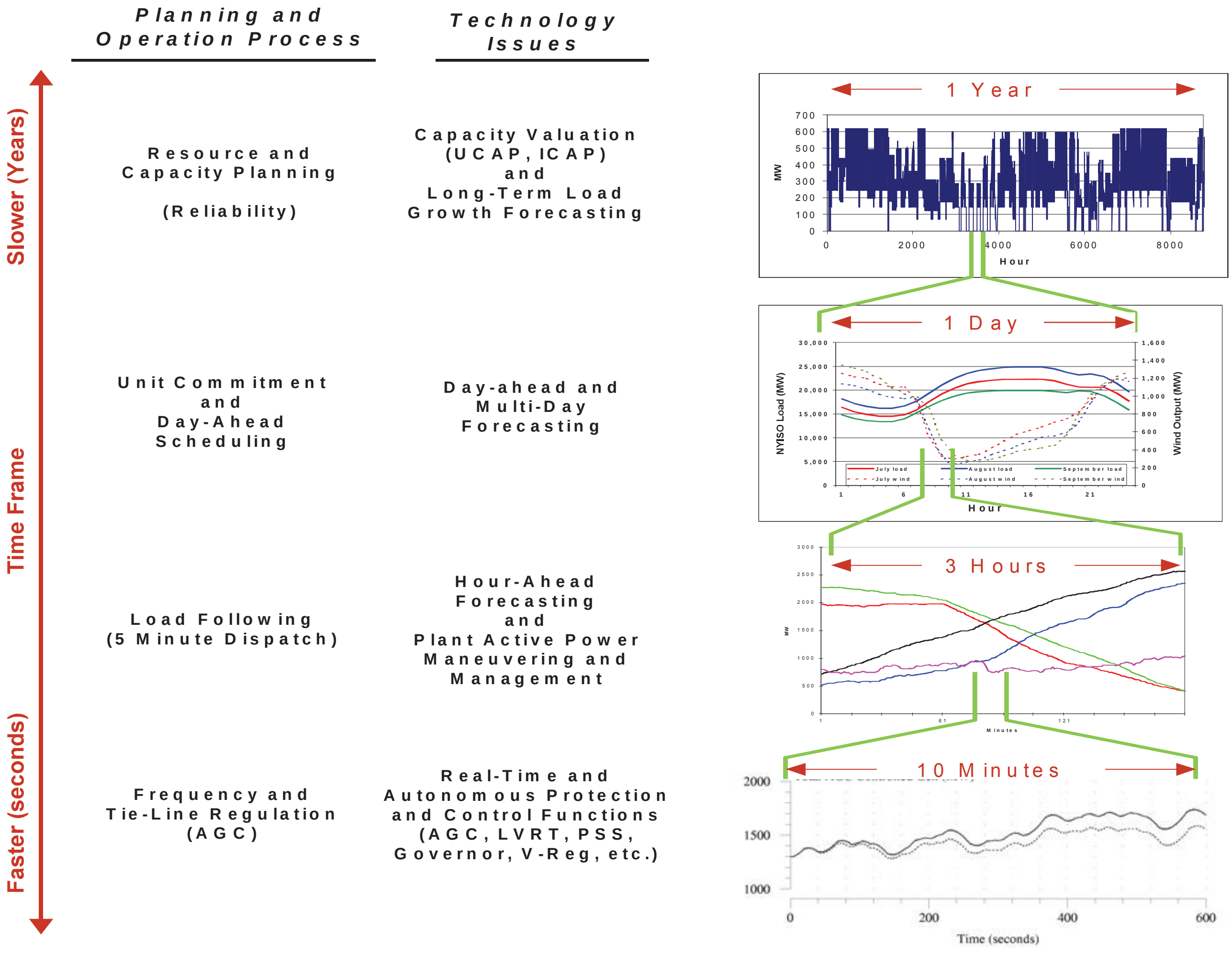

Figure 2.1 Power System Planning and Operation

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

In each of the operational planning and real-time operations domains, the characteristics of the bulk power system must be understood to ensure reliable operation. For example, regulating reserves and ramping capabilities are critical attributes 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.

At higher levels of variable generation, the operation and characteristics of the bulk power system can be significantly altered. These changes need to be considered and accommodated into the planning and operational processes. For example, as shown in Figure 2.2, wind generation can increase the gap between net demand at peak and off-peak periods, increasing the need for more dispatchable ramping capability from the resources on the system that provide this ramping capability.[14]

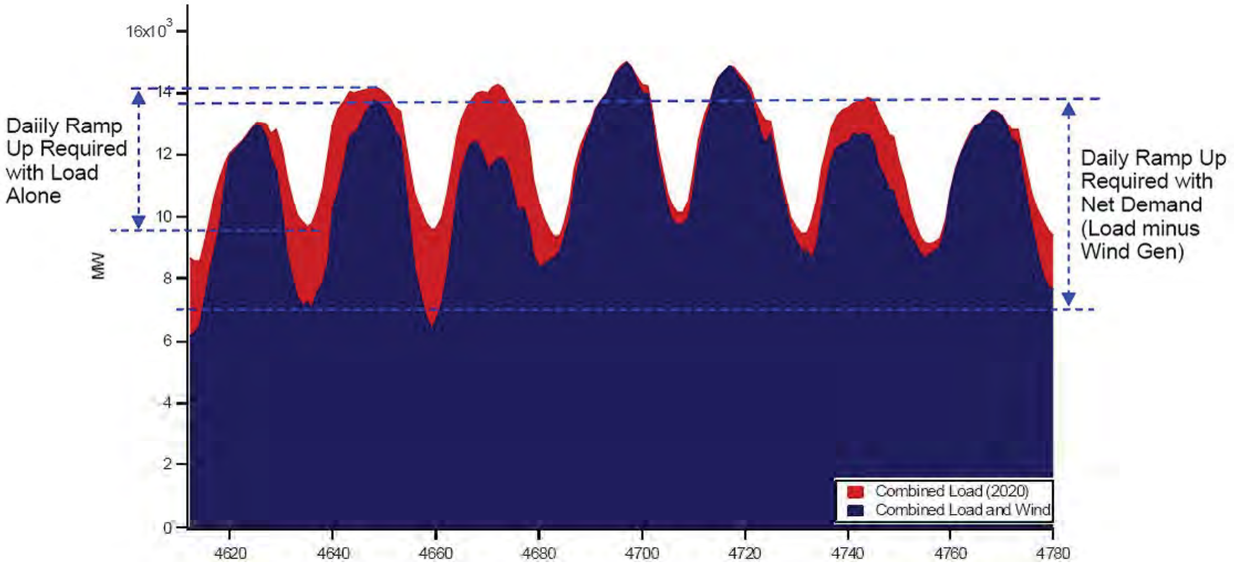

Figure 2.2: Variable Generation can Increase System Flexibility Needs

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[14] If we assume that conventional generation resources provide all the ramping capability for the system, Figure 2.2 shows that in the absence of wind generation, these conventional resources must be able to ramp from 9,600 MW to 14,100 MW (4,500 MW of ramping capability) in order to meet the variation in load demand during the day shown in the figure by the red curve. With additional wind generation, the variation in net demand, defined as load demand minus wind generation, must be met using the ramping capability from the same conventional generators on the system. As shown in Figure 2.2, wind generation is significantly higher during the off peak load period than during the peak load period. Hence, the net demand during the day, shown in blue, varies from about 7,000 MW to 13,600 MW requiring the conventional generators to ramp from 7,000 MW to 13,600 MW (6,600 MW of ramping capability) which is approximately 45% greater than the ramping capability needed without wind generation.

Variable generation can ramp-up in unison with demand, easing ramping requirements from conventional generators, or in opposition to demand, increasing system ramping requirements and thereby creating operational challenges (See Figure 2.3).

Because the aggregate variability of the system is expected to increase at higher levels of wind penetration, the ramping requirements to be supplied from conventional system resources will also increase. This can be particularly pronounced during the morning demand pickup or evening demand drop-off time periods. During those time periods, it is vital to ensure sufficient ramping capability (i.e. flexible generation, storage and/or demand response) is committed and available, which further emphasizes the importance of accurate wind forecasting and proper procedures for dispatching and committing and dispatching needed generation and/or demand resources system-wide.

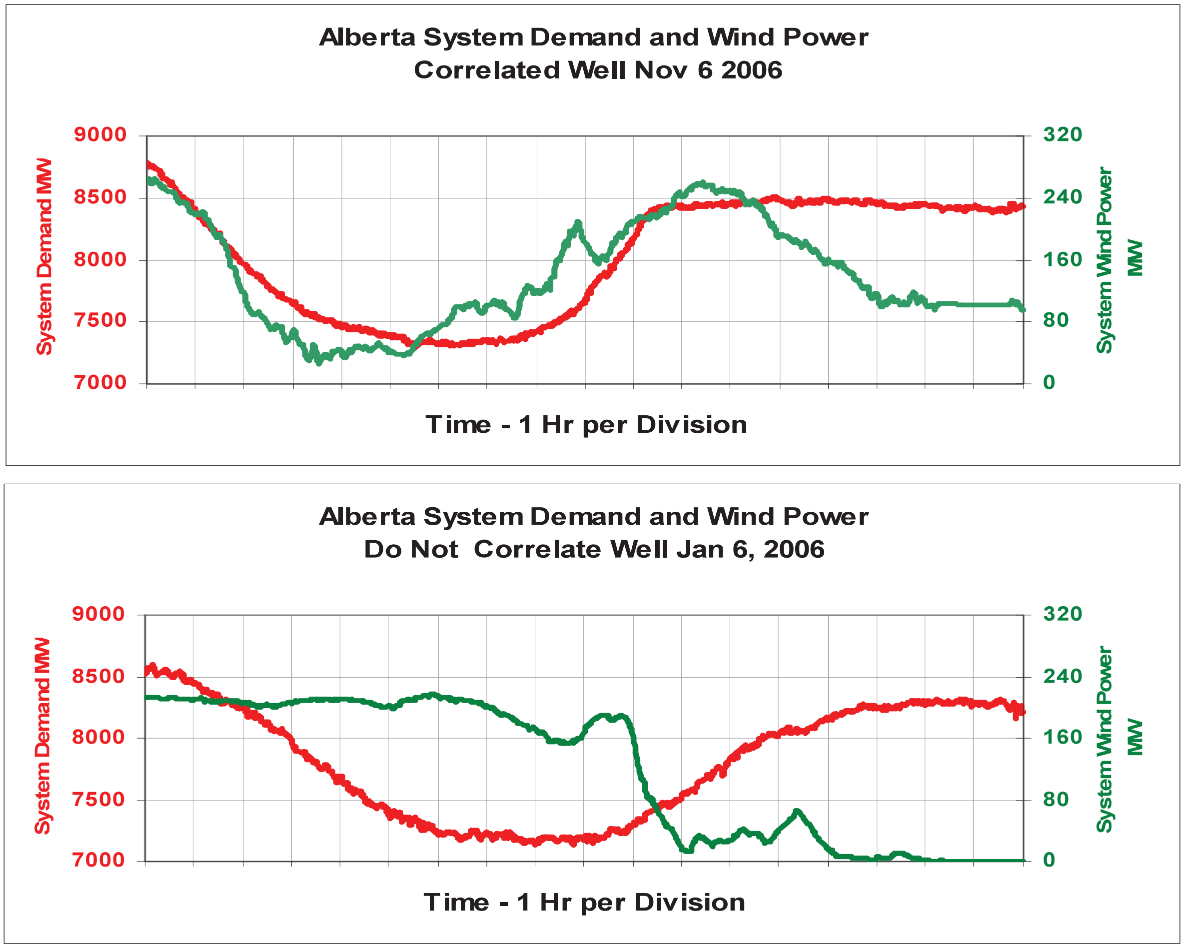

Figure 2.3: Wind and load ramps on the Alberta interconnected electric system[15]

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

Consequently, additional flexibility may be required from conventional dispatchable generators, storage, and demand resources so the system operator can continue to balance supply and demand on the bulk power system. In this respect, the inherent flexibility of the incumbent generating fleet may be assessed by the:

- Range between its minimum and maximum output levels;
- Ability to operate at any MW level from minimum and maximum output levels;
- Start time; and
- Ramping capability between the minimum and maximum output levels.[16]

To maintain reliable and efficient operation of the power system, operators must use forecasts of demand and generator availability. Today the majority of supply-demand balancing in a power system is achieved by controlling the output of dispatchable generation resources to follow the changes in demand. Typically, a smaller portion of the generation capacity in a Balancing Area is capable of and is designated to provide Automatic Generation Control (or AGC) service in order to deal with the more rapid and uncertain demand variations often within the seconds-to-minutes timeframe. AGC is expected to play a major role in managing short-term uncertainty of variable generation and to mitigate some of the short-term impacts (i.e., intra-hour) associated with variable generation forecast error. Hence, it may be necessary for planners and operators to review and potentially modify the AGC performance criteria, capabilities[17] and technologies to ensure that these systems perform properly.

AGC typically includes both load frequency and interchange control algorithms that work together to optimally move generating units on AGC to maintain system frequency. The AGC system resides in the system control center and monitors the imbalance between generation and demand within a Balancing Area. At higher levels of variable generation, the AGC algorithms and parameters may need to be modified for better performance.[18] Within a Balancing Area, AGC adjusts supply automatically between dispatch intervals to ensure that the Balancing Area is contributing to maintaining system frequency and keeps its interchange(s) with neighboring Balancing Area(s) at scheduled value(s).

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[16] Ramping capability may require different characteristics for ramping up than for ramping down

[17] Including an assessment of available AGC as a percent of total generation by individual Balancing Area and interconnection

[18] EPRI TR-1018715, "EPRI Evaluation of the Effectiveness of AGC Alterations for Improved Control with Significant Wind Generation," Hawaiian Electric Light Company Study Report, Oct 2006.

2.2. Interconnection Procedures and Standards

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

- Design standards and requirements (as instituted by various standard organizations such as the Institute of Electrical and Electronic Engineers, American National Standards Institute, International Electrotechnical Commission, etc.) ensure that equipment does not fail under expected operating conditions.
- Standards related to overall reliable performance of the bulk power system (as instituted by NERC, reliability entities, ISOs and RTOs, regulatory bodies, etc.) ensure the integrity of the bulk power system is maintained for credible contingencies and operating conditions.

Clearly, there is an interrelationship between these standards as bulk system reliability standards may affect the equipment standards and vice versa. For example, in some jurisdictions, wind resources may need to address the need for Low-Voltage Ride Through (LVRT) capability in order to ensure satisfactory system performance. This need has been reflected in equipment design for wind turbines.

The overall behavior expected from a power system with high levels of variable generation will be different from what is experienced today; therefore both the bulk power system equipment design and performance requirements must be addressed. In this respect, reliability-focused equipment standards must be further developed to facilitate the reliable integration of additional variable generation into the bulk power system. However, NERC's focus on standards is on system performance and neutral to specific technologies or designs.

From a bulk power system reliability perspective, a set of interconnection procedures and standards are required which applies equally to all generation resources interconnecting to the power grid. There is considerable work required to standardize basic requirements in these interconnection procedures and standards, such as the ability of the generator owner and operator to provide:

- Voltage regulation and reactive power capability;
- Low and high voltage ride-through;
- Inertial-response (effective inertia as seen from the grid);
- Control of the MW ramp rates and/or curtail MW output; and
- Frequency control (governor action, AGC etc.).

The ability and extent to which variable generation (with its unique characteristics, variable nature and technology) can provide the above functions, affects the way in which they can be readily integrated into the power system. Interconnection procedures and standards should recognize the unique characteristics of various generation technologies, but focus on the overall bulk power system performance rather than the performance of an individual generator. A uniform set of interconnection procedures and standards, phased in over a reasonable time frame will provide clarity to equipment vendors and generation developers regarding product design requirements and ensure efficient and economic manufacturing and installation/interconnection of new generation resources.

The following NERC Planning Committee action is recommended:

> ***NERC Action:*** Interconnection procedures and standards should be reviewed to ensure that voltage and frequency ride-through, reactive and real power control, frequency and inertial response are applied in a consistent manner to all generation technologies. The NERC Planning Committee should compile all existing interconnection requirements that Transmission Owners have under FAC-001 and evaluate them for uniformity. If they are inadequate, action should be initiated to remedy the situation (e.g. a Standard Authorization Request).

A good example of the development of interconnection procedures and standards is the voltage ride-through requirement. The bulk of the power grid is exposed to the elements (i.e. severe weather) and subject to many conditions that can cause faults on the grid. The protective relaying and control schemes on the transmission system are designed to detect and clear line faults within a few cycles. During this very short period of time, the fault can cause system voltages 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 due to zero/low voltage at their terminal. In some jurisdictions (e.g. U.S.,[19] Ontario and Manitoba), full-scale on-site testing of wind plant Low Voltage Ride-Through (LVRT) capability has been conducted to validate performance.

In Ontario, changes to some wind plant control parameters have been required to achieve acceptable low voltage ride-through performance. The Independent Electricity System Operator (IESO) of Ontario has established a central information repository on its wind web page (See "Wind Interconnection Requirements") to better reflect the needs of new wind proponents, wind developers and market participants. This dedicated web page includes information pertaining to specific wind-related Connection Assessment and Approval processes including grid connection requirements and market entry processes.[20]

In light of the discussions on the need for updated interconnection procedures and standards, bulk power and distribution system planners and operators need to change how they consider bulk power system reliability. The bulk power system is generally planned assuming the

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[19] FERC order 661-A - *Standardization of Generator Interconnection /Interconnection for Wind Energy and other Alternative Technologies*, article 9.6.1 requires -.95 to +.95 power factor at the Point of Interconnection (POI), see http://www.ferc.gov/EventCalendar/Files/20051212171744-RM05-4-001.pdf .

[20] http://www.ieso.ca/imoweb/marketdata/windpower_CA-ME.asp

distribution system is functioning properly. However, a comprehensive approach is needed for planning from the distribution system through to the bulk power system particularly with the increased penetration of variable generation on distribution systems. Local area issues severely stressing a distribution system can also impact bulk power system reliability. Therefore, these impacts need to be understood and resolved in the bulk power system planning and operation.

Planners and operators would benefit from one or more reference manuals which describe the evolving changes required to plan and operate a bulk power and distribution systems accommodating large amounts of variable generation. Therefore, the following recommendation is made for NERC's Planning and Operating Committees:

> ***NERC Action:*** NERC should prepare a reference manual[21] to educate bulk power and distribution system planners and operators on reliable integration of large amounts of variable generation. The reference manual should outline concepts, processes and best practices to be used by bulk power and distribution system planners and operators to reliably integrate large amounts of variable generation.

The following sections will describe the technical characteristics of variable generation and highlight their inherent characteristics including capabilities and limitations. Understanding these technical characteristics is vital to comprehend how to reliably integrate them into the bulk power system.

2.3. Variable Generation Technologies

As described previously, variable generation technologies generally refer to generating technologies whose primary energy source varies over time and 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.[22] There are two major attributes of a variable generator 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

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[21] Note that a reference manual is not a NERC Standard. If acceptable, it may become a NERC Planning Committee Guideline. "*Reliability guidelines* are documents that suggest approaches or behavior in a given technical area for the purpose of improving reliability. Reliability guidelines are not binding norms or mandatory requirements. Reliability guidelines may be adopted by a responsible entity in accordance with its own facts and circumstances." See Appendix 4, of the Planning Committee's Charter, entitled "Reliability Guidelines Approval Process," at http://www.nerc.com/docs/pc/Charter_PC_Approved_29Oct2008.pdf.

[22] 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.

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 electricity supply. The major underlying technologies 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 installed capacity over the last five years. On- and off-shore wind energy projects are now being built worldwide, with the commercial 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 broad 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) generators are the most common of the solar thermal systems. A CSP generator produces electric power by collecting the sun's energy to generate heat using various mirror or lens configurations. Other solar thermal systems, like the solar chimney and solar ponds, which 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. Those with reservoirs are normally not variable, but run-of-river hydroelectric plants are.
    - Wave power harnesses the energy in ocean waves - to date there are no commercial devices 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 as its generation pattern corresponds to easily predictable tides.

2.4. Principal Characteristics of Wind and Solar 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 Resources

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 demand and existing transmission infrastructure. Some excellent areas for wind generation development in North American include the province of Québec, 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 and high elevation sites in New Brunswick and New England, many areas of Midwest especially in the Dakotas and Wyoming, and High Desert areas of California.

The degree to which wind matches demand may differ 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. However, 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 may have higher outputs in spring and fall). Some wind regimes are driven by daily thermal cycles, whereas others are driven primarily by meteorological atmospheric dynamics.

Supply surplus conditions can also result when wind energy is available during times of low demand (quite typically due to daily thermal cycles) and these situations will generally be dealt with through operating procedures and wind power management. Because the same variables that impact demand can also impact the output of wind resources, it is critical to ensure 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 attribute, which can be much different than its variability in the shorter term. 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 wind ramping characteristics, which can present operating challenges. Figure 2.4 below shows an example of California wind generation from 5 geographic areas in California and illustrates how geographic diversity can smooth out the shorter term variability whereas over the aggregate longer-term all wind resources in a large geographic can be seen to be ramping (up and down) in relative unison.

In many geographic areas, both cold wintry periods and periods of summer heat are generally associated with stable high-pressure weather systems. Low wind levels are meteorologically symptomatic under these conditions. In addition, low and high temperature protection on wind turbines may remove wind facilities from service during extreme-temperature weather conditions. Consequently, the contribution made by wind energy to meeting electric system demand may be zero or relatively low during these periods.

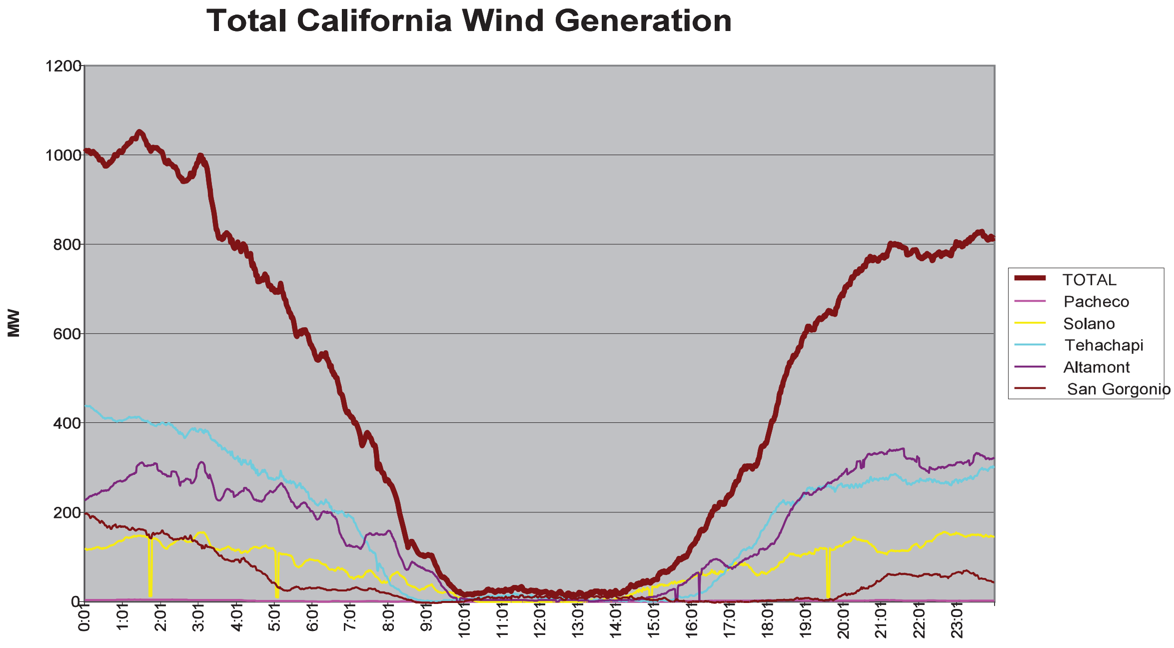

Figure 2.4: California wind power ramps from five diverse locations and total

2.4.1.1.Wind turbine technologies

The principal technical characteristics of wind generation are different than traditional synchronous generator technology. This section will pay particular attention to the ability of wind generators to contribute to bulk power system performance as specified by a standard set of interconnection procedures and standards (See Appendix II 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 a squirrel cage 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 output). The primary advantage of Type 1 induction generators is their simplicity 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 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 and 2 wind turbines have limited performance capability. However, their performance can be enhanced to meet more stringent interconnection performance requirements through the addition of suitable terminal equipment such as Static VAR Compensator (SVC) or STATCOM in order to control or support power system voltage.

Type 3 Double-fed induction (asynchronous) generator (DFG) **-** Power electronic applications have led to a new generation of wind generating technologies with utility interface characteristics which can make a large contribution to overall power system performance and provide for improved operation and system reliability than earlier technologies. The double-fed induction (asynchronous) generator (DFG), 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 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, DFGs have a light overall weight which is important during construction. The fast response of the converters also enables improved fast voltage recovery and voltage ride-through capability. Advanced features include governor-type functions (for speed control in Type 3 and 4) and, in some cases, dynamic reactive power can be supplied when the wind turbine is not generating real power.

Type 4 Wind Turbine-Generator (full conversion) **-** The Type 4 wind turbine-generator (full conversion), passes all turbine power output through an AC-DC-AC power electronic converter system. It has many similar operating characteristics to the DFG (Type 3) system, including variable speed, reactive power control, pitch control, and fast control of power output. Type 4 wind turbine-generators also decouple the turbine-generator drive train from the electric power grid, controlling the dynamics of the wind turbine-generator during grid disturbances. In common with Type 3 wind turbine-generators, this decoupling means that in the standard design inertial response can be a programmed feature during a frequency event[23] and the Type 4 wind turbine-generators can provide comparable inertial response/ performance to a conventional generator. The converter system also reduces dynamic stresses on drive train components when grid disturbances occur. Finally, the output current of a Type 4 wind turbine generators can be electronically modulated to zero; thereby limiting its short-circuiting current contribution and reducing the short-circuit duty of standard protection equipment.

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 generators with the full range of performance capability which is comparable, and in some cases superior, to conventional synchronous generators:[24]

- **Frequency Control and Power Management:** Many modern wind turbines are capable of pitch control, which allows their output to be modified (curtailed) in real-time by adjusting the pitch of the turbine blades (i.e., “spilling wind” or “feathering the blades”). 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 2.5 and 2.6. This capability can be used to limit ramp rate and/or power output a wind generator and it can also contribute to power system frequency control.

  Turbines without pitch control cannot limit their power output in the same fashion. However, a similar effect can be realized by shutting down some of the turbines in the wind plant (sometimes known as a “wind farm”). 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 for islanded systems or in interconnections with high penetration scenarios when the turbine can operate below the total available power in the wind.

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[23] 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.

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

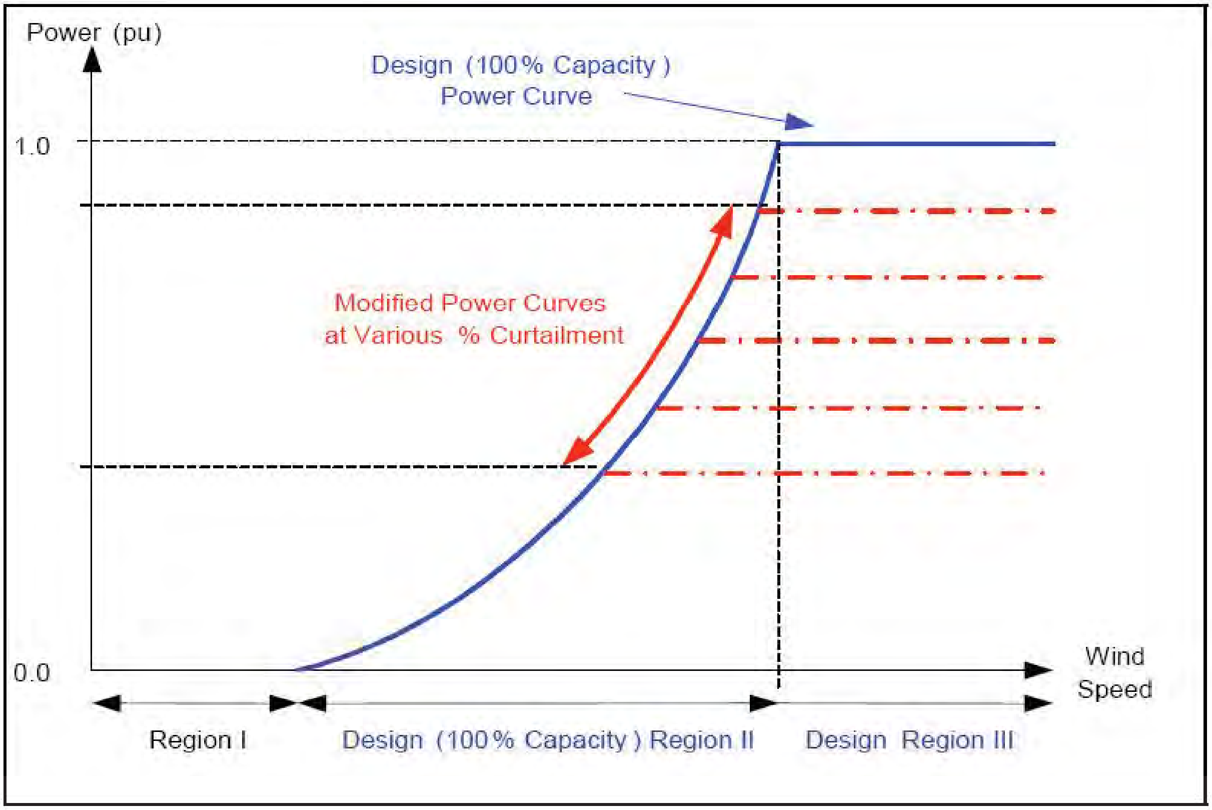

Figure 2.5: Regulation of Wind Turbine-Generator output using blade pitch control (Source: BEW report for CEC, May 2006)

Type 3 and 4 wind-turbine generators do not automatically provide inertial response and, with large wind penetrations of these technologies, frequency deviations could be expected following a major loss of generation.[25] Some manufacturers are now implementing control strategies that will provide inertial response[26] responding to some interconnection procedures and standards requiring this capability.[27] Unlike a typical thermal power plant whose output ramps downward rather slowly, wind plants can react quickly to a dispatch instruction taking seconds, rather than minutes. Operators need to understand this characteristic when requesting reductions of output.

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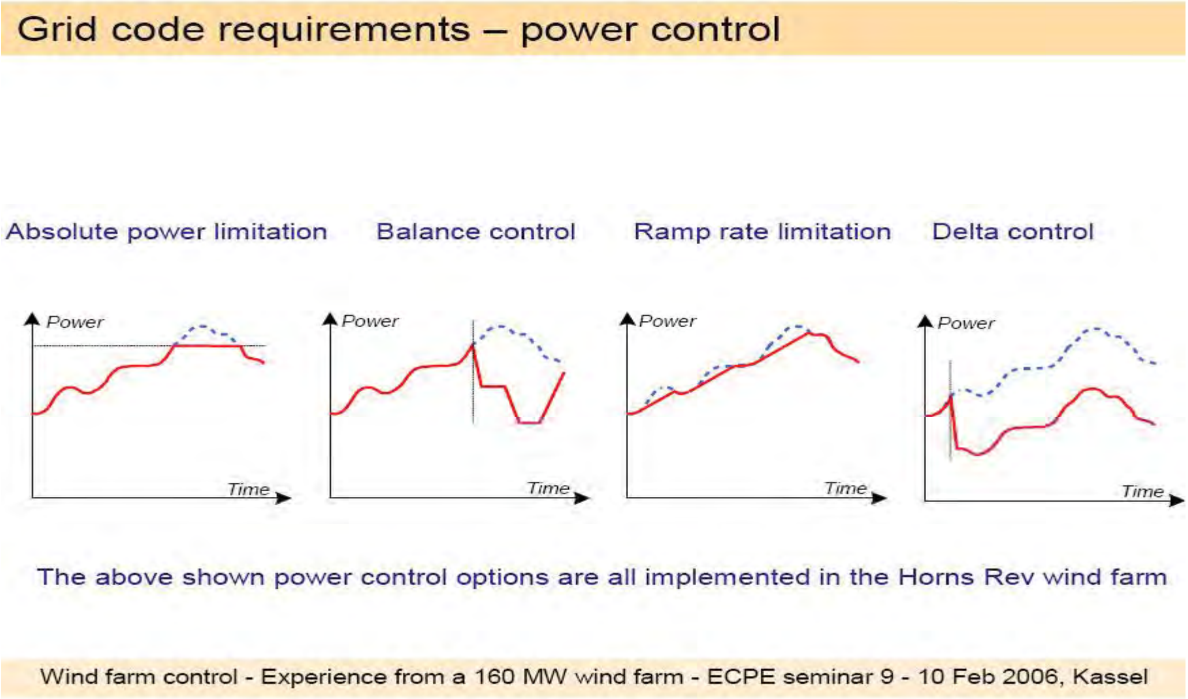
[25] Mullane, A. and O'Malley, M.J., "The inertial-response of induction-machine based wind-turbines," *IEEE Transactions on Power Systems*, Vol. 20, pp. 1496 – 1503, 2005.

[26] Miller, N.W., K. Clark, R. Delmerico, M. Cardinal, "WindINERTIA: Controlled Intertial Response from GE Wind Turbines Generators," CanWEA, Vancouver, B.C., October 20, 2008.

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



Grid code requirements – power control

Absolute power limitation

Balance control

Ramp rate limitation

Delta control

The above shown power control options are all implemented in the Horns Rev wind farm

Wind farm control - Experience from a 160 MW wind farm - ECPE seminar 9 - 10 Feb 2006, Kassel

Figure 2.6: Power control of the Horns Rev wind plant[28]

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 also be equipped to provide governing and participate in frequency regulation. Some 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, with the continued maturing of the technology, wind generators may participate in AGC systems in the future.

Ramping control could be as simple as electrically tripping all or a portion of the variable generation plant. However, more modern variable generation technologies allow for continuous dispatch of their output. Continuous ramp rate limiting and power limiting features are readily available for Type 3 and 4 wind turbine generators. 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 (or ramp rate limit) to a reliable limit that can be accommodated on the power system at that time.[29] Circumstances where wind power

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

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

management techniques may be used are during system emergency conditions (i.e. system restoration), supply surplus conditions (peak production of variable generation during low demand periods), and an unexpected ramp-up of the variable generation when demand is dropping.

- **Pitch Controlled Wind Turbines:**[30] In most modern wind turbines, rotor blades are able to turn around their longitudinal axis (pitch). In these turbines, an electronic controller measures the power output of the turbine several times per second. When the power output increases beyond the scheduled generation value (normally the nameplate capacity), it sends an order to the blade pitch mechanism which immediately pitches (turns) the rotor blades slightly out of the wind. Conversely, the blades are turned back into the wind whenever the wind drops again. During normal operation, the blades will pitch a fraction of a degree at a time.

  A wind turbine's pitch controller uses advanced computer-based schemes to ensure the rotor blades pitch exactly the amount required. This control scheme will normally pitch the blades a few degrees every time the wind changes to keep the rotor blades at the optimum angle and maximize output for all wind speeds. The same control mechanism could be used, in aggregate, by the operator to dispatch variable generation between minimum and maximum available power output.

- **Passive and Active Stall-Controlled Wind Turbines:** Passive stall controlled wind turbines have the rotor blades bolted onto the hub at a fixed angle. The geometry of the rotor blade profile, however has been aerodynamically designed (blade is twisted slightly along its longitudinal axis) to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade which is not facing the wind. This stall prevents the lifting force of the rotor blade from acting on the rotor.

  Currently, nearly all modern wind turbines are being developed with an active stall power control mechanism. The active stall machines resemble pitch controlled machines. In order to get a reasonable turning force at low wind speeds, the machines are programmed to pitch their blades much like a pitch controlled machine at low wind speeds - often they use only a few fixed steps depending upon the wind speed. When the machine reaches its scheduled (normally) rated power, however, the machine will pitch its blades in the opposite direction and will increase the angle of attack of the rotor blades in order to make the blades go into a deeper stall, thus not using this wind energy.

- **Other Power Control Methods**: Some older wind turbines use ailerons (flaps) to control the power of the rotor, just like aircraft use flaps to alter the geometry of the wings to provide extra lift at takeoff. Another theoretical possibility is to yaw the rotor partly out of the wind

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[30] http://www.windpower.org/en/tour/wtrb/powerreg.htm

to decrease power. This technique of yaw control is in practice only for small wind turbines (1 kW or less), as it subjects the rotor to cyclically varying stress which may ultimately damage the entire structure.

- **Voltage Control**: As variable resources, such as wind power facilities, constitute a larger proportion of the total generation on a system, these resources may provide voltage regulation and reactive power control capabilities comparable to that of conventional generation. Further, wind plants may provide dynamic and static reactive power support as well as voltage control in order to contribute to power system reliability. Figure 2.7 shows an example of the performance of a voltage control scheme at a 160 MW wind plant in the western U.S. illustrating the plant's ability to support and control voltage.[31]

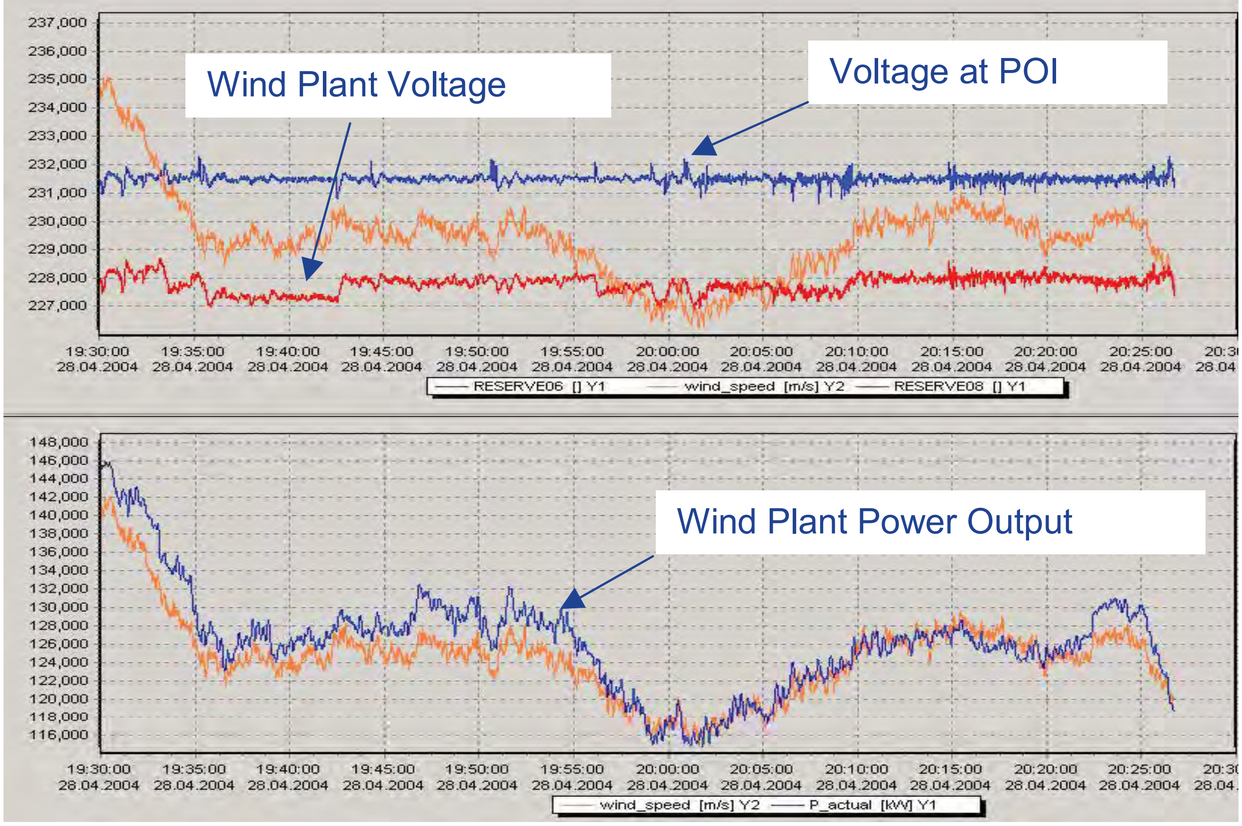

Figure 2.7 Wind Plant voltage control with significant variation in wind power

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[31] This plant consists of 108 wind turbine generators (1.5 MW each), connected to a relatively weak and remote 230kV utility interconnection substation by approximately 75 km of 230kV transmission line. The short circuit ratio (fault duty/plant rating) at the point of interconnection is about 3.5. The voltage regulator continuously adjusts the reactive power output to maintain constant voltage at the interconnection bus.

2.4.1.3.Summary of Wind Controls

The major functional control capabilities of modern wind turbine generation are:

1. **Voltage/VAR control/regulation:** Reactive support and power factor control can be provided either through built-in capability (available for wind turbine generators Types 3 and 4) or through a combination of switched capacitor banks and/or power electronic transmission technologies such as SVC/STATCOM (applicable for all wind generator types).

2. **Voltage ride-through:** Voltage ride-through can be achieved with all modern wind turbine generators, mainly through modifications of the turbine generator controls. In some cases, with older Type 1 or 2 wind turbine-generators at weak short-circuit nodes in the transmission system, there may be a need for additional transmission equipment (subject to detailed studies).

3. **Power curtailment and ramping:** Power curtailment and ramping can be achieved through unit control mechanism for units with active-stall or pitch control, and/or discrete tripping of units.

4. **Primary frequency regulation:** Primary frequency regulation can be supplied by all turbines that are equipped with some form of pitch regulation (i.e. active-stall or pitch-control).

5. **Inertial response**: Inertial response is inherent in Type 1 and 2 units and can be achieved through supplemental controls in the converter to emulate inertial behavior for Type 3 and 4 units.

Modern wind turbine generators can meet equivalent technical performance requirements provided by conventional generation technologies with proper control strategies, system design, and implementation.[32]

2.4.2. Solar Generation

In addition to forecasts for significant wind resource additions, large solar projects are also forecast to increase dramatically. For example, in the California ISO generation connection queue, requests for solar (all types) increased from 51 applications representing 17,600 MW in January 2008 to 91 applications representing nearly 30,000 MW.[33] In Arizona, the number of

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[32] 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)

[33] Source: California ISO website

(non-California ISO) interconnection applications for large solar increased from four interconnection requests representing 920 MW in November 2007 to 33 requests representing 8,013 MW in December 2008.[34]

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 technology to another. One important characteristic shared by all types of solar power is their diurnal and seasonal pattern (i.e. peak output usually occurs 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 power 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 available. The example in Figure 2.8 illustrates this phenomenon and compares the average demand with the aggregate wind and solar plant output in California.[35] Variability around these average demand values, especially for individual wind and solar resources, can fluctuate significantly on a daily basis. However, as illustrated in Figure 2.8, the solar and wind plant profiles when considered in aggregate can be a good match to the load profile and hence improve the resulting composite capacity value for variable generation.

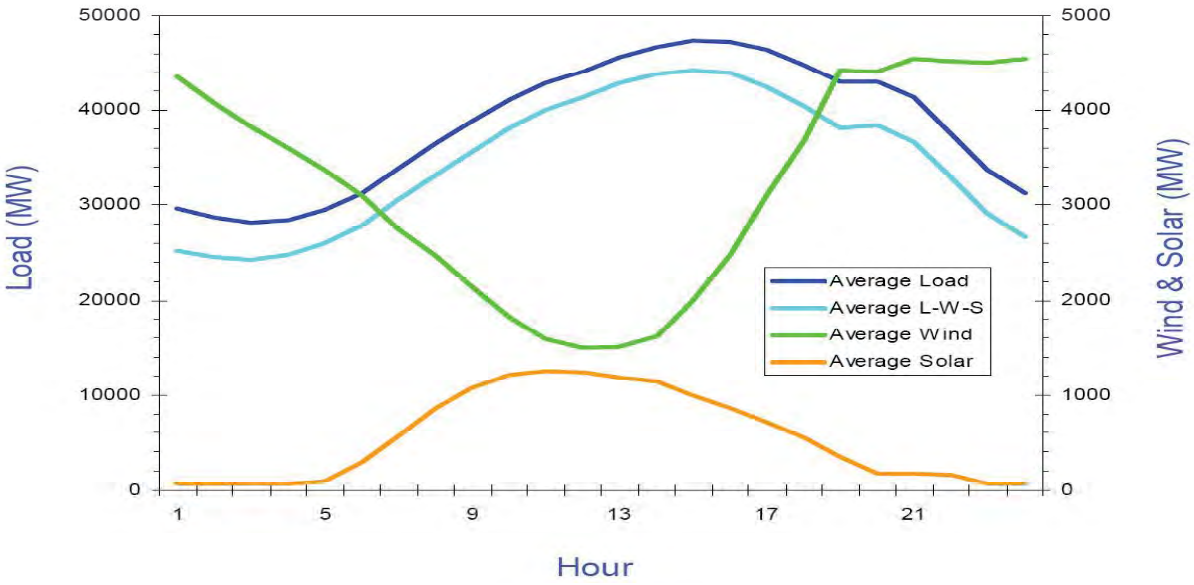

Figure 2.8: California average wind and solar output, along with net demand, July 2003.

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[34] Source: SWAT Renewable Transmission Task Force Presentation, January 2009

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

Large photovoltaic (PV) plants, as have been proposed in the Southwestern U.S. and southern California, have the potential to place extremely fast ramping resources on the power system. Under certain weather conditions, PV installations can change output by +/- 70% in a time frame of two to ten minutes, many times per day. Therefore, these plants should consider incorporating the ability to manage ramp rates and/or curtail power output.

2.4.2.1.Concentrating Solar Thermal Technology

Concentrating solar thermal plants (CSP) use mirrors by focusing direct normal irradiance (DNI) to generate intense heat used to drive an electric generator. The fact that concentrating solar plants use DNI limits their geographic application within NERC's footprint, limiting large-scale application to the southwestern U.S. 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 or oil; molten salt may be used for energy storage. 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 in the absence of clouds or adverse ground conditions (e.g. dust storms). 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.

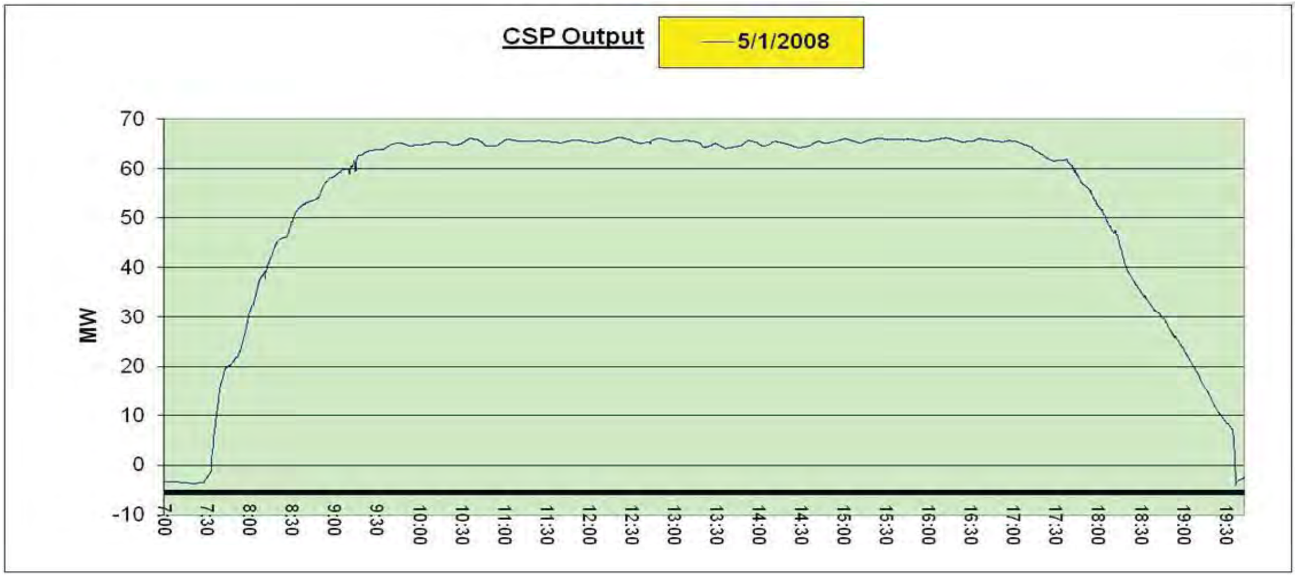

Figure 2.9: Parabolic trough CSP plant on a sunny day (Sampling time of 10 sec.)

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

CSPs 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. CSPs may also achieve similar economies of scale as turbine-generators when their 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 generation.

Several forms of solar thermal generation, including dish-Stirling and "solar chimney" projects, have been proposed for utility scale application. Proposed dish-Stirling projects are a collection of thousands of individual turbine-generators with individual ratings from 10-50 kW. Several projects have been proposed to be 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" is expected to 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 U.S., southern California 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 wind turbine generators Types 4) 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.

The nature of PV is such that PV does not involve a rotating mass and therefore does not have inertia.[36] As a result, operating PV systems have demonstrated the potential for substantial ramps during partially cloudy days. PV systems can experience variations in output of +/- 50% in to 30 to 90 second time frame and +/- 70% in a five to ten minute time frame. Furthermore, the ramps of this magnitude can be experienced many times in a single day during certain weather conditions. This phenomenon has been observed on some of the largest PV arrays (ranging from 3-10 MW) deployed in the U.S. 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.[37]

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[36] Energy storage such as batteries can be added to PV however the inertial response of a PV plant will be driven by characteristics of the inverter.

[37] NV Energy (former Nevada Power Company), Renewable Energy Department.

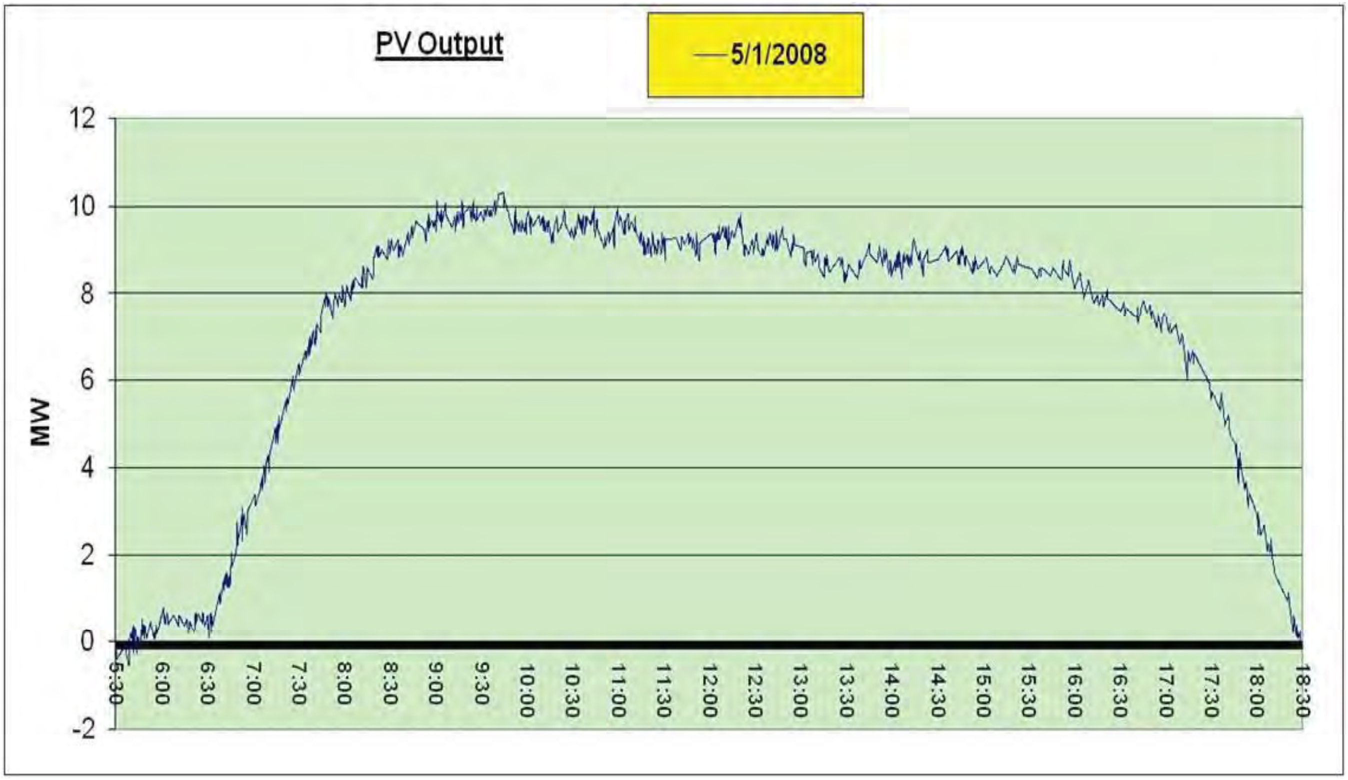

Figure 2.11: PV plant output on a sunny day (Sampling time 10 seconds)

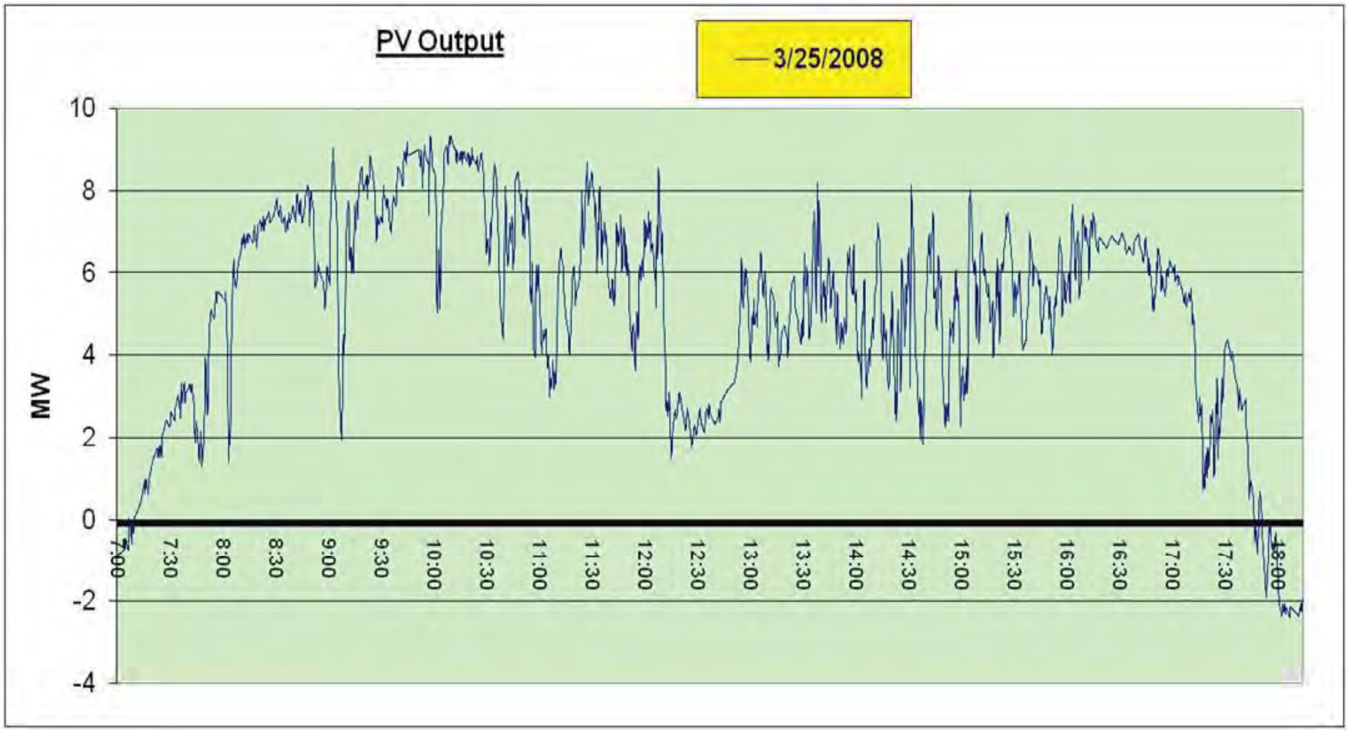

Figure 2.12: PV Plant output on a partly-cloudy day (Sampling time 10 seconds)

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 hundreds of MW are being proposed throughout the North America. It is unclear if the scale of these plants will limit the impact on ramping by virtue of significantly greater land coverage.

PV connected at distribution levels, e.g. residential and small commercial installations are subject to IEEE Standard 1547. This standard prohibits distributed generation, including PV, from riding through grid disturbances involving significant voltage or frequency excursions, and also prohibits providing voltage control.[38] Thus, widespread deployment of small distribution connected variable generation has the potential to have adverse impacts on grid performance. Evidence of this problem is starting to surface in some small grids now. Further evolution and reconciliation of IEEE 1547 to take broader grid performance considerations into account is needed.

2.4.3. Power Management

For variable generation to provide power plant control capabilities, it must be visible to the system operator and able to respond to dispatch instructions during normal and emergency conditions. Real-time wind turbine power output, availability, and curtailment information is critical to the accuracy of the variable generation plant output forecast, as well as to the reliable operation of the system. It is critical that the Balancing Area operator have real-time knowledge of the state of the variable generation plant and be able to communicate timely instructions to the plants. In turn, variable generation plant operators need to respond to directives provided by the Balancing Area in a timely manner. The need for this information was clearly illustrated during the restoration of the UCTE system following the disturbance of Nov. 9, 2006 when there was a lack of communications between distribution system operators (DSOs) and transmission system operators (TSOs) delayed the TSO's ability to restore the bulk power system.[39]

Therefore, as small variable generation facilities grow into significant plants contributing significantly to capacity and energy, balancing areas will require sufficient communications for monitoring and sending dispatch instructions to these facilities.[40] Further, Balancing areas and

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[38] See IEEE Standard 1547, "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems," page 7, 4.2, "Response to EPS Abnormal Conditions"

[39] http://www.ucte.org/resources/publications/otherreports /

[40] An international standard communications protocol has been prepared, 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.

generator owner/operators must ensure procedures, protocols, and communication facilities are in place so dispatch and control instructions can be communicated to the variable generation plant operators in a timely manner.

Adequate communication of data from variable generation and enhanced system monitoring is not only a vital reliability requirement, but is also necessary to support the data analysis posed by other recommended NERC and Industry actions. In this respect, the deployment of phasor measurement units (PMUs) may become a vital planning and operational tool[41] and assist in monitoring the dynamic performance of the power system, particularly during high-stress and variable operating conditions. PMU deployment can help power system planners, operators and industry better understand the impacts of integrating variable generation on the grid.[42]

The following action is therefore recommended for the NERC Operating Committee:

> ***NERC Action:*** Balancing areas must have sufficient communications for monitoring and sending dispatch instructions to variable resources. The NERC Operating Committee should undertake a review of COM-002, FAC-001 and registry criteria to ensure adequate communications are in place. Further, as NERC Standards' Project 2006-06 is reviewing COM-002, input to this review should be provided. If these standards are found to be inadequate, action should be initiated to remedy the situation (e.g. a SAR).

2.5. Variable Generation Modeling

Existing NERC system modeling standards require reliability entities to develop comprehensive steady-state data and reporting procedures needed to model and analyze the steady-state and dynamic performance of the power system (MOD-011 and MOD-013). Equipment operators are required to provide steady state and dynamic models (MOD-012) to the reliability entities. This information is required to build a reasonable representation of the interconnected system for planning purposes, as stated in MOD-014 and MOD-015.[43] Specifically, models are required to perform load flow, short circuit, and stability studies necessary to ensure system reliability. NERC standards also deal with periodic verification of the models, such as required by MOD-023, which deals with verification of reactive power limits. Highly-detailed models are sometimes provided by owners, but cannot be passed on to Regional Entities due to their proprietary nature. However, Regional Entities do require generic models, suitable for power system studies.

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[41] "Phasor Measurement Unit (PMU) Implementation and Applications," EPRI Report 1015511, October 2007 and details for application potential at http://www.eow2007proceedings.info/allfiles2/162_Eow2007fullpaper.pdf

[42] See North American SynchroPhasor Initiative for more information at http://www.naspi.org/

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

Much work has been done, particularly in recent years,[44] 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 provided. This effort will require significant collaboration between the power engineering community and the wind turbine manufacturers and vendors, since these entities generally privately hold 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.

In contrast to wind generation, simulation models for CSP steam turbine generator sets are fully developed, though the models for dish-Stirling engines are considered proprietary. It is not known if simulation models have been validated against performance of commercially-available PV inverter modules.

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 for the needed work and refinements in this area. Variable generation models are required to comply with existing NERC Modeling, Data and Analysis Standards (MOD) and this requirement should be clearly understood. 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:

- Variable generator owners and operators must comply with appropriate NERC MOD 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 variable generation; and

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[44] (a) WECC Wind Generator Power Flow Modeling Guide
(b) Nevada Power Company, Renewable Energy Department
(c) ESB National grid, "Dynamic modeling of wind generation in Ireland", January 2008
(d) 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.
(e) 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)

- Appropriate test procedures should be developed to comply with NERC model validation and performance verification requirements (such as reactive limits).

There is a need to develop and deploy valid, generic, non-confidential, and public standard power flow and stability (positive-sequence) models for variable generation technologies. Such models should be readily validated and publicly available to power utilities and all other industry stakeholders. Model parameters should be provided by variable generation manufacturers and a common model validation standard across all technologies should be adopted. Recommended NERC and Industry actions to address these needs are:

> ***NERC Action:*** Standard, valid, generic, non-confidential, and public, power flow and stability models (variable generation) are needed and must be developed, enabling planners to maintain bulk power system reliability. The NERC Planning Committee should undertake a review of the appropriate Modeling, Data and Analysis (MOD) Standards with a view towards improvements required to simulate high levels of variable generation. Feedback to the group working on NERC Standards' Project 2007-09 will be provided.
>
> ***Industry Action:*** Industry activities (e.g. those of the Institute of Electrical and Electronic Engineers (IEEE) and Western Electricity Coordinating Council (WECC)) on short circuit and dynamic models should be supported and encouraged. Variable generation vendors need to be familiar with the NERC's Modeling, Data and Analysis (MOD) Standards and materials which explain their intent and purpose. Further, industry should develop appropriate test procedures to comply with NERC model validation and performance verification requirements (such as reactive limits).

Variable generation plants are often located in remote areas of the network where the short-circuit level is weak and, as a result, problems such as under-/over-voltages, harmonics or voltage unbalances may be observed. Furthermore, controls for variable generation located near HVDC interconnections or near series compensation may interact with such equipment.[45]

Therefore, variable generation manufacturers' detailed 3-phase equipment level models are also needed to support specialized studies under these and other circumstances. The task force recommends:

> ***Industry Action:*** The variable generation manufacturers should support the development of detailed 3-phase models required for special system studies.

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[45] 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)

2.6. Summary

This Chapter provided an overview of the basic concepts of power system planning and the key considerations and characteristics of variable generation with emphasis on those attributes that may impact the reliable integration of these technologies onto the North American bulk power system. Particular attention was given to the need for adequate interconnection procedures and standards and variable generator models for power system analysis.

The following two Chapters further consider the characteristics of variable generation and explore necessary changes in planning (Chapter 3) and operations (Chapter 4) processes to maintain the reliability of bulk power systems with increasing levels of variable generation.

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 efficient 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 and ensure adequacy of supply and 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 necessary system resources exist to reliably serve demand under credible contingencies such as the loss of a generating unit or transmission facility.[46]

Traditionally, bulk system planning included centralized, tightly-coordinated generation and transmission planning. In today's power system, generation and demand-side resource adequacy planning and assessment can be performed by multiple independent entities. Transmission planning and resource adequacy assessment are inter-related as there must be adequate transmission to reliably interconnect generation needed to 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 Need for Transmission

Many new variable generation plants interconnecting to the bulk power system will be located in areas remote from demand centers and existing transmission infrastructure due to fuel availability. NERC's *2008 Long-Term Reliability Assessment* estimates that more than 145 GW of wind generation is either planned or proposed by the year 2017 in North America. Figure 3.1[47] shows the projected increases in installed wind capacity in 2008 and 2017 in various regions.[48]

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

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

[48] The installed capacity calculation method between regions is considerably different and, therefore, may not consistently represent the actual quantities that will be developed.

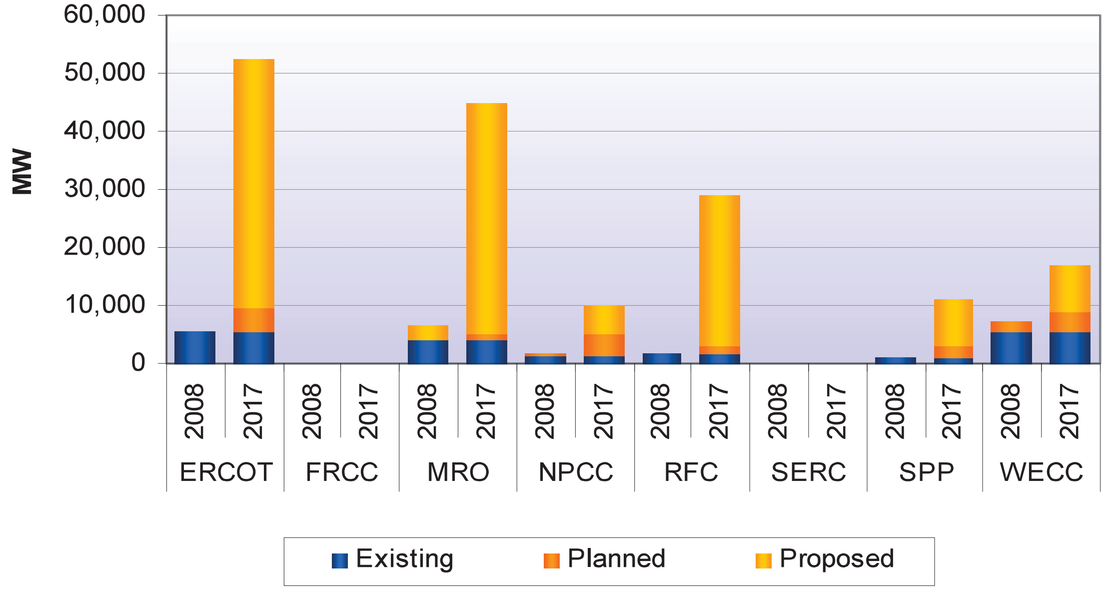

Figure 3.1 : Projected Increase in Summer Wind Nameplate/Installed Capacity

Additional transmission infrastructure is therefore vital to reliably accommodating large amounts of wind resources, specifically in order to:

1. Interconnect variable energy resources planned in remote regions;
2. Smooth the variable generation output across a broad geographical region and resource portfolio; and
3. Deliver ramping capability and ancillary services from inside and outside a Balancing Area to equalize supply and demand.

High levels of variable generation will require significant transmission additions and reinforcements to maintain bulk power system reliability.[49] The Joint-Coordinated System Plan, released in February 2008, for example, suggests that 15,000 miles of new transmission lines at a cost of $80 billion will be needed to meet a 20% wind energy scenario in the Eastern Interconnection. 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

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[49] See http://www.20percentwind.org/, http://www.JCSPstudy.org, and http://www.aeso.ca/downloads/Southern_Alberta_NID_DEC15_POSTED.pdf, for more background

obstacles, accelerate siting, and approve permits for transmission infrastructure construction and upgrades. Customer education and outreach programs should be fostered 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 infrastructure to support variable generation (renewable) resources. The task force recommends:

Industry Action: State, provincial and federal agencies and policy makers should consider:

- The impacts of variable generation integration on interstate and provincial bulk power system reliability in their oversight and evaluations.
- Collaborative efforts needed to remove obstacles, accelerate siting, and approve permits for transmission line construction.
- The importance of coordinated transmission and resource planning.
- The issues and opportunities associated with larger balancing areas and the desirability of shorter resource scheduling intervals or regional dispatch optimization.

3.2. Resource Adequacy Planning

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

In high variable generation penetration scenarios, a larger portion of the total supply resource portfolio will be comprised of energy-limited resources when compared to today's power system. This fact somewhat complicates, but does not fundamentally change existing resource adequacy planning processes in that the process must still be driven by a reliability-based set of metrics. The analytical processes used by resource planners range from relatively simple calculations of planning reserve margins to rigorous reliability simulations that calculate system Loss of Load Expectation (LOLE) or Loss of Load Probability (LOLP) values.[50] In the latter case, planners then periodically confirm resource adequacy indicated by the calculated reserve

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

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 typically include probabilistic production cost simulations for meeting a specified demand (or chronological) curve from a specified generation fleet while incorporating the forced and unforced outage rates over the simulation period.

Because both the availability of variable generation energy sources and demand for electricity are often weather dependent, 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.[51]

For example, Figure 3.2 shows the California Independent System Operator (CAISO) aggregate wind generation output over the ten-day July 2006 heat-wave.[52] Aggregate wind generation output during the peak demand hours of each day of the heat-wave typically ranged from 5 – 10% of nameplate capacity. Wind generation may tend to provide significantly higher output during shoulder months, however, which may be a high-risk period for some Balancing areas due to other resources being unavailable due to scheduled maintenance.

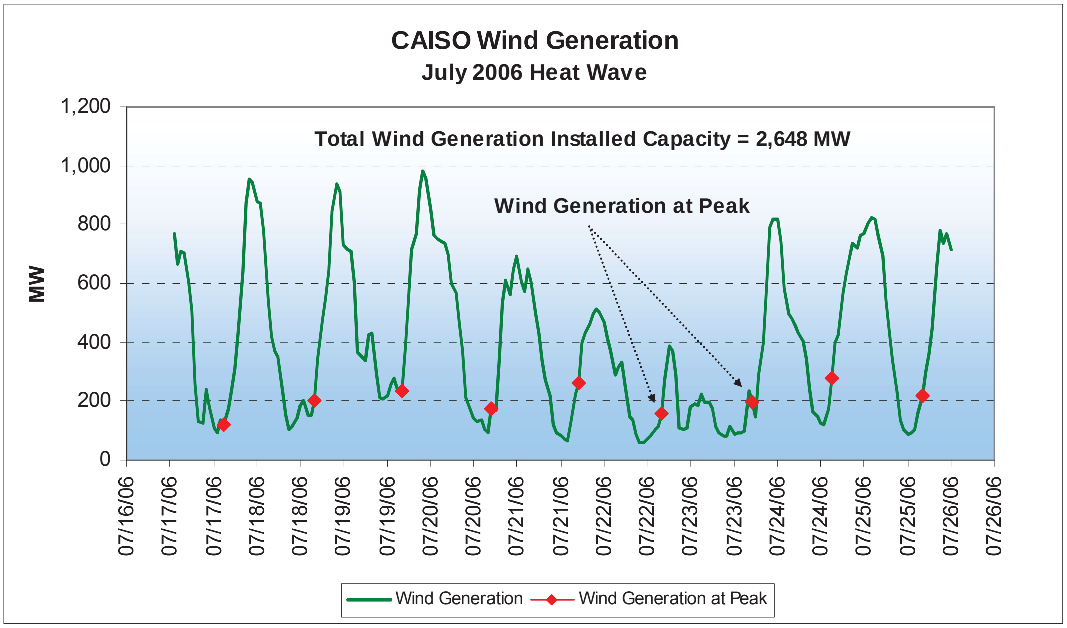

Figure 3.2: CAISO wind generation during the 2006 heat wave

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[51] EoN Netz Wind Report 2005

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

While planners are accustomed to accounting for conventional generating units which may be forced out of service, they also must consider the additional uncertainty in available capacity when a large portion of the total supply portfolio is supplied from variable generation. Traditionally (and primarily for simplicity), resource planning has been a capacity-focused process. However, with high penetrations of variable generation 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 performance rating, forced outage rate, and annual unforced maintenance cycle. However, the capacity contribution of variable generation is not intuitive due to its inherent characteristics of variability and uncertainty.

Current approaches used by resource planners[53] fall into two basic categories:

- A rigorous LOLE/LOLP - based calculation of the Effective 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 represent high-risk reliability periods (typically peak hours).

The ELCC approach considers all hours in a given planning period (typically a year) and the contribution of the variable generation output to capacity requirements during all time intervals of that period. 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 hourly primary fuel (e.g. wind or solar) data and characteristics of the generator. Care should be taken to account for the correlation between hourly variable generation and the hourly demand series. To perform this analysis, a significant amount of time-synchronized 8,760 hourly wind generation and demand data is required and this data is needed for variable generation plants in the specific geographic regions being studied. Further, in the near-term, this data will also be required for variable generation plants that are yet to be built. Currently, for wind generation, the best approach for obtaining such data is through large-scale Numerical Weather Prediction (NWP) 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. At the same time, the implementation of the

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

ELCC approach is also very much dependent on system characteristics (e.g. interconnection, storage, fuel availability, and hydro-dominated systems pose complications).

Given that the hourly variable generation output will be different in any year based on availability of the primary fuel, planners must attempt to ensure that they have an 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 variable generation output from measurements or NWP models that is time synchronized to the system demand 8,760 time series. Because the variable generation output varies from year to year, multiple years of 8,760 variable generation data must be used to generate the aggregate LOLE results across the multiple simulations considered. The concern with this approach is determining how many years of variable generation output data are adequate to accurately reflect the behavior of variable 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 variable 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 approach by assuming that the demonstrated output of the variable generation (calculated using a regression method from historical or synthesized data) is available during time periods which typically reflect high-risk reliability hours.[54] 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 U.S. use peak period definitions to calculate an approximate wind capacity value (sometimes referred to as "Net Qualifying Capacity"), as illustrated in Figure 3.3.[55] As the number of hours included in the time period increases, the results from the CF and ELCC approaches tend to converge. The ELCC method is always considered the more accurate method to calculate the capacity value of a variable generator, but requires much more data and computational resources than the CF approach.

The correlation between variable generation technologies and demand is an important factor in determining a capacity value. For example, wind and solar technologies typically have patterns that are driven by seasonal and diurnal cycles. Wind tends to be correlated across a region and the capacity value of wind in relative terms decreases as the penetration of wind increases. This phenomenon is consistently observed in capacity value studies. As incremental amounts of wind

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[54] For example, see http://www.nwcouncil.org/library/2008/2008-07.pdf

[55] 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

generation are added to a system with a given correlation between the existing and added wind capacity, the incremental contributions to reliability decrease. Once the LOLP in a given hour is sufficiently small, the addition of more capacity in that hour has a relatively small contribution to reliability.

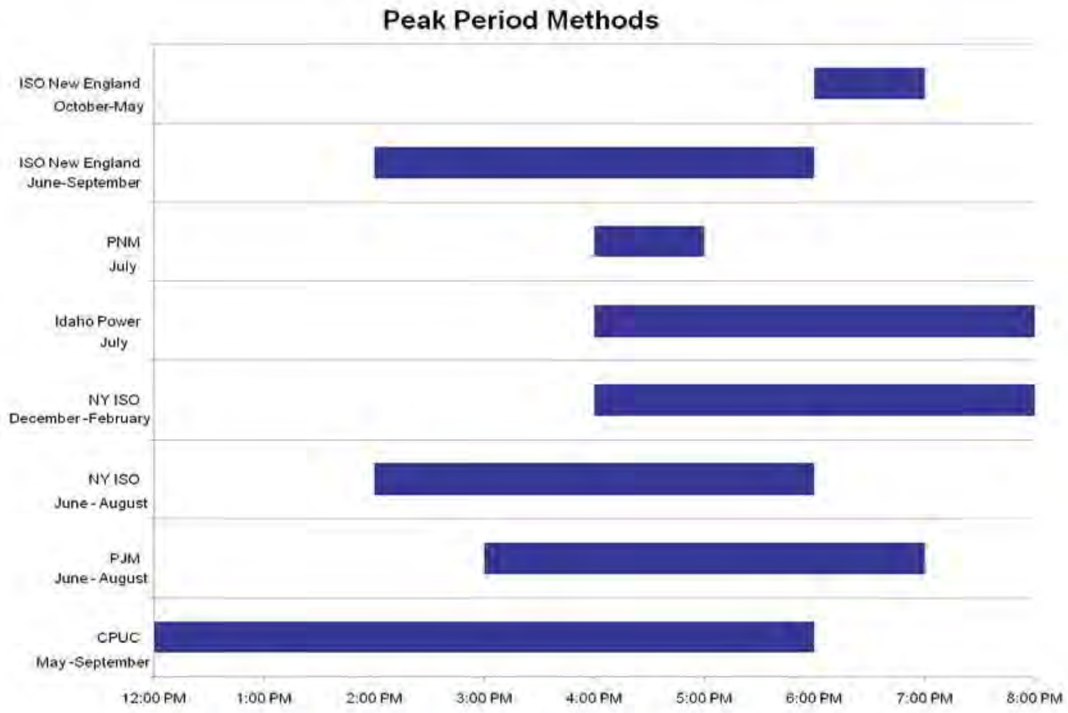

Figure 3.3: Alternative peak periods are used to assess wind capacity value in the U.S.[56]

In high variable generation penetration scenarios, a larger portion of the total supply resource portfolio, in comparison to today's power systems, will be increasingly comprised of energy-limited resources – meaning that their availability at times of peak electricity demand is limited. Energy output from variable resources is not as consistent as output from thermal power plants and cannot be dispatched when the fuel (wind, solar, etc.) is not available. This fact somewhat complicates, but does not fundamentally change existing, capacity-driven resource adequacy planning processes in that the process must still be driven by a reliability-based metric such as LOLE, LOLP, or EUE. Consistent methods are required to represent capacity values of variable generation suitable for NERC reliability assessments. Therefore, the recommended NERC action is:

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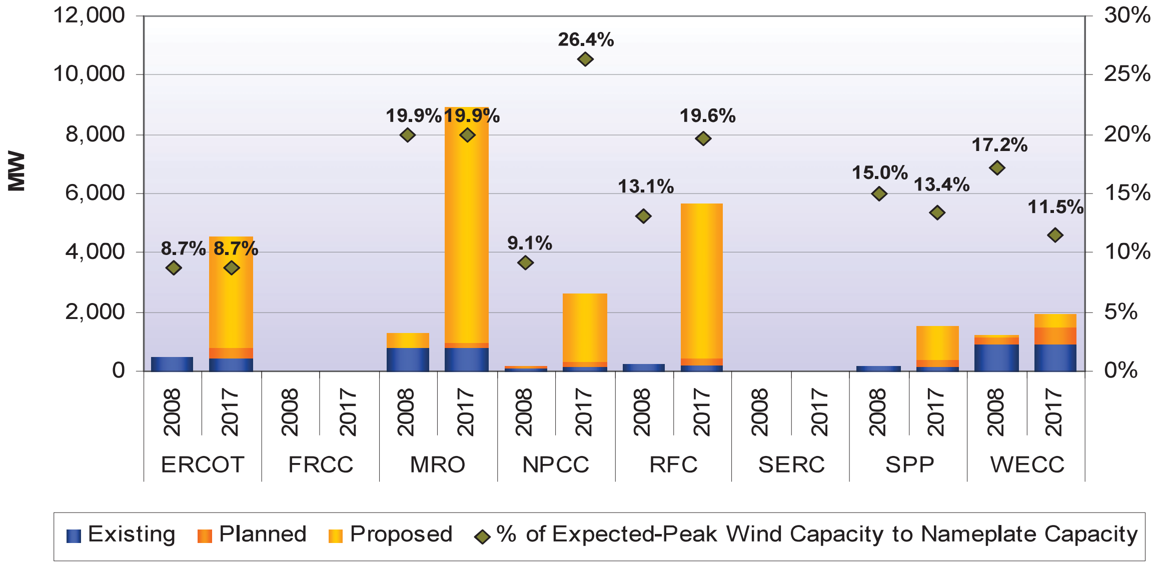
[56] Note PNM does not have an official method for calculating Capacity Value.

NERC Action: Consistent and accurate methods are needed to calculate capacity values attributable to variable generation. The NERC Planning Committee should direct the Reliability Assessment Subcommittee to collect the capacity value of variable generation based on their 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.[57]

Figure 3.4 illustrates the projections of wind on peak capacity in North America for wind generation.[58]

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



In addition to considering the correlation of variable generation to system demand during specific high-risk load periods, the weather dependence of variable generation output may also necessitate consideration of additional longer-term (seasonal or annual) resource planning scenarios. It may be necessary to consider scenarios based on broad forecasted weather patterns in addition to scenarios that consider historical statistical or typical weather data. Such consideration will be important for regions with high levels of variable generation resources and

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[57] To support this action, NERC's Generation Availability Data System (GADS), which is a voluntary data collection system, can be a source of some of the data, though other sources may also be available.

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

other weather-dependent energy sources, such as hydro, as their mutual weather dependence could result in correlated decline or increase in output across multiple resource groups for certain weather patterns. For example, if seasonal weather patterns are shown to result in both dry (low-hydro) and low-wind conditions (low-wind), planning scenarios should consider simultaneous low production levels from the affected resources. Similarly, if wet seasonal conditions are shown to occur with high wind conditions, seasonal planning scenarios should consider simultaneous high wind and hydro production.

3.3. Transmission Planning

Transmission planning processes to integrate large amounts of variable generation rely on a number of factors, including:

- Whether government renewable policies or mandates exist;
- Level of variable generation mandated and available variable generation in remote locations;
- Time horizon across which capital investments in variable generation are to be made; and
- Geographic footprint across which the investments occur.

At low variable generation penetration levels, traditional approaches towards sequential expansion of the transmission network and managing wind variability in Balancing areas may be satisfactory. However, at higher penetration levels, a regional and multi-objective perspective for transmission planning identifying concentrated variable generation zones, such as those being developed in ERCOT's Competitive Renewable Energy Zone (CREZ) process, California's Renewable Energy Transmission Initiative (RETI) and the Midwest Independent System Operator's Joint Coordinated System Planning Study,[59] may be necessary.

Within a balancing area, as the level of variable generation increases, the variability when coupled with extreme events may not be manageable with the existing conventional generation resources within the balancing area alone. Furthermore, base load generation might have to be heavily cycled for the local generation to follow the sum of load and variable generation variations, posing reliability concerns as well as economic consequences. If there is sufficient bulk power transmission, this situation can be managed by obtaining ancillary services and flexible resources from a larger generation base, such as through participation in wider-area balancing management or balancing area consolidation (see Chapter 4). Transmission planning and operations techniques, including economic inter-area planning methods, should be used for

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[59] www.jcspstudy.org

such inter-area transmission development to provide access to and sharing of flexible resources. Therefore, the composite capacity value of variable generation resources significantly improves when inter-area transmission additions allow variable generators across much wider geographic areas to interact with one another, hence improving overall system reliability.

As such, the resource adequacy planning process should no longer solely be a function of planning the resource mix alone. Transmission system expansion is also vital to unlock the capacity available from variable generation. Further, in those regions with a competitive generation marketplace, regulatory targets such as Renewable Portfolio Standards heavily influence the location and timing of renewable generation investments and their development. Furthermore, government policy and any associated cost allocations (i.e. who pays for transmission, additional ancillary services and ramping capability) will be a key driver for variable generation capacity expansion. Therefore, an iterative approach between transmission and generating resource planning is required to cost-effectively and reliably integrate all resources.

In summary, transmission expansion, including greater connectivity between balancing areas, and coordination on a broader regional basis, is a tool which can aggregate variable generators leading to the reduction of overall variability. Sufficient transmission capacity serves to blend and smooth the output of individual variable and conventional generation plants across a broader geographical region. Large balancing areas or participation in wider-area balancing management may be needed to enable high levels of variable resources. As long as existing transmission pathways are not congested, transmission expansion may not be required to achieve the benefits of larger balancing areas or sharing ramping capability and ancillary services between adjacent areas, depending on how existing and planned inter-area transmission assets are used.

Currently, high-voltage transmission overlay expansions are being considered in various parts of the NERC footprint. High-Voltage Alternating Current (HVAC), High-Voltage Direct Current (HVDC) transmission or a hybrid combination of both provides expansion alternatives for this overlay approach. HVAC can flexibly interconnect to the existing AC grid, including tapping by generation and load centers, as the grid evolves. However, for very long, over ground distances (wind sites are hundreds of miles away from demand centers), or for special synchronous purposes, dedicated HVDC may be a more suitable solution. In addition to long distances, offshore applications also offer technical challenges that can preclude HVAC cables. With the advent of voltage-source converter (VSC) technologies, additional HVDC benefits (e.g. reactive power control voltage and frequency control) have proven useful for offshore wind plants[60] and may be useful in other applications.

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

3.4. Voltage Stability and Regulation Considerations

There are many large metropolitan and populate regions of the South and South Western states of the U.S. where the transmission system has become voltage stability limited due to growing residential load (particularly residential air-conditioning) and economic and environmental concerns pushing generation to be remote from the load centers. A typical solution for these scenarios has been reactive compensation at the transmission level near load centers (e.g. Static VAR Compensation). Locating conventional fossil-fired generation closer to the load centers can potentially mitigate the problem (due to the inherent reactive capability of synchronous generators), however many factors, such as emission constraints, economic reasons (cheaper power can be bought from remote generation if the transmission system is supported by smoothly control reactive support), etc., may preclude the viability of this option.

Wind and solar (CSP) resources are typically located remote from load centers (see Figure A in the Executive Summary). This condition further heightens the need to pay careful attention to the issues of voltage stability and regulation.

The key conclusion here is, whether due to the advent of larger penetration of variable renewable generation resources (which are typically remote from load centers) or the fact that new conventional generation facilities of any kind, are being located more remotely from load centers, issues related to voltage control, regulation and stability must be carefully considered and the power system must have sufficient reactive power resources (both dynamic and static) to maintain reliability.

3.5. Planning Tools and Techniques

The addition of significant amounts of variable generation to the bulk system changes the way that transmission planners must develop their future systems to maintain reliability. Current approaches are deterministic based on the study of a set of well-understood contingency scenarios. With the addition of variable resources, risk assessment and probabilistic techniques will be required to design the bulk power system.

One vital goal of transmission planning is to identify and justify capital investments required to maintain power system reliability, improve system efficiency and comply with environmental policy requirements. A transmission planner is required to identify and advance new transmission facilities to maintain system reliability and improve system efficiency by allowing new demand growth to be supplied, managing transmission congestion, and integrating new generation resources, among other reasons. To perform transmission planning, the planner needs to study power flow, time-domain and small-signal stability along with short-circuit duty analyses tools.

Figure 3.5 illustrates an example of the total wind power distribution in Spain for the years of 2001 through 2005.[61] This figure illustrates that the total wind generation on a power system is rarely at its peak capacity. In this particular example, the median power output is around 27% of the nameplate capacity. 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 forecast scenarios will not be sufficient as it does not represent a very likely scenario. Addition of variable generation substantially increases the need to investigate many more scenarios in order to ensure bulk power system reliability.

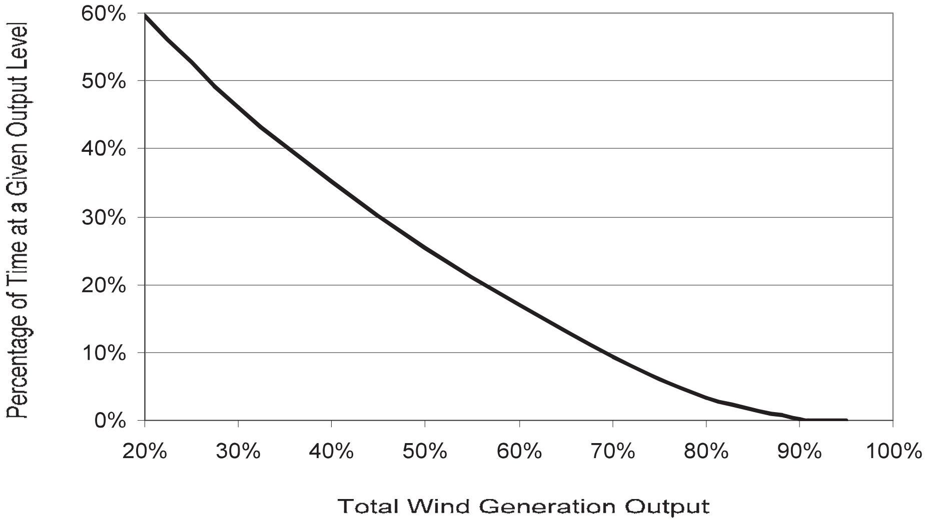

Figure 3.5: Wind power distribution for 2001 – 2005 in Spain

Traditionally, both transmission and operational planning studies have, for the most part, relied on deterministic reliability criteria and methods, mainly for ease of analysis. The paradigm in today’s power industry is one of separated generation, transmission and distribution entities accentuated by the need to plan for significant penetration of variable resources. These factors render planning based solely on deterministic criteria for system expansion less effective since:

1. The restructuring of the utility business in most regions has made it more difficult to accurately predict the location of new generation facilities and their respective dispatch patterns (i.e. market driven). Consequently it is significantly more difficult to plan for transmission reinforcements on purely a deterministic basis.

2. High penetration levels of renewable generation will mean an added level of uncertainty on generation dispatch levels even when the locations of these renewable generators are

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[61] 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)

> known. For example, selection of a specific dispatch level for these generators, as is required under deterministic planning methods, may not identify important scenarios impacting reliability which should be studied and for which actions should be taken.

NERC's Transmission Planning (TPL) Standards are the foundation for transmission planning in North America. These standards are deterministic in nature and are based on the pre-specification of critical conditions. However, with the incorporation of variable generation resources, planning process will need to be augmented as the number of scenarios for which sensitivity analysis must be performed to "bracket" the range of probable outcomes, which can dramatically increase.[62]

Probabilistic or risk-based approaches are becoming more popular worldwide for system planning. Some probabilistic planning criteria, tools and techniques have been developed over the past several decades; however, they will require critical review for completeness and applicability before they can become an industry-accepted approach to consistently measure bulk power system reliability.

There is a marked benefit in pursuing probabilistic methods for both long-term and operational planning of the power system in order to more systematically and adequately quantify the risks associated with various planning options due to the high variability and probabilistic nature of many of the elements of the modern power system (variable generation, market forces, etc.). Much research is likely to be needed to fully develop and employ such methods. As a first step, a present CIGRE effort[63] is identifying the gaps between deterministic and probabilistic methods, assessing the benefits that can be reaped from probabilistic methods, considering the practical challenges with attempting to apply probabilistic methods to planning, and identifying the research and tools development that may be needed to move towards probabilistic methods.

The necessary detailed datasets to study all types of variable generation are not yet available. To ensure the validity of variable generation integration study results, high-quality, and high-resolution (sub-hourly if possible) output data is required. Currently, historical data of variable generation performance is very limited and difficult to obtain. As substantial amounts of variable generation are expected to be added to the bulk power system during the next ten years, industry must begin obtaining the data as required to design robust bulk power systems. To this point in time, extensive modeling has been used to generate simulated data 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.

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[62] FERC order 693, paragraphs 1694 to 1719 http://www.ferc.gov/whats-new/comm-meet/2007/031507/E-13.pdf

[63] CIGRE Working Group C4.601, Power System Security Assessment.

In summary, new tools and techniques for system planning are needed to accommodate the increased resource uncertainty and variability to complement existing deterministic approaches. Additional data will be required to support these new planning processes:

> ***NERC Action:*** Probabilistic planning techniques and approaches are needed to ensure that bulk power system designs maintain bulk power system reliability. The NERC Planning Committee should identify necessary data requirements to conduct planning studies and recommend that Planning Authorities and Reliability Coordinators collect and retain such data. This action should identify how probabilistic approaches for transmission planning may go beyond current generally accepted industry approaches (for example, FERC Order 890[64]) as well as consider the NERC TPL Standard (Project 2006-02) drafting activities.[65]
>
> ***Industry Action:*** The use of probabilistic planning techniques and approaches should be investigated and adopted for the planning and design of bulk power systems with high levels of variable generation. Additional research and development on probabilistic power system planning techniques and the data needed to perform this analysis are required.

3.6. Flexibility in the 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 (i.e. Interconnection capability) is available to serve demand and maintain reliability during the expected range of operating conditions (including severe variable ramping conditions) in a balancing area?" If the underlying fuel is available, new variable generation technologies can readily contribute to the power system ancillary services and ramping needs. Upward ramping and regulation needs, beyond the maximum generation afforded by availability of the primary fuel (wind or sun), are important planning considerations. Unless renewable resources in the balancing authority are designed to provide inertial response, the planner must ensure other sources of inertia are available to meet bulk power system reliability requirements under contingency conditions.

A comprehensive variable generation integration study should be conducted assessing the appropriate level of system flexibility to deal with system ramping and reserve needs. There are many different sources of system flexibility including; 1) ramping of the variable generation (modern wind plants can limit up- and down-ramps), 2) regulating and contingency reserves, 3)

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[64] See paragraph 602 of FERC Order 890 http://www.ferc.gov/whats-new/comm-meet/2008/061908/E-1.pdf

[65] http://www.nerc.com/filez/standards/Assess-Transmission-Future-Needs.htm

reactive power reserves, 4) quick start capability, 5) low minimum generating levels and 6) the ability to frequently cycle the resources' output. Additional sources of system flexibility include the operation of structured markets, shorter scheduling intervals, demand-side management, reservoir hydro systems, gas storage and energy storage. System planners must ensure that suitable system flexibility is included in future bulk power system designs, as this system flexibility is needed to deal with, among many conditions, the additional variability and uncertainty introduced into power system operations by large scale integration of variable generation. This increased variability/uncertainty occurs on all time scales, particularly in the longer timeframes, (i.e. ramping needs). In fact, some power systems[66] have already experienced significant ramping events across a large geographic area creating significant operating challenges.[67]

Many areas also consider the overall system load factor 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. Under these circumstances, a large penetration of variable generation would require the addition of added flexible resources or access to additional resources (via interconnections) and requirements for increased flexible performance including from variable resources themselves. In addition, in some regions the amount of regulating reserves and demand following capacity can be as little as 1% of the total peak demand.[68] In this respect, wind plant integration requirements are not generic and will be affected by the circumstances and characteristics of each area (i.e. interconnection capability, load factor, system resource mix, etc.).

Location and flexibility of resources is critical in the future design of the system. As resources become more distributed, control and storage equipment (e.g. STATCOMs, storage devices, SVCs) may also be distributed. In this respect, it may be necessary to relocate control and storage equipment to maintain proper function of the system as new resources connect.

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.[69]

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

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

[68] 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

[69] 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.

Wind plant aggregation across broad geographical regions can also significantly reduce output variability, decrease uncertainty and, consequently, reduce the need for additional flexibility.

Therefore, integration studies need to be conducted to assess the appropriate level of system ramping capabilities (intra-hour and load following), reserves, minimum demand levels, rapid start capability, scheduling intervals, additional transmission and system inertial response. The individual characteristics of each system (i.e. generation resource mix, ramping capability, amount of dispatchable resources, etc.) will affect these impacts. High-quality, high-resolution (typically sub-hourly) variable generation and load data is required to ensure the validity of the study results.

Therefore, resource planning processes should be adjusted to ensure that the designed system will include resources that provide the desired flexibility. The task force recommends:

> ***NERC Action:*** Resource adequacy and transmission planning approaches must consider needed flexibility to accommodate the characteristics of variable resources as part of bulk power system design. The NERC Planning Committee's Resource Issues Subcommittee should study changes required to current resource adequacy assessment processes to account for large-scale variable generation integration. Considerations should include ramping requirements, minimum generation levels, required shorter scheduling intervals, transmission interconnections, etc.
>
> ***Industry Action:*** Minimum requirements and/or market mechanisms (e.g., price signals) should be developed to ensure that all generation, the bulk power system and resulting system operations has the desired characteristics (e.g., ramping requirements, minimum generation levels, shorter scheduling intervals, etc.) and to foster the development of an appropriate resource mix that will maintain reliability.

3.7. Smart grid developments

Smart grids can be defined from a reliability perspective as a power system, from generation source to end-user, which integrates two-way flow of communications and energy as application of existing and new technologies enable new forms of supply, delivery and consumption.[70] There are several developments under the category of "smart grids" which may assist in the integration of variable generation. This may include the deployment of smart meters to facilitate more demand response programs, incentives to promote the installation of stationary and mobile (e.g. plug-in electric vehicles) 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 large amounts of variable generation.

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[70] For example, www.ieso.ca/smartgridreport

Demand response can operate in every time frame of interest, from seasons to seconds, supporting variable generation integration. Demand response has already been shown in some balancing areas to be a flexible tool for operators to use with wind generation[71] and is a potential source of flexibility equal to supply-side options (i.e. to counter variable generation down ramps). Different demands have different response capabilities, and different costs to respond. More work is required to identify demand response opportunities and to develop commercial arrangements to obtain a significant aggregate response.

Energy storage technologies also have the potential to assist the large-scale integration of variable generation.[72] The ability of storage to transform energy into capacity has many advantages depending on the technical capabilities and economics of the technology. Pumped hydro comprises the vast majority of energy storage used today, though there are numerous storage technologies in various stages of development and commercialization that can provide effective system flexibility. Technologies, like battery energy storage (BESS), flywheel energy storage (FESS), and Compressed Air Energy Storage (CAES), are rapidly becoming commercial. [73] The present economic drivers for energy storage with fast discharge are stronger and growing faster than those with longer term discharge characteristics.

However, the cost of storage devices compared to other methods of flexibility currently has limited 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 plants.[74] As a system resource, energy storage 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. As a network resource, it is available to balance variability of any combination of resources and demands.

Nevertheless, the recent Department of Energy 20% by 2030 report[75] indicates that serving 20% of annual energy with wind resources in the United States would not require storage resources, assuming sufficient transmission exists.[76]

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

[72] KEMA, "White Paper - Benefits of Fast Response Storage Devices for Regulation," November, 2008

[73] 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*, Volume 35, pp. 1474 – 1492, 2007.

[74] 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.

[75] See http://www.20percentwind.org/ for more details

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 limits market penetration of electric vehicles is battery requirements (i.e. cost and length of charge).[77] Lightweight, high power density batteries suitable for this application are not yet available at the necessary quantity and price. As electric vehicles become available, they could also provide energy storage services that can benefit a bulk power system experiencing increasing levels of variability. However, many design hurdles need to be overcome, particularly on distribution system where the storage most likely will be charged/discharged, to fully capture the potential benefits of synergies between variable generation and electric vehicles.[78] Further, as each vehicle contains a converter, monitoring and study are required to investigate the potential generation of harmonics which could impact power quality.[79]

Developments in electric vehicles, storage and demand response may provide characteristics which will help accommodate high levels of variable generation.[80] Therefore, the task force recommends:

> ***NERC Action:*** Integration of large amounts of plug-in hybrid electric vehicles, storage and demand response programs may provide additional resource flexibility and influence bulk power system reliability and should be considered in planning studies. NERC Planning Committee should assess the influence on reliability of accommodating large energy storage capability both stationary and mobile (such as Plug-in Hybrid Electric Vehicles), along with large amounts of demand response.
>
> ***Industry Action:*** The following industry research and development activities are needed:
>
> - Develop demand response and storage technologies.
> - Monitor the impact on reliability of distributed variable generators.
> - Improve forecasting methods, in particular, specific applications such as severe weather and next hour(s) ramping event forecasting.

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[76] "20% Wind Energy by 2030 – Increasing Wind Energy's Contribution to U.S. Electricity Supply," U.S. Department of Energy, May 2008.

[77] 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.

[78] 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.

[79] See http://www.spinnovation.com/sn/Presentation/EV_charging_evaluation_-_impact_on_utility.pdf

[80] http://www.nerc.com/docs/pc/drdtf/NERC_DSMTF_Report_040308.pdf

Another significant consideration is the influence of high levels of variable generation on the distribution system. As the penetration of distributed resources grows,[81] their influence on bulk system supply and delivery planning, including their variable generation characteristics (e.g. ramping), cannot be ignored. For example, to maintain bulk power system reliability, distribution system designs may need to be enhanced to accommodate reactive power control requirements,[82] coordinated system restoration, visibility of and communication with distributed variable resources by bulk power system operators, as well as system protection and safety concerns. In addition, the NERC Functional Model may need to be enhanced in the future 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 the future, as has occurred in some regions of Denmark and Germany.[83] As mentioned earlier, under these circumstances, the requirement for bulk power system voltage ride-through capability can be in conflict with the anti-islanding voltage drop-out requirements of distribution connected generation which comply with IEEE Standard 1547.[84] A study is needed to reconcile bulk power system voltage ride-through requirements and IEEE Standard 1547 in order to maintain the reliability of the bulk power system (e.g. tripping of local generation during distant faults, tripping of generation during under-frequency load shedding, complications with system restoration).

Distributed variable generators, individually or in aggregate (e.g. small scale photovoltaic), can impact the bulk power system and need to be treated, where appropriate, in a similar manner to transmission connected variable generation. The issues of note are forecasting, restoration, voltage ride-through, safety, reactive power, observability and controllability. High levels of distributed generation may require new network design. Further, distributed variable generation units may fall below the MW size requirements which might require a Generation Owner or Generator Operator to register and therefore to be held to NERC's standards. The NERC registry criteria[85] may need to be broadened to include smaller generators not covered by the

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[81] For example, the U.S. Department of Energy's Energy Information Administration's definition of Distributed Generator is "A generator that is located close to the particular load that it is intended to serve. General, but non-exclusive, characteristics of these generators include: an operating strategy that supports the served load; and interconnection to a distribution or sub-transmission system (138 kV or less)"

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

[83] 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.

[84] http://grouper.ieee.org/groups/scc21/1547/1547_index.html

[85] See page 8 of http://www.nerc.com/files/Statement_Compliance_Registry_Criteria-V5-0.pdf

current registry criteria; for example, distributed generators that are 1 MVA or greater and all distributed generator plants/facilities that are 5 MVA or greater.

Therefore, the task force recommends:

> ***NERC Action:*** Variable distributed resources can have a significant impact on system operation and must be considered and included in power system planning studies. The NERC Planning Committee should review and study the impact of distributed generation on bulk power system reliability, and the possible need to recognize owners and operators of such distributed generation in the NERC registry criteria.
>
> ***NERC & Industry Action:*** Existing bulk power system voltage ride-through performance requirements and distribution system anti-islanding voltage drop-out requirements of IEEE Standard 1547 must be reconciled by the NERC Planning Committee and IEEE Power and Energy Society.
>
> ***Industry Action:*** Research and development activities to measure the impact on reliability of distributed variable generators should be encouraged and supported.

3.8. Summary

Power system planning is intended to ensure that a reliable and robust power system is available to the power system operator within the planning horizon. This Chapter has addressed the need for the development of new planning methods and techniques that consider the characteristics of variable generation. The Chapter also discussed the development of new planning methods and techniques that consider the characteristics of variable generation resources. Further, this Chapter explored the ability of storage technologies to transform energy into capacity, which has many advantages depending on the technical capabilities and economics of the technology. Finally, the impacts of distributed variable generation resources were discussed.

Power system operations is distinct from power system planning as it involves the actual real time operation of the system, including supply/demand balancing, managing operating limits and voltage control. The operational impacts resulting from the large-scale integration of variable generation are discussed in the next Chapter.

4. Power System Operations

This chapter describes the key issues and considerations related to the operation of the bulk power system with large-scale integration of variable generation, with a focus on the integration of wind resources, where substantial industry experience has begun to accumulate. That said, much of this valuable experience can also be applied to the reliable integration of other variable generation resources

As discussed in Chapter 2, where it is uncontrolled, the output of variable generation is dependant upon the availability and characteristics of its primary fuel. For example, a variable generator may produce no energy at the time of system peak demand even if it is not in an outage condition, or it may produce peak energy during an off-peak period, and may ramp up or down in opposite direction to system needs for ramping (See *Resource Adequacy Planning* in Chapter 3). This Chapter first describes the major operational characteristics and potential challenges associated with high levels of variable generation in a power system and then provides a description of potential solutions to address these challenges. These aspects are discussed within three related, but distinct time domains: forecasting, commitment and dispatch. The issues and opportunities associated with larger balancing areas or participation in wider-area balancing management, along with reduced scheduling intervals is also discussed.

4.1. Forecasting

As described in Chapter 2, variable generation resources have a certain amount of inherent uncertainty. However, in many areas where wind power has not reached high penetration levels, uncertainty associated with the wind power has normally been less than that of demand uncertainty. Operating experience has shown that as the amount of wind power increases (i.e., greater than 5% of installed capacity) there is not a proportional increase in overall uncertainty. Consequently, power system operators have been able to accommodate current levels of wind plant integration and the associated uncertainty with little or no effort.

Forecasting the output of variable generation is critical to bulk power system reliability in order to ensure that adequate resources are available for ancillary services and ramping requirements. The field of wind plant output forecasting has made significant progress 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. Some balancing areas in North America have already implemented advanced forecasting systems, and others are in various stages of implementation process including the information gathering and fact-finding stage.

In the case of wind power, forecasting is one of the key tools needed to increase the operator's awareness of wind plant output uncertainty and assist the operator in managing this uncertainty. Rapid developments are occurring in the field of wind plant output forecasting and its application to effective management of the hour ahead and day-ahead operational planning processes.[86] For example, the Independent Electricity Service Operator of Ontario (IESO) has established a near-term forecasting method that facilitates day-ahead and near-term operational planning and adequacy assessment needs.[87]

Power system operators are familiar with demand forecasting and, while there are similarities, forecasting variable generation output is fundamentally different. The errors in demand forecasting are typically small (in the order of a few percent) and do not change appreciatively over time. On the other hand, wind generation output forecasting is very sensitive to the time horizon and forecast errors grow appreciably with time horizon.

> **Demand Example:** On a system with a 10,000 MW peak demand, the error for a 12 hour forecast is normally about 300 MW (3% error) and unlikely to be more than 1,000 MW (10% error).
>
> **Wind Example:** For a system with 10,000 MW of wind power, the error for a 12 hour wind forecast could readily be 2,000 MW (20% error) or as much as 10,000 MW (100% error).

Figure 4.1 shows an example where the standard deviation of the wind generation output error grows with time horizon. Note that different regions can have different errors and error characteristics. However, in practically all cases, the wind forecast errors are larger than those of demand forecast and thus introducing greater uncertainty with longer term operational planning.

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[86] 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

[87] http://www.ieso.ca/imoweb/pubs/consult/windpower/wpsc-20080220-Item5_NearTermWind.pdf

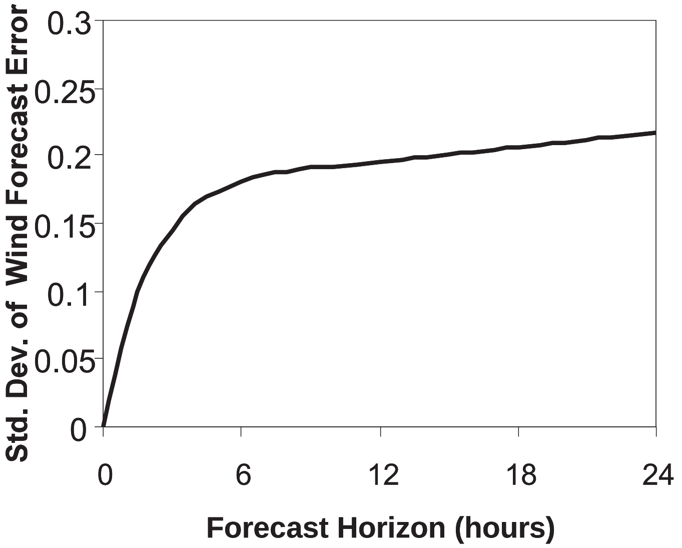

Figure 4.1: Forecast error as a function of time horizon[88]

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 products over the course of a year and to determine an effective approach to wind power forecasting in Alberta. As can be seen from the results of this study (Figure 4.2), there can be significant variations in the amplitude and phase (i.e. timing) between the actual and the forecast wind generation output. Improvements to short term forecasting techniques are necessary to provide the system operator with the needed tool for the reliable operation of the system. An important conclusion of this research was accuracy of forecasting was improved when it covered a larger geographic area.[89]

While significant effort has gone into developing accurate wind plant output forecasts for real-time dispatch and hour ahead/day-ahead operational planning purposes, a significant effort is still needed to integrate the forecasting tools and methods into the actual operational procedures and supporting software systems. Major software vendors are just now beginning to focus on this emerging need.

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[88] 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.

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

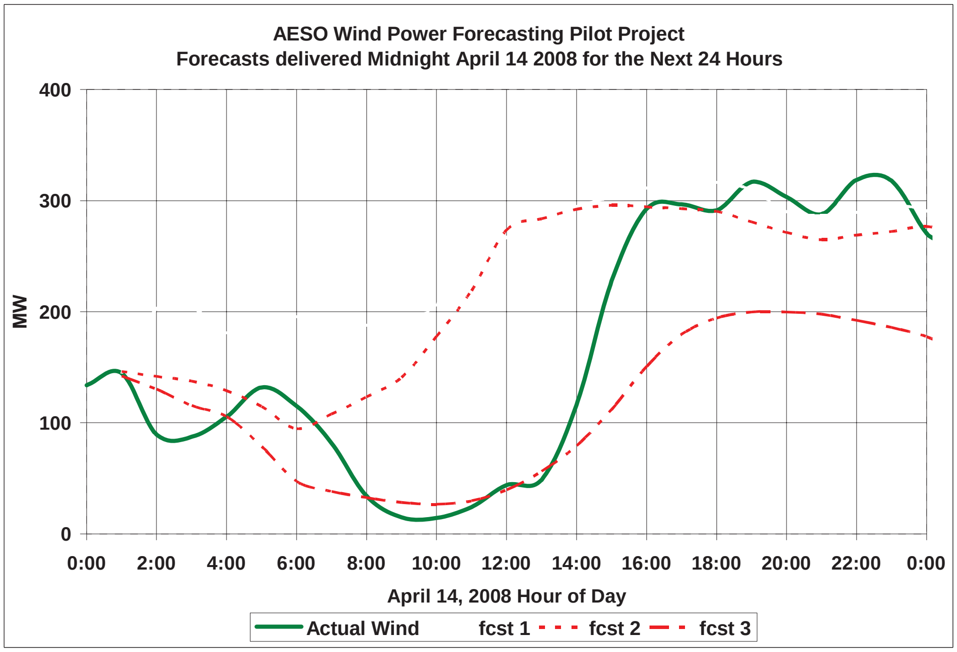

Figure 4.2 AESO wind forecasting pilot

The integration of accurate rapid-update hour-ahead wind generation forecasts into system operating procedures can more effectively address operational concerns, as illustrated through the recent ERCOT event of February 26, 2008.[90] There are four different forecasting features that are essential for improved power system operations:

- ***Severe Weather Alert*** improves situational awareness in the control room. This is a real-time system which will enables operators to visualize and react to high wind events. 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 formats along with high wind forecasts for winds exceeding 20 m/s and real-time color-coded high wind observations.[91] Operators can identify the impact of an extreme wind event on a timely basis and prepare for proper preventive/corrective actions.

  As noted above, the sudden loss of full power from a large wind plant under an extreme wind event due to turbine high speed cut-off is a principal concern for an operator. In addition to extreme wind events, cold temperatures can also cause wind turbine shut-down. Although extreme wind events should be of great concern to the power system

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

[91] 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

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, rather it causes turbines to shut down individually. For example, experience with several high wind events in Texas shows that it can take one to two hours for a large wind event to ramp down a significant portion of the wind fleet. Furthermore, as noted above, the severe weather alert capability should make these conditions readily predictable with sufficient lead time allowing for proper preventive and corrective actions by the operator.

- ***Day-Ahead Forecast*** provides hourly power values typically for a 48-96 hour time horizon and is typically updated every 6-12 hours. This forecast is used by system operators or generation operators in the unit commitment process. Accounting for the uncertainty associated with the wind plant output forecast in this time frame is important, and this is an area where significant development, investigating the use of ensemble forecasts, is underway.

- ***Hours-Ahead Forecast*** provides finer time resolution of wind generation output, including ramp forecasting for the next few hours. It is used by operators for next-hour planning, and as input for preventative and corrective operating strategies during large ramps. 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 prepare for proper preventive/corrective actions. Such actions might include curtailing the wind plant output under some scenarios, limiting the wind generation up-ramp in other scenarios, or procuring additional ramping and reserve capabilities from both conventional and variable resources.

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

Wind forecasting techniques and products require substantial amounts of high quality data. The data needs may include on-site meteorological data from the wind power facilities and electrical data such as real power production and real power capability in terms of the sum of turbine availability. This type of high quality data should be provided in a timely manner through the Supervisory Control and Data Acquisition (SCADA) systems for use in the operator’s Energy Management System (EMS). Coordination of maintenance schedules and provision of records regarding curtailments should also be provided and available.

In summary, variable generation output forecasts in multiple time frames are critical for reducing uncertainty and maintaining system reliability. The meteorological and electrical data should be provided through the SCADA systems using standard communication protocols for use in state of the art forecasting and system operations. This forecasting requirement should be incorporated into bulk system operations. The task force recommends:

NERC Action: Forecasting techniques must be incorporated into day-to-day operational planning and real-time operations routines/practices including unit commitment, and dispatch. NERC's Operating Committee should ensure that accurate forecasting data requirements are addressed in FAC-001, TOP-002-2 and/or TOP-006-1.

Industry Action: Government and industry should support research and development to improve forecasting methods, and in particular, niche applications such as severe weather and ramp forecasting.

4.2. Unit Commitment and Dispatch

The unit commitment and dispatch process ensures that, under normal conditions, the bulk power system will operate with sufficient capacity on-line and sufficient reserves to serve demand and respond to system contingencies. The expected considerable increase in variable generation on the bulk power system will 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 available variable generation to deal with system reliability. In practical terms, the system operator may decide to dispatch additional capacity for ramping capability and ancillary services, use demand response, and/use wind power management capability (i.e. ramp rate or power limiting function) of the variable generation pre-positioning the bulk power system to withstand credible contingencies. On the surface, this may seem inefficient, but the system operator must be able to use operating criteria, practices and procedures, some yet to be developed, to make operating decisions based on the best available information in order to ensure system reliability.

Enhancements to existing operating criteria, practices and procedures to account for large penetration of variable generation should be developed under the leadership of the relevant reliability bodies, such as NERC, Regional Entities, RTOs, etc., and with full participation of industry stakeholders. It is critical that criteria, practices and procedures regarding wind forecasting, unit commitment and dispatch, reserve procurement, use of demand side resources, and use of variable generation power management functions, among others, are reviewed and enhanced to assist the system operator in managing the increased uncertainty from variable generation. This should also include the consideration of risk-based operating criteria and operational planning criteria, methods and techniques.

A well known operating challenge with variable generation is the possibility of over-generation during light load conditions when conventional generators that must be kept on line are dispatched to their minimum operating level. Under these circumstances, the power system operator must have the ability to limit or reduce the output of variable generation, according to the criteria, practices and procedures mentioned above in order to maintain system reliability during over-generation periods. For example, to mitigate the potential for over-generation conditions in response to this circumstance, balancing areas may consider trading frequency responsive reserves during light load conditions or explore the use of batteries, flywheels, loads, etc. to provide this capability. Greater visualization provided by state-of-the-art system monitoring technology, like PMUs, may assist operators and planners in managing these new resources.

In summary, with high levels of variable generation, existing operating practices in unit commitment and/or dispatch along with reserve management will need to change in order to maintain bulk power system reliability. Timely forecasting of large variable generation ramping events is particularly important. Therefore, the task force recommends:

> **NERC Action:** NERC's Operating Committee should identify the additional or enhanced operational criteria, practices and procedures required to accommodate large levels of variable generation integration. For example, probabilistic methods may be needed to forecast uncertainty in wind plant output and included in the operations planning process. The Committee should, further, increase the awareness of these needs through established NERC programs and/or initiatives.

4.3. Ancillary Services and Reduced Scheduling Intervals

Ancillary services are a vital part of balancing supply and demand and maintaining bulk power system reliability. Organizations have taken advantage of demand aggregation, provision of ancillary services from other jurisdictions and interconnected system operation, for decades. Since each balancing area must compensate for the variability of its own demand and random load variations in individual demands, larger balancing areas with sufficient transmission proportionally require relatively less system balancing through "regulation" and ramping capability than smaller balancing areas. Smaller balancing areas can participate in wider-area arrangements for ancillary services to meet NERC's Control Performance Standards (CPS1 and CPS2).

As mentioned in earlier chapters, with sufficient bulk power transmission, larger balancing areas or participating in wide-area arrangements, can offer reliability and economic benefits when integrating large amounts of variable generation.[92] In addition, they can lead to increased diversity of variable generation resources and provide greater access to more dispatchable resources, increasing the power systems ability to accommodate larger amounts of variable generation without the addition of new sources of system flexibility. Balancing areas should evaluate the reliability and economic issues and opportunities resulting from consolidation or

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

participating in wider-area arrangements such as ACE sharing (such as WECC's ACE Diversity Interchange[93]) or wide area energy management systems.

In many locations, balancing energy transactions are scheduled on an hourly basis. With the advent of variable generation, more frequent and shorter scheduling intervals for energy transactions may assist in the large-scale integration of variable generation. For example, as noted above, balancing areas that schedule energy transactions on an hourly basis must have sufficient regulation resources to maintain the schedule for the hour. If the scheduling intervals are reduced for example to 10 minutes, economically dispatchable generators in an adjacent balancing area can provide necessary ramping capability through an interconnection.[94]

In summary, with adequate bulk power transmission, variable generation plants aggregated across larger balancing areas or participation in wider-area balancing management may significantly reduce variability (both of variable generation and demand), increase predictability and therefore reduce the need for additional flexible resources. With adequate available transmission capacity, larger balancing areas and more frequent scheduling within and between areas provide more sources of flexibility. Therefore, the task force recommends:

> ***NERC Action:*** The impact of securing ancillary services through larger balancing areas or participation in wider-area balancing management on bulk power system reliability must be investigated. The NERC Operating Committee should review and study the consequences of larger balancing areas or participation in wider-area balancing management like provisions of ancillary services from other jurisdictions, ACE sharing, and/or shorter scheduling intervals within and between balancing areas to effectively manage variability of generation resources over a larger footprint. In addition, existing and proposed BAL Standards should be reviewed to determine their sufficiency.
>
> ***Industry Action:*** State, provincial and federal government agencies and policymakers should be informed of the issues and opportunities associated with transmission and larger balancing areas which can increase access to ancillary service requirements and the desirability of more frequent scheduling intervals, including sub-hourly scheduling or regional dispatch optimization.

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[93] See http://www.wecc.biz/index.php?module=pnForum&func=viewtopic&topic=909

[94] Reduced scheduling intervals would also produce a system response more closely aligned with real-time events and provide closer to real-time market data for providers of demand response services

4.4. Summary

The expected significant increase in variable generation additions on the bulk power system will 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 variable generation forecasting techniques and have access to sufficient flexible resources to mitigate the added variability and uncertainty associated with the large scale integration of variable generation. In this respect, operating criteria, forecasting, commitment, scheduling, dispatch and balancing practices, procedures and tools must be enhanced to assist operators in maintaining bulk power system reliability.

5. Conclusions & Recommended Actions

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

As this major shift in resource implementation is underway, it is imperative that power system planners and operators understand the potential reliability impacts associated with large scale integration of variable generation. They also need to develop the planning and operational practices, methods and resources needed to reliably integrate variable generation resources into the bulk power system.

Following is a summary of the consolidated conclusions, recommended actions and observations developed by the IVGTF:[95]

1. **Power system planners must consider the impacts of variable generation in power system planning and design and develop the necessary practices and methods to maintain long-term bulk power system reliability (NERC's Planning Committee)**

    1.1. Standard, valid, generic, non-confidential, and public power flow and stability models (variable generation) are needed and must be developed, enabling planners to maintain bulk power system reliability.
    1.2. Consistent and accurate methods are needed to calculate capacity values attributable to variable generation.
    1.3. Interconnection procedures and standards should be enhanced to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response and must be applied in a consistent manner to all generation technologies.
    1.4. Resource adequacy and transmission planning approaches must consider needed system flexibility to accommodate the characteristics of variable resources as part of bulk power 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 influence bulk power system reliability and should be considered in planning studies.

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[95] A draft work plan can be found in Appendix I

1.6. Probabilistic planning techniques and approaches are needed to ensure that system designs maintain bulk power system reliability.
1.7. Existing bulk power system voltage ride-through performance requirements and distribution system anti-islanding voltage drop-out requirements of IEEE Standard 1547 must be reconciled.
1.8. Variable distributed resources can have a significant impact on system operation and must be considered and included in power system planning studies.

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

2.1. Forecasting techniques must be incorporated into day-to-day operational planning and real-time operations routines/practices including unit commitment and dispatch.
2.2. Balancing areas must have sufficient communications for monitoring and sending dispatch instructions to variable resources.
2.3. Impact of securing ancillary services through larger balancing areas or participation in wider-area balancing management on bulk power system reliability must be investigated.
2.4. Operating practices, procedures and tools will need to be enhanced and modified.

3. **Planners and operators would benefit from a reference manual which describes the changes required to plan and operate the bulk power and distribution systems to accommodate large amounts of variable generation (NERC's Operating and Planning Committees)**

3.1. NERC should prepare a reference manual to educate bulk power and distribution system planners and operators on reliable integration of large amounts of variable generation.

In addition, a number of issues, not under the purview of NERC, should be addressed by industry and policy makers:

4. **Industry Actions**

4.1. Existing bulk power system voltage ride-through requirements and the distribution system anti-islanding voltage drop-out requirements of IEEE Standard 1547 must be reconciled.
4.2. Industry activities (e.g. the Institute of Electrical and Electronic Engineers (IEEE) and Western Electricity Coordinating Council (WECC)) efforts on developing short circuit and dynamic models should be supported and encouraged.
4.3. Variable generation owner, operators and vendors must familiarize themselves with the intent and purpose of NERC's Modeling, Data and Analysis (MOD) Standards.
4.4. The use of probabilistic planning techniques and approaches should be investigated and adopted for the planning and design of bulk power systems with high levels of variable

generation. Additional research and development on probabilistic power system planning techniques and the data needed to perform this analysis is required.

4.5. Minimum requirements and/or market mechanisms (e.g., price signals) should be developed to ensure that all generation, the bulk power system and resulting system operations has the desired characteristics (e.g., ramping requirements, minimum generation levels, shorter scheduling intervals, etc.) and to foster the development of an appropriate resource mix that will maintain reliability.

4.6. The variable generation manufacturers should support the development of detailed 3-phase models required for special power system studies.

4.7. State, provincial, and federal agencies and policy makers should consider:

- The impacts of variable generation integration on interstate and provincial bulk power system reliability in their oversight and evaluations.
- Collaborative efforts needed to remove obstacles, accelerate siting, and approve permits for transmission line construction.
- The importance of coordinated transmission and resource planning.
- The issues and opportunities associated with larger balancing areas and the desirability of shorter resource scheduling intervals or regional dispatch optimization.

4.8. The following industry research and development activities are needed:

- Develop demand response and storage technologies.
- Monitor the impact on reliability of distributed variable generators.
- Improve forecasting methods, in particular, specific applications such as severe weather and next hour(s) ramping event forecasting.
- Develop advanced probabilistic power system planning techniques.

Appendix I: 2009-2011 NERC Objectives and Work Plan

Changes to planning and operations criteria, practices and procedures are required 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, in order of priority (blue is highest, yellow medium and green the lowest), and proposed work plan, are provided as a guide for the next phase of activities:

Objectives

1. **Power system planners must consider the impacts of variable generation in power system planning and design and develop the necessary practices and methods to maintain long-term bulk power system reliability (NERC's Planning Committee)**

   1.1. Standard, valid, generic, non-confidential, and public power flow and stability models (variable generation) are needed and must be developed, enabling planners to maintain bulk power system reliability.

   1.2. Consistent and accurate methods are needed to calculate capacity values attributable to variable generation.

   1.3. Interconnection procedures and standards should be enhanced to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response and must be applied in a consistent manner to all generation technologies.

   1.4. Resource adequacy and transmission planning approaches must consider needed system flexibility to accommodate the characteristics of variable resources as part of bulk power 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 influence bulk power system reliability and should be considered in planning studies.

   1.6. Probabilistic planning techniques and approaches are needed to ensure that bulk power system designs maintain bulk power system reliability.

   1.7. Existing bulk power system voltage ride-through performance requirements and distribution system anti-islanding voltage drop-out requirements of IEEE Standard 1547 must be reconciled.

   1.8. Variable distributed resources can have a significant impact on system operation and must be considered and included in power system planning studies.

2. **Operators will require new tools and practices, as well as, enhanced NERC Standards to maintain bulk power system reliability (NERC's Operating Committee)**

   2.1. Forecasting techniques must be incorporated into day-to-day operational planning and real-time operations routines/practices including unit commitment and dispatch.

   2.2. Balancing areas must have sufficient communications for monitoring and sending dispatch instructions to variable resources.

   2.3. Impact of securing ancillary services through larger balancing areas or participation in wider-area balancing management on bulk power system reliability must be investigated.

   2.4. Operating practices, procedures and tools will need to be enhanced and modified.

3. **Planners and operators would benefit from a reference manual which describes the changes required to plan and operate the bulk power and distribution systems to accommodate large amounts of variable generation.**

   3.1. NERC should prepare a reference manual to educate bulk power and distribution system planners and operators on reliable integration of 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 NERC's Planning and Operating Committees (PC/OC) including the suggested lead organization for each assignment. The PC/OC will make the ultimate decision on the appropriate groups and assignments respecting these recommendations.

1. **Power system planners must account for the impacts of variable generation on power system planning and design and develop the necessary practices and methods to maintain long-term bulk power system reliability (NERC's Planning Committee)**

   The primary goal of this effort 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 approaches, study of distributed resources, impacts of integrating large amounts of storage and demand response, and wind plant modeling requirements.

1.1. Standard, valid, generic, non-confidential, and public power flow and stability models (variable generation) are needed and must be developed, enabling planners to maintain bulk power system reliability

IVGTF – Planning sub-group	Start Date: 2nd Qtr. 2009	End Date: 4th Qtr. 2010

Review the Modeling, Data and Analysis Standards[96] (MOD) for improvements required to support simulation of power system with high amounts of variable generation.

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

1.2. Consistent and accurate methods are needed to calculate capacity values attributable to variable generation.

Reliability Assessment Subcommittee	Start Date: 2nd Qtr. 2009	End Date: 4th Qtr. 2010

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, estimating resource contribution using historical data.
- Probabilistic planning techniques and approaches needed to support study of bulk power system designs to accommodate large amounts of variable generation.

1.3. Interconnection procedures and standards should be enhanced to address voltage and frequency ride-through, reactive and real power control, frequency and inertial response and must be applied in a consistent manner to all generation technologies.

IVGTF – Planning sub-group	Start Date: 2nd Qtr. 2009	End Date: 4th Qtr. 2010

Review NERC's Facilities Design, Connections, and Maintenance (FAC) Standard FAC-001-0[97] to ensure that the following are addressed:

- Establish appropriate interconnection procedures and standards.
- Ensure adequate communications considering COM-002-2[98] and registry criteria.

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

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

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

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

Resource Issues Subcommittee	Start Date: 2nd Qtr. 2009	End Date: 4th Qtr. 2010

- Study resource and transmission planning process changes required to include variable generation characteristics such as ramping, fuel mix, minimum generation levels, shorter scheduling intervals, etc.
- Identify data requirements to support resource adequacy assessment and which NERC entities should collect, retain and provide this data.

1.5. Integration of large amounts of plug-in hybrid electric vehicles, storage and demand response programs may provide additional resource flexibility and influence bulk power system reliability and should be considered in planning studies

IVGTF – Planning Sub-Group	Start Date: 2nd Qtr. 2009	End Date: 3rd Qtr. 2010

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. Probabilistic planning techniques and approaches are needed to ensure that system designs maintain bulk power system reliability.

IVGTF – Planning Sub-Group	Start Date: 2nd Qtr. 2009	End Date: 3rd Qtr. 2010

Define probabilistic techniques/criteria that can be used with variable generation and produce a handbook on study methods for system planning.

1.7. Existing bulk power system voltage ride-through performance requirements and distribution system anti-islanding voltage drop-out requirements of IEEE Standard 1547 must be reconciled.

IVGTF – Planning Sub-Group	Start Date: 2nd Qtr. 2009	End Date: 4th Qtr. 2010

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" in order to reconcile voltage ride-through requirements for distributed resources and IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems.

1.8. Variable distributed resources can have a significant impact on system operation and must be considered and included in power system planning studies.

IVGTF – Planning Sub-Group	Start Date: 1st Qtr. 2010	End Date: 2nd Qtr. 2011

Study the impact of distributed variable generation on bulk power system reliability. The task force should make recommendations regarding recognizing owners and operators of distributed generation in the NERC Functional Model.

2. Operators will require new tools and practices, including enhanced NERC Standards to maintain bulk power system reliability (NERC's Operating Committee)

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 enhancement requirements, balancing area capability/size, and Standards/Criteria required to maintain bulk power system reliability.

2.1. Forecasting techniques must be incorporated into day-to-day operational planning and real-time operations routines/practices including unit commitment and dispatch

IVGTF – Operations Sub-Group	Start Date: 2nd Qtr. 2009	End Date: 2nd Qtr. 2010

Study variable resource-forecast tool requirements suitable for large amounts of variable generation and identify any gaps.

2.2. Balancing areas must have sufficient communications for monitoring and sending dispatch instructions to variable resources.

IVGTF – Operations Sub-Group	Start Date: 2nd Qtr. 2009	End Date: 1st Qtr. 2010

Review NERC's Facilities Design, Connections, and Maintenance (FAC) Standard FAC-001-0 to ensure that the following are addressed:

- Establish accurate variable resource forecast requirements.
- Establish appropriate interconnection procedures and standards.
- Ensure adequate communications considering COM-002-2 and registry criteria.

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

2.3. Impact of securing ancillary services through larger balancing areas or participation in wider-area balancing management on bulk power system reliability must be investigated.

IVGTF – Operations Sub-Group	Start Date: 2nd Qtr. 2009	End Date: 1st Qtr. 2010

Study the influence on bulk power system reliability of enlarging balancing areas. ACE sharing and/or shorter scheduling intervals between and within areas should also be investigated. Existing and proposed NERC Standards (e.g. BAL), should be reviewed to determine their sufficiency.

2.4. Operating practices, procedures and tools will need to be enhanced and modified.

IVGTF – Operations Sub-Group	Start Date: 1st Qtr. 2010	End Date: 2nd Qtr. 2011

Study the need for operational planning and operations practices, procedures and tools compared to existing applications. Recommend needed enhancements.

3. **Planners and operators would benefit from a reference manual which describes the changes required to plan and operate the bulk power and distribution systems to accommodate large amounts of variable generation.**

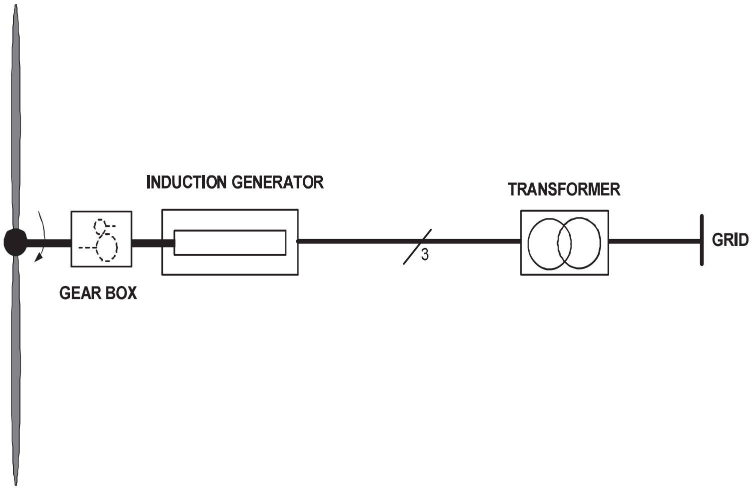
The goal of this effort is write a reference manual outlining the planning, design and operating considerations needed to integrate large amounts of variable generation.

3.1. Planners and operators would benefit from a reference manual which describes the changes required to plan and operate the bulk power and distribution systems to accommodate large amounts of variable generation

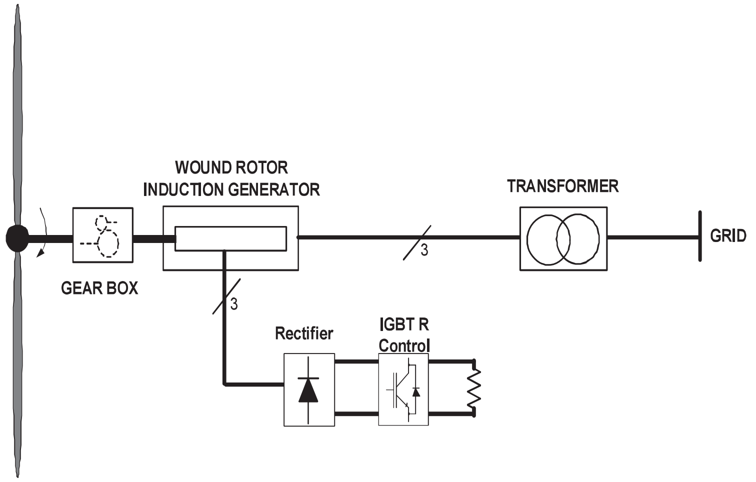
IVGTF	Start Date: 2nd Qtr. 2009	End Date: 1st Qtr. 2010

Develop a comprehensive reference manual useful for bulk power and distribution system planners and operators based on materials gathered in the preparation of this report.

Appendix II: 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 [99]

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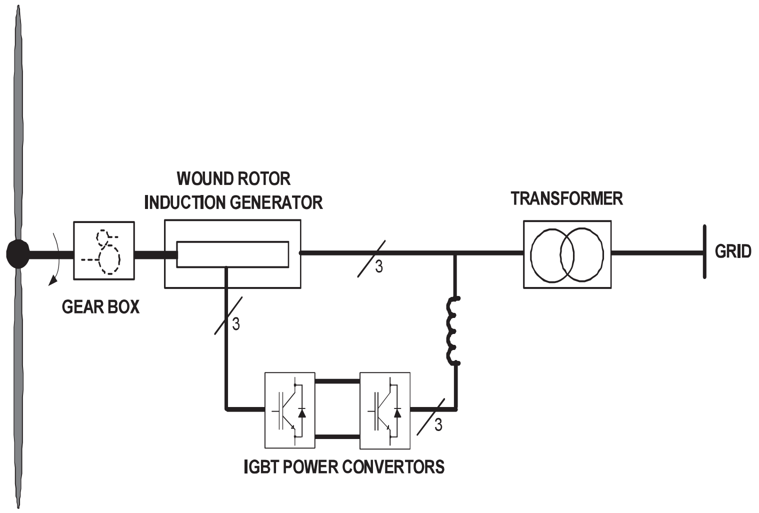
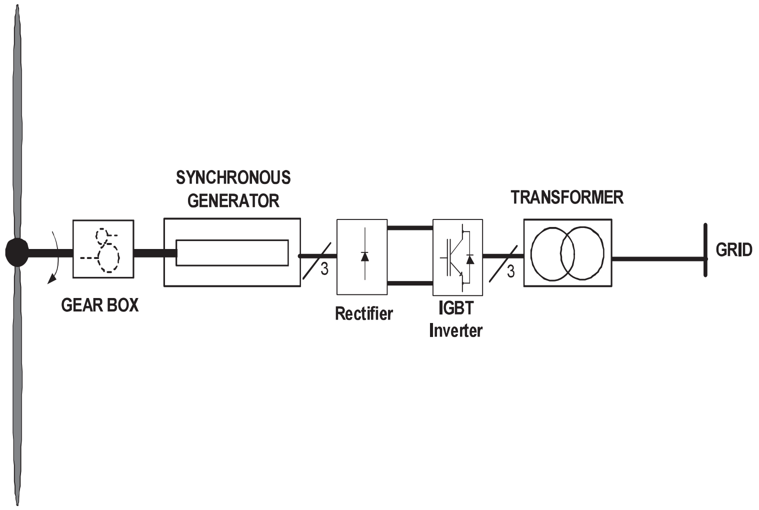
[99] IBGT R control= Isolated Gate Bi-Polar Transistor controlled by Resistor



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



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

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

DFG - 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

IVGTF – Integration of Variable Generation Task Force

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

DOE – U.S. Department of Energy

PHEV – Plug-in Hybrid Electric Vehicle

PV – Photovoltaic

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

PMU – Phasor Measurement Unit

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

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

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Further Reading

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