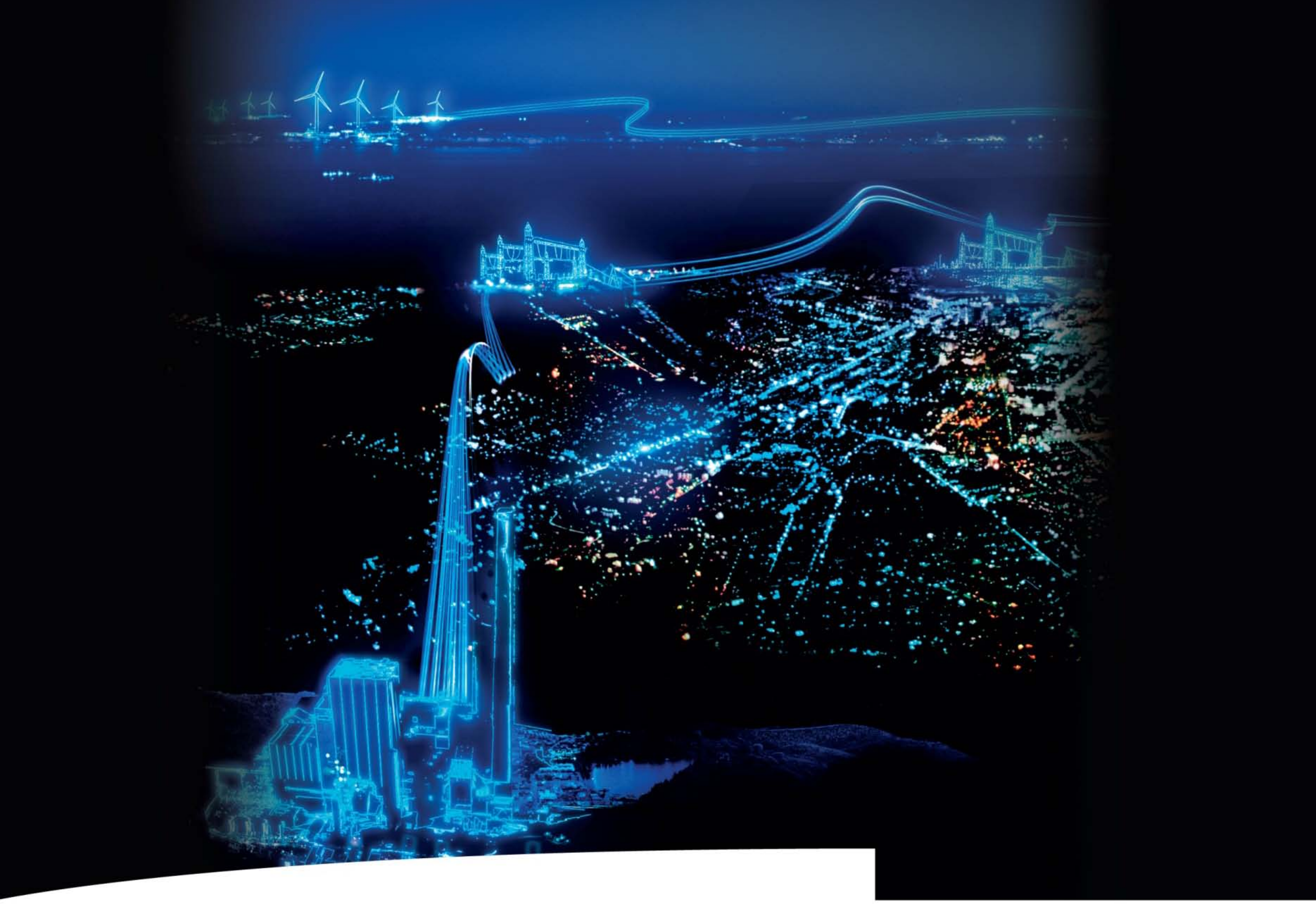

Strategies and Decision Support Systems for Integrating Variable Energy Resources in Control Centers for Reliable Grid Operations

Global Best Practices, Examples of Excellence and Lessons Learned

Executive Summary

Lawrence E. Jones

NOTICE

The submitted manuscript has been offered by an employee of Alstom Grid Inc., a subcontractor of the U.S. Government under Award Number DE-EE0001375.

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FOREWORD

A variety of studies have recently evaluated the opportunities for the large-scale integration of wind energy into the U.S. power system. These studies have included, but are not limited to, “20 Percent Wind Energy by 2030: Increasing Wind Energy’s Contribution to U.S. Electricity Supply”, the “Western Wind and Solar Integration Study”, and the “Eastern Wind Integration and Transmission Study.” Each of these U.S. based studies have evaluated a variety of activities that can be undertaken by utilities to help integrate wind energy.

The integration of wind energy into the power grid introduces additional variability and uncertainty into grid operations beyond that created by system load. It has been said by some in the utility industry that the integration of large amounts of wind energy into the power grid requires a paradigm shift in how the grid is operated. The following report provides an evaluation of how system operations worldwide are changing in response to increases in wind penetration. It provides unique insights into what has worked well, what has not, and how operators see the future of their responsibilities changing as we introduce more wind into the grid.

While there is no “silver bullet” solution to successful wind integration that applies to all power systems, experience from actual operators provides some of the most valuable feedback on how operations are changing, what tools are needed, and which actions are providing the most benefit. This report constitutes the first time grid operators from across the globe have provided consolidated feedback on how wind energy is affecting them and what concrete measures are being taken to manage the system in the face of the increased challenges posed by the increased variability and uncertainty presented by wind generation. The U.S. Department of Energy is pleased to support this project through the American Recovery and Reinvestment Act, to enable such valuable information to be provided to the utility industry as a whole.

Charlton Clark

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy

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Gathering research data and pulling together such a global sample of utilities for this project took the work of many dedicated individuals.

Utilities and their Representatives

This report would not have been possible without the participation and contribution of the utilities and personnel who dedicated time and resources to complete the lengthy questionnaire, and provided additional relevant information about their decision support tools, processes and procedures for managing wind energy in their control room. The important contribution of the following individuals and their companies is hereby acknowledged:[1]

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Ming Hu, John Kehler	Alberta Electric System Operator, Canada
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François Boulet, Joris Soens	CORESO, Belgium
Ivan Dudurych, Frank Groome, John O’Sullivan, Alan Rogers	Eirgrid, Ireland
Heidi Tinkerperi	ELERING OU, Estonia
Christophe Druet, Jean-Jacques Lambin	ELIA, Belgium
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Claudine D’Annunzio, John Dumas, Coleen Frosch, David Maggio	ERCOT, USA
Richard Candy, Rosalette Ungerer	ESKOM, South Africa
Lisa Dangelmaier	Hawaii Electric Company, USA
Alain Forcione, Richard Mailhot, André Robitaille	Hydro Quebec, Canada

[1] The list is sorted based on the first character of the utility’s name, beginning with numbers and followed by characters. The corresponding list of individuals is sorted based on the first letter of the last name of each person.
[2] Previously employed by 50Hertz.

Rich Bauer	Idaho Power, USA
Bill Henson, John Norden	ISO New England, USA
Kim Hung-Sak	Korea Power Exchange, Korea
David Jacobson	Manitoba Hydro, Canada
Agnes Gerse	MAVIR, Hungary
Todd Hillman, Marc Keyser	Midwest ISO, USA
Dave Daley, George Porter	New Brunswick System Operator, Canada
David Edelson, Allen Hargrave, Emilie Nelson, John Ravalli	New York ISO, USA
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Doug Faulkner, Irena Netik	Puget Sound Energy, USA
José-Luis Mata, Pablo Martin Muñoz, Miguel de la Torre	Red Eléctrica de España, Spain
Rui Pestana	Rede Eléctrica Nacional, S.A., Portugal
Magali Glachant, Emmanuel Neau	RTE, France
Lanny Nickel, Geraldo Ugalde	Southwest Power Pool, USA
Jiang Liping, Li Qonghui	State Grid Corporation of China, China
Maria Antonietta Sidoni	TERNA SpA, Italy
Ajay N. Mahyaraj,[3] Paul Oxley	Transend Networks, Australia
Doug Goodwin	Transpower, New Zealand

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Eric King, Bart McManus, Jodi Obradovich[4]	Bonneville Power Administration, USA
Jens Møller Birkabæk, Henning S. Christensen, Thomas Krogh	Energinet, Denmark

[3] Ajay N. Maharaj was employed by Transend Networks when the survey was conducted. In September 2010 he joined the Power and Water Corporation in Darwin, Northern Territory, Australia.
[4] Jodi Obradovich is employed by Pacific Northwest National Laboratory (PNNL) but was working on a project at BPA at the time of the visit.

Jon O'Sullivan — Eirgrid, Ireland

Claudine D'Annunzio, John Dumas, Coleen Frosch, David Maggio — ERCOT, USA

David Edelson, Allen Hargrave, Emilie Nelson, John Ravalli — New York ISO, USA

José-Luis Mata, Pablo Martin Muñoz, Miguel de la Torre — Red Eléctrica de España, Spain

These individuals participated in, on average, five hour interviews during which they and several of their colleagues generously shared their expertise and lessons learned in integrating wind energy into utility control center and grid operation. Their perspectives and the support from their organizations made it possible to correlate the best practices identified to the questionnaire findings.

Industry Advisory Committee

Thanks to the members of the voluntary Industry Advisory Committee (IAC) for their input to the development of the questionnaire, review of draft versions of this report and their insights on various aspects of the project:

Mark Ahlstrom — WindLogics, USA

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John Dumas — ERCOT, USA

Brendan Kirby — Energy Consultant, USA

J. Charles Smith — Utility Wind Integration Group, USA

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EXECUTIVE SUMMARY

ES.1 Introduction

Electricity generated from variable energy resources (VER), with wind being the leading source, is developing rapidly worldwide—and is only expected to increase further. The stats say it all: about 194.4 gigawatts (GW) of installed wind capacity worldwide was operable at the end of 2010, a 22% increase compared to 2009. The U.S. alone accounts for more than 40 GW of total installed capacity. In its landmark 2008 report *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, the U.S. Department of Energy (DOE) examined a scenario and found it feasible that wind power can contribute 20% to the U.S. electricity supply by 2030 if challenges identified in that report are addressed.

Nevertheless, effectively integrating a large amount of wind energy into current and future power grids is still a prominent issue for grid operators, regulators and the electricity industry today. In response to DOE's solicitation for proposals that address the potential challenges and solutions to realizing a scenario of "20% Wind Energy by 2030," researchers at Alstom Grid Inc. endeavored to investigate and identify the best ways in which to guide operational strategies, business processes and control room tools that support this overall objective.

To accomplish this, the Alstom Grid Inc. investigators surveyed 33 operators of electric power systems in 18 countries about wind integration, their operating policies, best practices, examples of excellence, lessons learned and decision support tools now in place. The power systems represented in this report have different network topologies, mix generation and load profiles, and a range of penetration levels of wind generation. Further, the combined amount of wind power capacity referenced in this report is 141 GW or 72% of the total installed capacity in the world. The power grids are located in varying geographies with diverse weather regimes and many of the utilities surveyed operate under dissimilar regulatory frameworks, and in regulated or deregulated electricity markets.

The power grids represented in this report have a combined total of 141GW of installed wind capacity or 72% of the installed wind capacity in the world.

Garnering participation from these worldwide utilities with high penetration levels of wind generation was crucial to meeting the research project's objectives. Having a unique and diverse set of respondents was also a prerequisite when gathering insights about wind integration practices. Figure 1 shows the total installed wind capacity of several countries and regions represented by utilities that participated in the survey.

As noted above, special emphasis was placed on how these utilities incorporate wind forecast information into operating policies, strategies, processes and decision support tools which dispatchers use in the daily operations of electric power grids. The current approach of electric utility control centers and ways in which these tactics have evolved are reflected in the findings. The survey also focuses on those control centers that have experienced fast rates of wind penetration in the past decade.

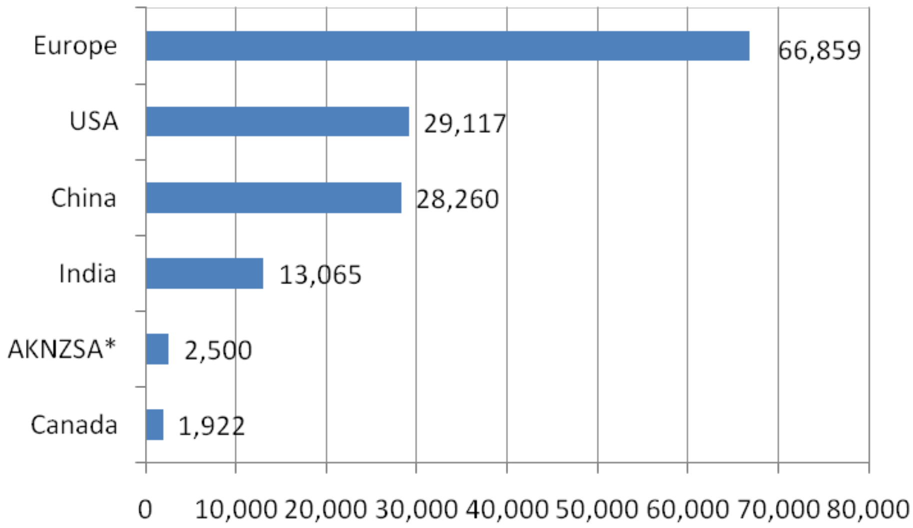

Figure 1. Distribution of Installed Wind Capacity (MW) in the Survey by Regions & Countries[6]

This report provides utilities with recommendations and examples of success stories aimed at informing the design of decision support tools, solutions and strategies for integrating more wind energy into their own power systems. The findings help to increase the industry-wide understanding of the operational impacts of wind integration and how wind power forecast is being used today. The identified practices from a broad group of utilities can be a foundation to fast-tracking the training of dispatchers. This report could also inform the formulation of regulatory policies for wind energy, as well as aid in the establishment of future operating procedures and practices for managing wind integration in the control room environment.

This willingness to consider what others have done and share operational success stories was clearly demonstrated by the respondents, considering the amount of time they allowed their staff to spend completing the questionnaire, as well as the quality and level of details provided. This project clearly indicated that more utilities are interested and open to using industry best practices and examples of excellence from their peers as the starting point for developing and deploying their own solutions.

[6] AKNZSA is short for Australia, Korea, New Zealand and South Africa.

ES.2 Methodology

Three complementary methods were used in the study: a questionnaire was developed, grid operators control centers were visited and a survey of existing literature was conducted.

In the first method, questions were grouped under one of the following seven categories: organizational; wind forecasting; integration of wind forecast; decision support systems and tools; processes and procedures; wind energy information; and training. Thirty-four out of more than sixty utility companies responded to the survey.

On-site visits to control centers of three grid operators in the U.S. and three in Europe comprised the second method of gathering information. The utilities visited in the U.S. were Bonneville Power Administration (BPA), Electric Reliability Council of Texas (ERCOT), and the New York Independent System Operator (NYISO). The European grid operators visited were Eirgrid, Ireland; Energinet, Denmark; and Red Eléctrica España (REE), Spain. The visits allowed the investigators to further explore some of the survey questions through in-depth interviews of operators and other control center personnel, as well as to see first-hand successful implementation of decision support tools and processes that demonstrate examples of excellence.

Grid operators who were not visited are also featured in this report. They have demonstrated exemplary efforts in their successful deployment of software systems and tools, as well as processes to support wind integration in control centers. They are 50Hertz Transmission GmbH in Germany, Alberta Electric System Operator (AESO) in Canada and RTE in France.

The third method in the study incorporated a survey of existing literature about tools, processes and procedures that utilities around the world have deployed to support the integration of wind, solar and other variable energy resources in general. This report presents the first-known research based on such a global sampling of grid operators.

Participants in the Survey

33 grid operators from 18 countries, which include:

12 European Transmission Systems Operators

9 members of the Association of Very Large Power Grid Operators

6 U.S. Regional Transmission Organizations/Independent System Operators

4 U.S. Transmission Utilities

4 Canadian Transmission System Operators

3 German Transmission System Operators

2 Australian Transmission System Operators

1 Transmission System Operator from China, India, Korea, New Zealand and South Africa, respectively

1 European Power Grid Monitoring and Coordination company

ES.3 Wind Penetration Levels

The challenges, issues, costs and other factors associated with integrating wind generation are closely related to the penetration level of wind power in a given system. A penetration level commonly used is the Wind Generation Penetration Level (WGPL), defined as the ratio of the total installed wind power capacity to the total installed generation in the system. Figure 2 shows a list of the survey respondents who represent systems that range from the highest wind generation penetration levels to the lowest. This diverse sampling of system operators captures a broad set of perspectives and experiences, as well as some common themes.

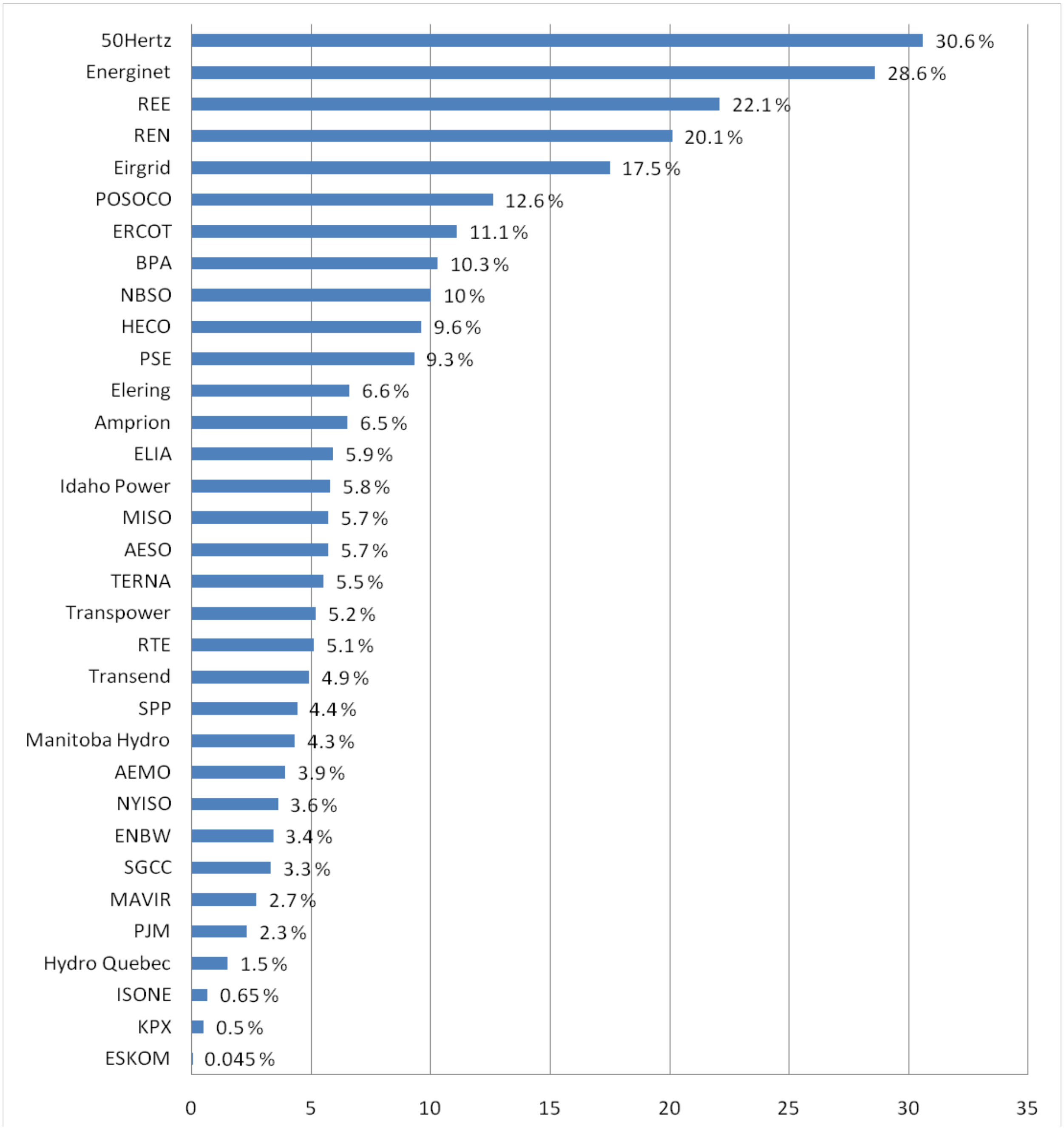

Figure 2. Wind Generation Penetration Level (%)

ES.4 Nine Current Best Practice Tools and Decision Support Systems

This report identifies and describes nine current best practice tools and decision support systems grid operators in the U.S. and Europe use to integrate and manage wind energy, and in several cases, solar energy as well. The tools are:

- Dispatch Decision Support Tool (DDST) at the Alberta Electric System Operator, Canada
- Integrated Curtailment and Re-Dispatch System (iCRS) at the Bonneville Power Administration, USA
- Wind Security Assessment Tool (WSAT) at Eirgrid, Ireland
- Nordic Operational Information System (NOIS) at Energinet, Denmark
- Drift Planlægnings System at Energinet, Denmark
- Ercot Large Ramp Alert System (ELRAS) at the Electric Reliability Council of Texas, USA
- Generación Eólica Máxima Admisible en el Sistema (GEMAS) at Red Eléctric de España, Spain
- Centro de Control de Régimen Especial (CECRE) at Red Eléctric de España, Spain
- Insertion de la Production Eolienne dans le Système (IPES) at RTE, France

Current and emerging best practices are discussed in the report. The best practices are put under six different categories: tools, data, situational awareness, training, wind power forecasting and processes/procedures.

This collection of practices is an excellent starting point to further expand the general requirements for the development of new or enhancement of existing tools for wind integration. While certain aspects of these practices have been identified, it is important to note that the survey responses reflect the current views of the grid operators in an otherwise very dynamic and changing environment. The practices therefore offer important guidance in helping grid operators, policymakers and other industry stakeholders determine how to proceed with integrating high levels of wind energy. Application of these best practices must always be examined in the proper context. This examination should consider the differences in the power system and the electricity market within which it operates.

ES.5 Highlights of Some of the Key Findings

ES.5.1 Wind Power Forecasting

Wind power forecast is the most important pre-requisite for successfully integrating wind energy into power systems. Predictability of wind plant output is the key to managing uncertainty. The accuracy or error of the wind forecast is of paramount concern for a grid operator. The error affects the level of confidence that operators place in the data, how it may be integrated or not, and how it is used in the control room.

94% of grid operators say that integrating a significant amount of wind will largely depend on the accuracy of the wind power forecast

ES.5.2 Centralized wind forecasting program is best for reliable grid operations

A broad agreement among operators exists today that, in order to effectively integrate wind energy into power system operations, centralized forecasting is the current best approach for reliably operating power grids with wind generation. Therefore, grid operators around the world are acquiring centralized wind forecasting systems and services. Eighty percent of respondents in this study have implemented some form of centralized wind forecasting system or are in the process of putting one in place. A few grid operators still rely on decentralized wind power forecasting, but even in those cases, a transition to the centralized approach seems inevitable. Since completing the survey, important new developments at one U.S. operator of a regional grid and electricity market have emerged that suggest a move towards a hybrid approach, comprised of both centralized and decentralized forecasting. The hybrid approach is currently the subject of preliminary discussions in other North American regions with electricity markets.

ES.5.3 Wind Forecasting Products

For many grid operators, Day-Ahead (DA) forecast has been the focus of much research attention. Tremendous improvements have been made to reduce the DA forecasting errors. However, as grid operators and researchers learn more about wind variability and the operational impacts of wind in different timescales, efforts are underway to continuously improve the accuracy and use of other forecast products. Figure 3, below, depicts how respondents rank the importance of several forecasting products in control room real-time operations. Two of the most highly-ranked products, ramp and ensemble forecasting, receive special attention in this report, based on additional interviews with respondents and the results from the survey literature.

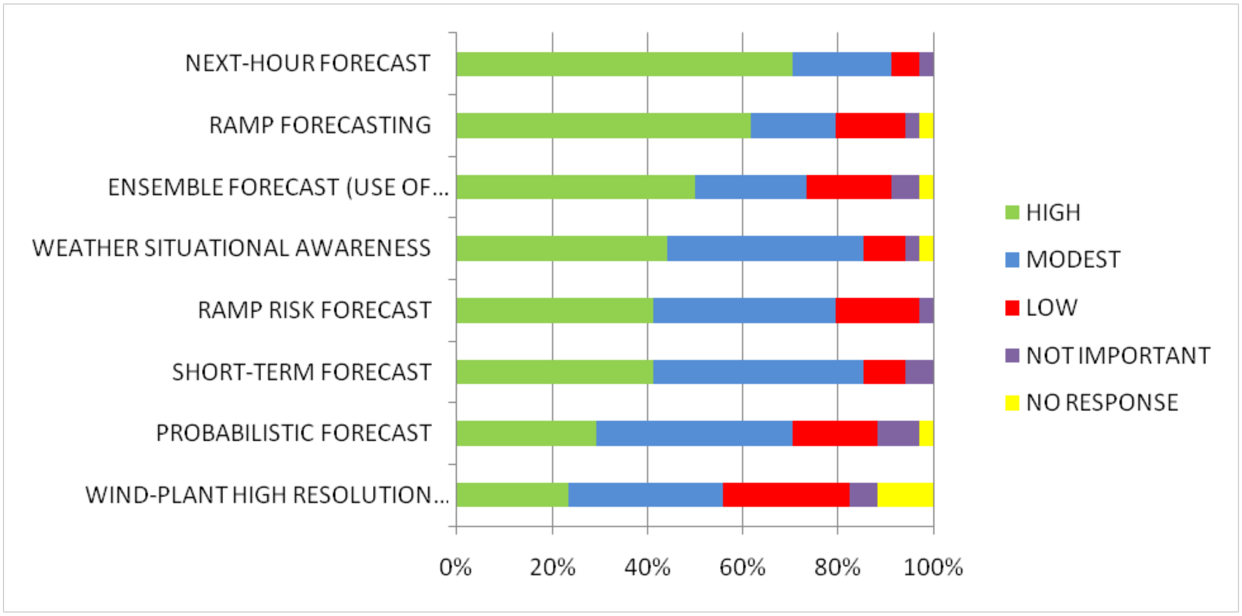

Figure 3. Importance of Wind Forecasting Products in Control Rooms

ES.5.4 Decision Support Systems and Operational Processes

In recent years, utilities in the U.S. and other parts of the world developed varying levels of expertise and knowledge in how to operate power grids with increasing amounts of wind power generation. While there may not be any insurmountable technical barrier to reaching the 20% wind energy by 2030 scenario described in the DOE report, the findings in this report suggest that such a scenario cannot be fully achieved without knowledgeable grid operators in control rooms equipped with the necessary decision support tools. Grid operators must be presented with accurate wind power forecast information in a useful and meaningful way. Ninety-four percent of respondents say that integrating wind energy will depend on the tools in the control room which is the nerve center for operating power systems. More and more grid operators no longer passively plan for high penetration of wind generation on their system. Rather, operators today already are at different stages in the deployment of decision support tools necessary to successfully integrate wind energy.

> *94% of grid operators agree or strongly agree that integrating wind energy depends on decision support tools in the control room*

The report addresses issues under the current operating conditions of utilities, but also ventures to anticipate conditions that could emerge as a result of meeting the 20% energy by 2030 scenario. It envisions different scenarios that could affect how control centers might look in the future, and the various decision support tools needed now or that will be available in the future.

ES.5.5 Integration of Wind Forecast in Decision Support Systems

With wind generation increasing in power systems, it is important to integrate wind forecast information with the strategies and decision support systems used in control room operations. The survey analysis highlights the different applications and processes that, when incorporated with wind power forecasts, are perceived to have the most value for integrating wind energy. Several grid operators are already implementing changes to the tools in their control rooms to cope with wind generation or they have plans to do so. Figure 4 shows the extent to which respondents have integrated wind forecast in different processes and tools, used in real-time operations.

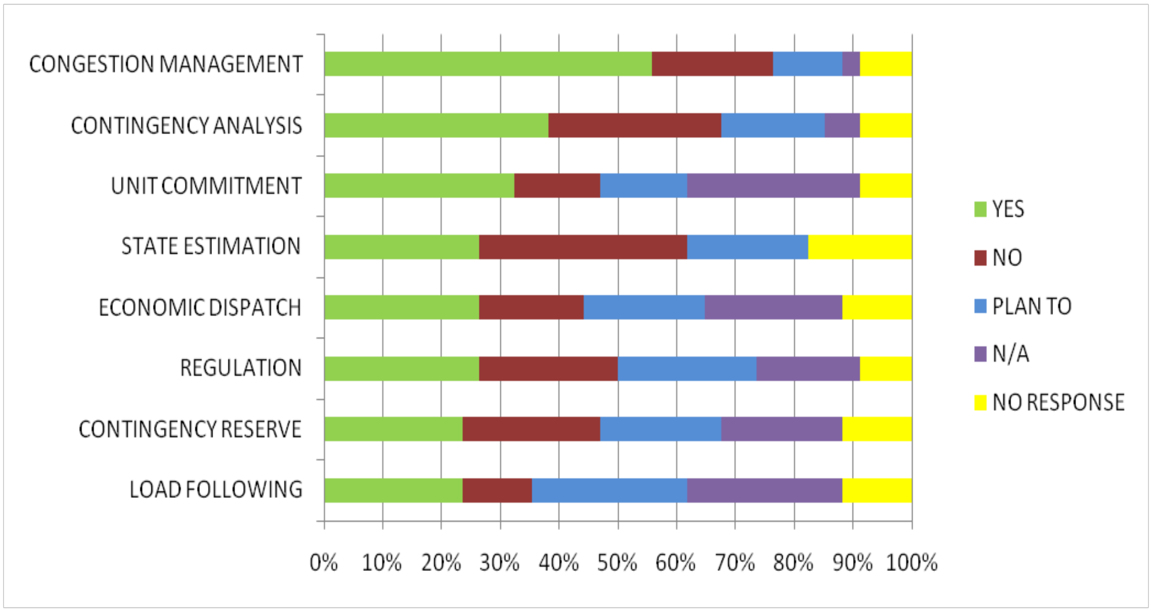

Figure 4. Integration of Wind Forecasts in Real-Time Applications and Processes

Congestion management is one of the most important functions of the grid operator. Higher penetration of wind power in the grid can introduce new patterns in the flow of power in the transmission and distribution networks. These unexpected flows could overload some transmission lines, causing new operational limits and congestion in the system. About 55% of the respondents have integrated wind forecast in their software tools or processes to manage congestion. Large RTOs/ISOs and TSOs that are interconnected to neighboring utilities were included in this percentage.

Twenty-five percent or more of all the respondents have incorporated wind forecast in real-time applications and processes for managing voltage stability, unit commitment (UC), state estimation (SE), regulation, load following, economic dispatch (ED), contingency reserves and contingency analysis (CA). SE, ED, CA, regulation and load following are implemented as part of the Energy Management System (EMS) in control centers. In most cases, UC and contingency reserve calculation are also integrated with the EMS. Yet, the extent to which wind power forecast has been integrated with these EMS applications varies.

ES.5.6 Advanced Decision Support Tools for Wind Integration

The North American Electric Reliability Corporation (NERC) identified new "advanced decision support tools" that are important to managing grids with large amounts of energy from wind and other VERs. The ranking of respondents' perception of the value of several tools in terms of supporting integration of wind power is shown in Figure 5.

Some of the respondents are currently implementing several tools. However, this snapshot of the perceived value of these applications in the industry is expected to change as grid operators gain more knowledge and experience about these tools.

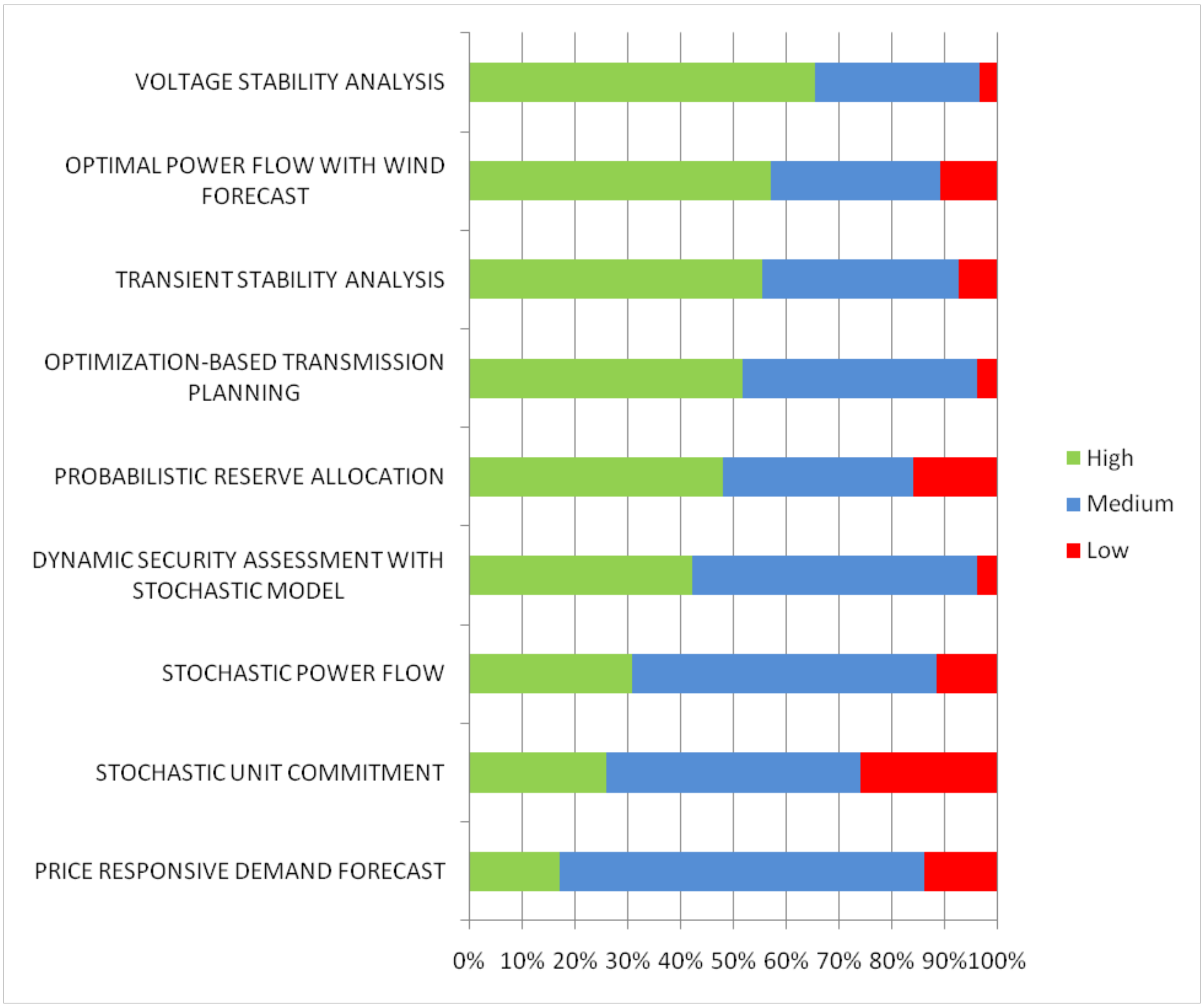

Figure 5. Ranking of Advanced Decision Support Tools to Support Wind Integration

ES.5.7 Changes in Operational Processes and Tools

Integrating wind generation could require changes in the physical grid (e.g., building more transmission), changes in operational business processes, and changes in information technology solutions that support the operators in the control room. The three most highly rated changes that need to be made are: more accurate wind forecasting; more flexible conventional generation; and building more transmission. See Figure 6.

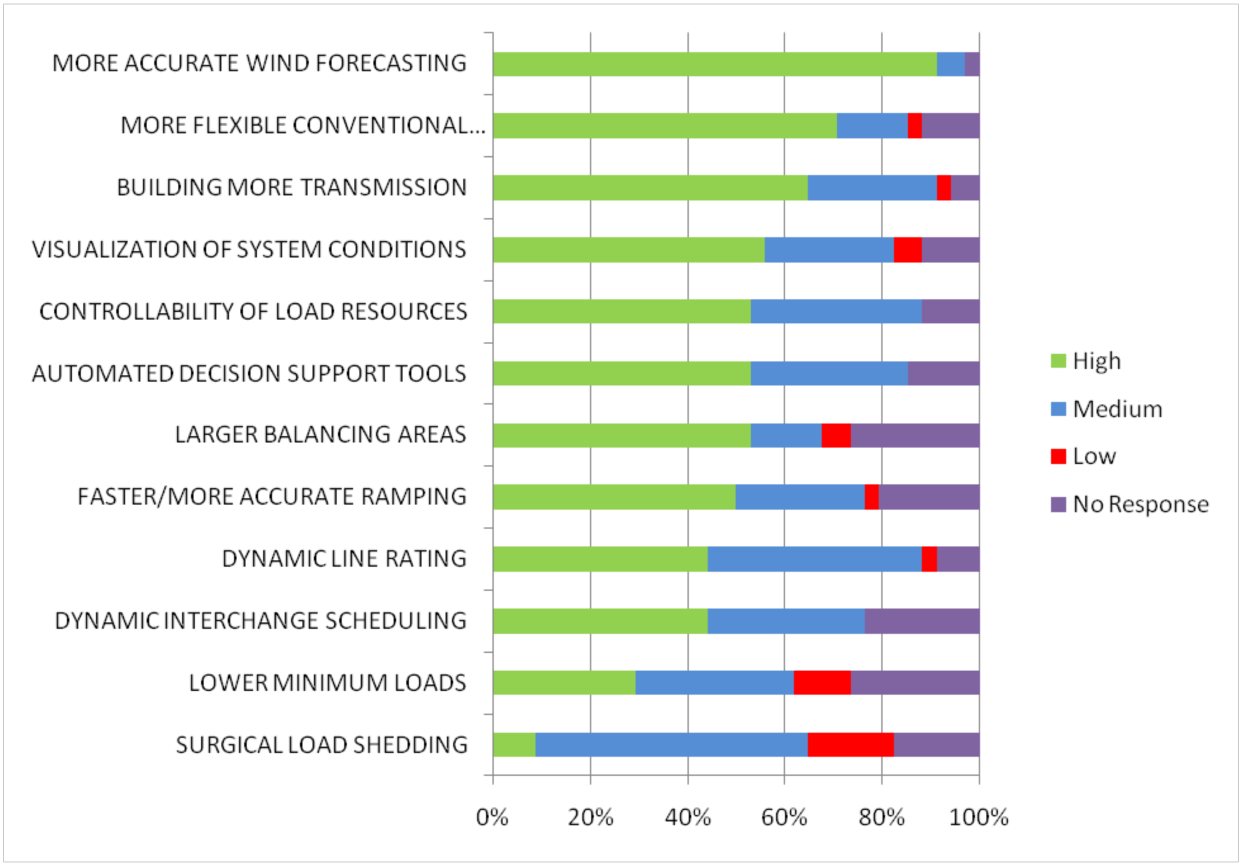

Figure 6. Value Rating of Grid Operational Changes for Large-Scale Integration of Wind Power

Some of these changes require new electricity regulation and market protocols (e.g., more flexible conventional generation, larger balancing areas, dynamic interchange scheduling, controllability of load resources, surgical load shedding). Others may need local or national policy measures (e.g., building new transmission), which might take longer to implement. Yet, grid operators can implement some changes in the short-term (e.g., more accurate wind forecasting, automated decision support tools, visualizations of system conditions).

ES.5.8 Policies and Standards Affect Wind Energy Integration in the Control Room Operations

Grid reliability standards and regulatory policies as well as the laws enacted at the local, state, regional, national and multi-national levels can affect the integration of wind generation in the control room. Seventy-nine percent of respondents agree or strongly agree that integrating a significant amount of wind generation will largely depend on the operating policies deployed to support operators in the control room. See Figure 7. Respondents who are in agreement with various policy statements have high wind penetration levels, while most of those who did not agree have low penetration of installed capacity.

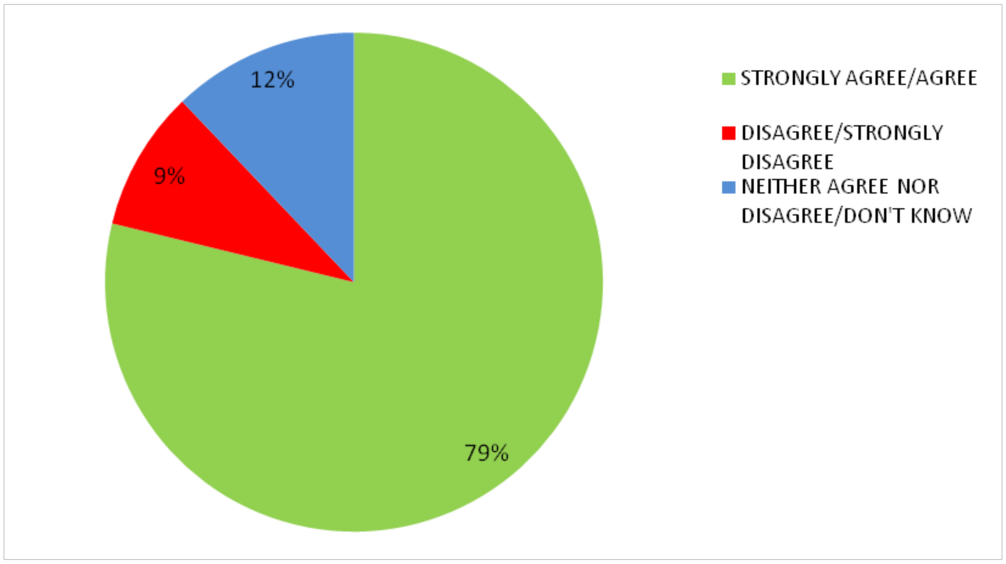

Figure 7. Large-Scale Wind Integration will Depend on the Operating Policies Deployed in Control Rooms

The key policy areas identified for wind integration, which will impact the tools, processes and procedures in the control room include:

- Design effective rules and protocols for electricity markets.
- Greater coupling and harmonization between national and regional electricity markets (e.g., reserve sharing and transmission scheduling).
- Congestion management.
- Standard grid code and interconnection guidelines.
- Standard data requirements for wind plants.
- National initiatives to improve weather service models.

ES.5.9 Impact of Smart Grid Technologies on Wind Integration

Governments, policy makers, regulators, utilities and other stakeholder groups are proposing "smart grids worldwide." Smart grid technologies improve the flexibility of power systems by increasing the accuracy of observation and boosting controllability, and maneuverability of certain loads, generation and storage resources, etc. From the view of the control room environment, Figure 8 shows the percentage of grid operators who have implemented or plan to implement several smart grid applications.

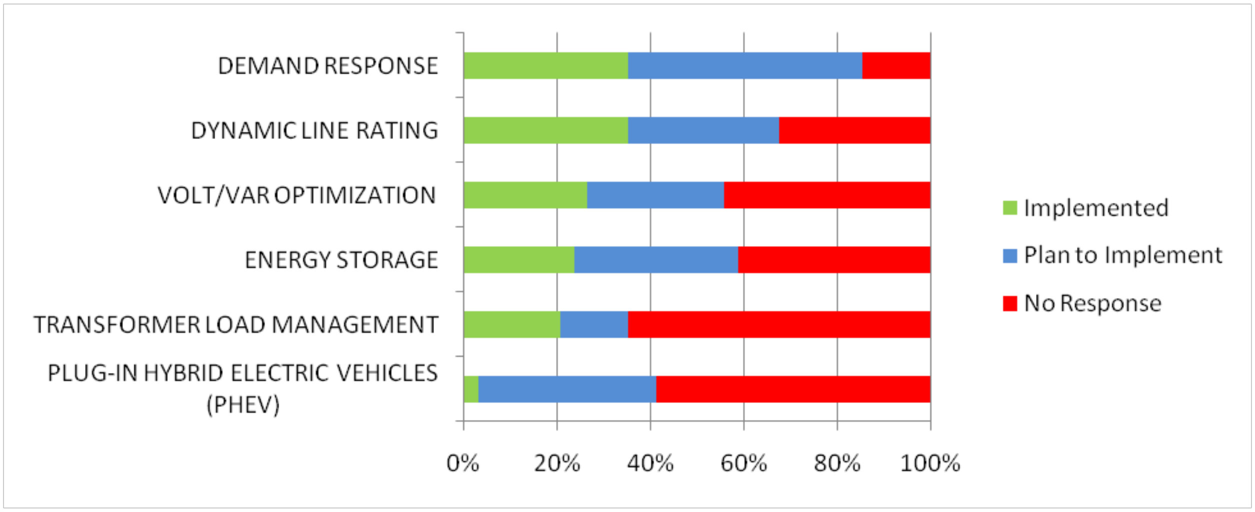

Figure 8. Smart Grid Applications Currently Implemented or Will Be Implemented

ES.5.10 Wind Power and Situation Awareness in Control Centers

A key finding from the questionnaire results and the visits to utilities is the importance of tools that help operators maintain situation awareness (SA) in the control rooms as more wind generation is connected to the grid. Focus is increasing on a new operating paradigm that is more predictive and proactive and less reactive. This is emerging in the control center as a result of greater variability and uncertainty in the power system.

ES.5.11 Look – Ahead and Predictive Solutions in the Control Room will Enhance Situation Awareness

Operational risk management will clearly require applications that allow operators to look ahead and assess the next system conditions before they occur. This ability to project into the future will certainly improve SA. Based on respondents' feedback, more wind power on the system is also expected to hasten the development of a third generation of control center applications, which are needed to support predictive and look-ahead operations.

ES.6 Recommendations

Three categories of recommendations are provided. They are: *Short Term*, *Medium Term*, and *Research*.

- *Short Term:* "Low hanging fruit" actions utilities can implement to successfully integrate wind energy into control rooms. They are not dependent on new regulatory or policy measures, additional research or other catalyst activities.
- *Medium Term:* Recommendations that depend on new regulatory and public policy measures, or that require additional technology development and demonstration before implementation can proceed.
- *Research*: These activities require more basic or advanced research with the support of public-private partnerships, and through collaboration between industry, national laboratories and academia.

ES.6.1 Short Term Recommendations

- **Centralized Forecast –** Implement a centralized wind power forecasting program.
- **Multiple Forecasting Providers –** Use ensemble forecasting which combines wind power forecast from several third-party forecasting providers.
- **Visualization of Wind Power Forecast –** Develop displays that allow operators to compare actual wind generation with wind power forecast data. Also, build displays to monitor net load across the system (i.e., load minus wind) in real-time.
- **Integration of Wind Power Forecast –** Enhance the EMS and other control room decision support tools incorporating wind power forecast data. The nine best practice tools presented in this report is an excellent starting point for defining initial functional requirements.
- **Rapid Update of Wind Power Forecast –** Provide rapid and more frequent updates of wind power information to control room operators and the applications they utilize. This will reduce the degree of uncertainty impacting real-time decision making.
- **Reserve Monitoring –** Implement a tool to monitor operating reserves.
- **Control Room Improvements –** Deploy new visualization tools and other decision support capabilities to enhance situational awareness in control rooms.
- **Look-Ahead and Predictive Operation –** Implement look-ahead and predictive operational capabilities in the control room. This can be accomplished by connecting the real-time production EMS with an ultra-fast dispatcher training simulator (DTS). The DTS includes replica models and algorithms of the real-time EMS. It must have the proper model of wind plants, such as a time series model with actual or simulated wind power forecast.
- **Change Management Process –** It is necessary to develop and follow a detailed change management process when integrating wind forecast in control rooms. For some operators and dispatchers, integrating wind can be a difficult cultural change. Successful integration of wind energy in the control room requires operators to be involved early in the process.
- **Wind Forecast Management –** Assign a dedicated team to manage the wind power forecast. As part of the activities, the team should, at a minimum, generate weekly and monthly performance reports including different forecast errors for the various wind forecasting products used.

- **Operator and Dispatcher Training –** Conduct training on how wind plants function and how wind forecasting can better support operational decision-making. Appropriate training tools for integrating wind power forecast will help operators develop a better understanding of how wind plants operate and how they can interact more effectively with the system. The training simulators should mimic the actual system and include representations of wind generation assets.
- **Industry Wide Training –** Federal and State governments, in partnership with utilities and other private sector parties, should invest in power engineering programs at universities and colleges, in addition to other forms of accelerated specialized training programs that produce the requisite number of engineers and technical workers to replace experienced technicians approaching retirement. More skilled engineers and technicians are needed to ensure a secure and reliable operation of the U.S. power grid infrastructure, which faces major challenges such as increased power generation from wind and other variable energy resources. Modernization of the nation's electricity delivery (transmission and distribution) system with smart grid technologies also will require new technical workers. Training of the workforce must start now, long before retirements begin draining control room expertise, in order to ensure a smooth transition and business continuity.
- **Information Dissemination –** Grid operators should develop a website portal to provide relevant wind and system information to key stakeholders such as wind plant operators, regulators and researchers. Examples of information that should be delivered via this portal include forecasted versus actual wind power generated on a system and regional level, and other performance metrics. Several utilities featured in this report have deployed web portals dedicated to wind generation.

ES.6.2 Medium Term Recommendations

- **Faster Electricity Markets –** New policies for operating power systems in market and non-market regions should be designed to support the frequent scheduling (e.g., sub-hourly) and dispatching of generation and transmission resources. These policies will facilitate better integration of wind generation.
- **Larger Electricity Markets –** Regulatory policies should be designed and implemented to support the development of multi-regional markets for ancillary services and reserves. This will foster a more flexible use of resources at both the local and global level.
- **More Transmission Capacity –** Inadequate transmission capacity is a key obstacle to integrating more wind energy into existing power grids. Grid operators in this survey cited the need to build transmission as one of the changes needed to increase the share of energy that comes from locationally-constrained wind resources. Federal and State regulatory policies should be enacted to accelerate the building of more transmission capacity. Regional transmission planning processes should be modified to accommodate alternative transmission solutions that support harnessing the huge potential of offshore wind resources in the U.S.
- **Dashboards in Control Rooms –** Increased uncertainty and variability in grid operations will require that new decision support systems be designed with Intelligent User Interfaces, in order to improve the communication between the operator and the computerized tools used in control rooms. By 2030, an avalanche of anticipated data, which operators must cope with, will require interfaces that can naturally be personalized and dynamic. Dynamic dashboard technologies will be needed to help operators develop higher levels of SA through the creation of new displays. These displays will be extracted from a geographic overview of a wide area, and will allow operators to zoom in and monitor an area with large wind plants and where extreme ramp events are predicted to occur.

- **Design Systems that Enhance Situational Awareness (SA) –** New control room tools should be designed to enhance SA. The requirements for achieving higher levels of SA must be taken into consideration during the design and not after.
- **Wind Event Warning System –** Develop a high wind event warning system in the control center, which will allow operators to visualize such events and take the steps necessary to protect the system.

ES.6.3 Research Recommendations

- **System Flexibility –** Develop more rigorous methods and tools to accurately quantify, monitor and assess the degree of flexibility in a given power system for a given level of wind power penetration. Collaboration between grid operators and the research community should foster such efforts.
- **Total Value of Wind Forecasting –** Conduct more research into how operational processes and procedures are affected as a result of using accurate wind power forecast. By doing so, operators can demonstrate the total value of the investments that should be made for continuous improvements in the performance of the wind forecasting system. Grid operators and commercial forecast providers should collaborate on these efforts.
- **Develop Tools to Make Better Use of Probabilistic Information –** While the operating conditions under which grid operators make decisions is clouded with varying degrees of uncertainty, the actual decision is deterministic and binary. To address the uncertainty related to wind forecasting, many researchers and power system practitioners suggest that probabilistic information be used. Research must consider how to best integrate probabilistic tools with conventional deterministic tools in the control room. More importantly, research also should examine how probabilistic information should be presented to system operators. Research also should be conducted on the use of stochastic methods for unit commitment, economic dispatch and other processes.
- **Risk-Based Decision Making –** With the onset of increased variability and uncertainty in power systems due to wind and other variable generation, the need to integrate a risk-based approach with decision-making in the control room is critical. Unlike the deterministic approach, a risk-based technique accounts for differing probabilities and grid contingencies. Research is needed on how to quantify relative operational risk and severity of contingencies such as extreme ramp events. Decision-support tools must be designed to incorporate the risks related with varying degrees of uncertainty in wind power forecasts.
- **Extracting Value from the Deluge of Data –** Research should be conducted in the application of advanced techniques such as data mining and pattern recognition in power systems operations. Operators have developed data-driven mental models around the power system. The uncertainty introduced by wind generation and other sources leads to unpredictability in power flow and other unfamiliar operating conditions represented by more data. Operators do not have the proper tools to extract any intrinsic values locked in the large volume of data, and then develop new mental models. Research should be conducted to develop new decision support tools based on data mining and pattern recognition techniques.
- **Improvements in Boundary Layer Forecast –** The U.S. should invest in improving its boundary layer weather forecasts at the national level. A collaboration of the public and private sectors is critical to improving the atmospheric observations, modeling, and numerical weather predictions needed to support a large-scale integration of national wind energy. Improvements of boundary layer weather forecasts will support integration of large-scale wind energy into the nation’s electric grid. From the public sector, National Oceanic and Atmospheric Administration (NOAA) should reduce errors in relevant meteorological parameters, such as wind speed and direction in the turbine layer, thereby allowing for

improved, foundational weather forecasts available for public consumption. The private sector parties, such as commercial forecasting service providers, should be responsible for providing value-added products and tailored forecasts of wind power to grid operators. Both the public and private sectors should contribute to the design and deployment of a national observation backbone network to support better boundary layer forecasts. While NOAA should provide an improved foundational weather forecast, the private sector must be the sole provider of wind power production forecasts and the related forecasting products. Investing in an improved foundational, boundary layer forecast will support many industry and national goals, including the addition of more wind and other renewable energies.

- **State-of-the-Art in Centralized Forecasting –** As more grid operators around the world gain experience from centralized wind power forecasting, it is important that lessons learned are captured and disseminated to the broader industry. Because of the benefit to the industry at-large, a new comparative study of centralized wind power forecasting should be conducted. While previous studies focused on grid operators in North America, a new study should consider the programs deployed by grid operators in other countries. Both public and private sectors should provide support for such a study.
- **Knowledge Management to Cope with the Aging Workforce –** The reality of an aging workforce will likely cause many utilities to lose experienced operators, along with vast amounts of undocumented knowledge of how the grid works. Simultaneously, utilities will have to hire new, less experienced operators, who must manage the grid in a hybrid state with both old and new equipment, most notably a mix of conventional and variable energy resources. Grid operators must begin documenting the operational knowledge and experience of existing staff before they retire. Once this information is stored and archived, sophisticated search engines and retrieval tools will be needed in the control rooms to integrate historical data with real-time operations. Being able to incorporate documented knowledge about historical grid operating conditions and critical equipment with other, more current information, will further reduce operators' uncertainty, thus enabling proper diagnosis and timely decision-making. This will lead to the emergence of a Knowledge Management System (KMS) in control rooms. Research into advanced information systems, analytical software and search engines should be conducted to specify requirements and recommendations for the implementation of advanced KMS applications. The research should be supported with investments from the public and private sectors.

ES.7 Summary of Conclusions

- More and more grid operators are interested in applying industry best practices and examples of excellence as the starting point for deploying their own decision support systems built specifically to address wind energy integration at the control center level.
- Realizing a scenario of 20% wind energy by 2030 in the U.S. will be difficult if existing decision support tools in utility control centers do not evolve to meet the new challenges.
- Grid operators worldwide are increasingly positive about integrating wind generation as they share best practices and learn about the successes of their peers.
- Wind power forecasting is indispensible for successful wind integration.
- Efficiently integrating wind energy in power systems requires that forecast and uncertainty information be incorporated into real-time decision support systems and planning tools.
- Higher levels of wind generation have shown to create uncommon system conditions and consequences that operators must learn to manage.
- Efficient integration of wind energy requires grid operators to have access to a proper mix of flexible resources ranging on the supply-side, delivery-side and demand-side.
- Smart grid technologies can aid wind integration by providing additional system flexibility.
- Having skilled operators is necessary for wide-scale deployment and the integration of wind and other variable energy resources.
- Achieving and maintaining the highest levels of situational awareness in control centers is, in general, of pivotal importance to grid operators and will be the case especially for systems characterized by high penetration of wind energy.
- Integrating wind generation could require changes in the physical grid, as well as changes in operational business processes and information technology solutions at work in control centers.
- Grid reliability standards and regulatory policies as well as laws enacted at the local, state, regional, national and multi-national levels affect the integration of wind generation in the control center.
- The industry is on the verge of a new operating paradigm as high levels of wind and other variable generation and increasing operational uncertainty become the norm today and even more so as we move towards 2030.