Investigating Smart Grid Solutions to Integrate Renewable Sources of Energy into the Electric Transmission Grid

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Abstract – **Lately, the electric utility industry is lately being hit by several drivers Worldwide. Resulting from policy concerns around Climate Change, these drivers have created the most significant impetuous for change and the subsequent alignment of politicians, regulators and customers, resulting in pressure on utilities to incorporate new sources of energy (e.g., Wind, Solar), reduce emissions (renewable energy sources, carbon reduction mechanisms, etc.) and so on.**

Most sources of new energy behave very differently from the normal sources of energy that we are all used to. They tend to be somewhat more expensive, somewhat erratic in their energy production and as a result are slowly becoming the biggest and newest source of headache for the electric grid operator. New tools will be needed to forecast and control these sources of energy as they become more and more prolific. Recent analyses have provided us with several new ideas that are being implemented within Battelle-managed labs at NREL, PNNL and ORNL to advance the capabilities associated with integrating these new sources of energy.

In this paper we will bring in some new concepts associated with wind energy forecasting, new concepts on power system visualization and transparency in grid operations, advanced concepts of power system automation and control through the use of SPMUs along with key benefits to support regional and national planning.

Index Terms—**Renewable Energy, Electric Transmission, Wind Forecasting, Control Area Management, Area Control Error, Smart Grid, Demand Response, Dispatchable Capacity.**

I. Introduction

Climate Change has become the major rallying cry behind several changes in the 21st century. Regardless of where one stands on this debate, everyone can agree on the following globally relevant facts:

- The cost of gasoline and other petroleum-related fuels is going up as the global demand for these fuels increases while availability of low cost reserves decrease making these fuels more expensive to produce.
- It is getting more difficult to get permits for new coal-fired generation.
- Auto-makers are increasingly moving towards electric vehicles leading to increased electrification of transport.
- The nuclear waste disposal issue has not yet been resolved.
- Electric load is continuing to grow both in quantity and complexity forcing utilities to think of new ways to deliver increased load without adding new generation.

The utility industry has agreed on these facts and has placed increased emphasis on developing and deploying new and alternative forms of energy generation and storage. To combat this new focus area, we have identified renewables integration as one of the key science and technology challenges which will need to be solved soon. Recognizing this challenge the U.S. Department of Energy (DOE), identified this area as a priority areas for its National Labs to investigate in cooperation with the energy industry [15].

In this paper, we will focus on the advent of new energy sources and issues associated with integrating them into the Electric Transmission and Distribution grid from an operational perspective. The paper starts with a contextual piece on why renewable sources of energy are important in Section II. In this section, a global subset of efforts in this area is also presented. Section III discusses the key characteristics of renewable sources of energy. This is important because the integration issues are in trying to deal with these characteristics. Section IV presents an in-depth overview of the key mechanisms that can be brought to bear to integrate renewable sources of energy into the grid. The authors have presented a framework to drive the integration process. In addition, the authors have also presented their experiences in using Demand Response as a tool to support the intermittency aspects of renewable sources of energy. In Section V, the authors have presented a sample overview of the work being done at some of the DOE's national labs, using the current efforts at the Pacific Northwest National Laboratory (PNNL), the National Renewable Energy Laboratory (NREL) and the Oak Ridge National Laboratory to outline current directions in renewable energy integration research.

II. Renewable Energy Resources and Why they are Of Increasing Importance

An energy resource qualifies as a renewable resource if it is replenished by natural processes at a rate comparable or faster than its rate of consumption by humans. This leads to two major dimension of renewable energy resources:

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- **Sustainability:** Sustainability from an energy perspective is meant to focus attention on using sources of energy at a rate comparable to that they can be replenished. As a result, they do not apply to the traditional sources of energy like coal and oil since we know that we will run out of them at some point in the future.
- **Reduced Environmental Footprint: Renewable energy resources should ideally significantly reduce the** emission of Green House Gases into the atmosphere, reduce the demand for limited resources such as water, and avoid the creation of other waste-products (i.e. fly ash) that cannot be easily recycled. Reduction of waste and its creation in a manner that can be disposed off in a harmless manner is a new area of focus.

While both traditional and renewable sources of energy have a financial aspect to them, the former creates a situation in which the commodity costs of the fuel used to produce energy will keep going up (as was evidenced by the cost of gasoline last year) and the potential to find new sources of inexpensive fuel are diminished over time. A renewable resource on the other hand can continue to deliver power for much longer.

The latter imposes a different restriction on the generation of power. Fossil fuels (coal / natural gas / oil) based energy generation all deliver green-house gases which have now been proven to contribute significantly towards global warming and mechanisms are being developed to reduce their emissions. Newer financial mechanisms are being thought of (e.g., carbon tax, cap and trade etc.) to recognize the broader societal costs of these emissions which will also result in increased costs of generating electricity from fossil fuels. Most of the newer renewable sources of energy are thought to be somewhat free from these taxes because they do not release any green-house gases.

In order to capture these broader societal benefits, several countries have moved to develop aggressive Renewable Portfolio Standards (RPS) as have several of the states in the US as well. A national RPS standard is currently under debate in the United States.

Some of the more aggressive targets include [3, 4]:

- **Ireland** has set aggressive national and regional targets of 15% electricity generation by wind by 2010, 40% renewable electricity generation by 2020 and NetZero Carbon by 2035.
- **California** currently has about 6000 MWs of generation from renewable resources (wind, solar, geothermal, biomass and small hydroelectric). This represents about 11% of the total energy required to serve load in CAISO. The state of California has also enacted a RPS standard requiring each retail seller of energy to deliver sufficient energy from renewable resources to serve 20% of retail load by December 31, 2010. More recently, California Governor also signed Executive Order S-14-08 which puts the renewable energy requirement at 33% by 2020, securing its place as the most aggressive renewable energy mandate in the country.
- **Germany** has approached the expansion of renewable energy resources differently by creating a tariff system which provides priority access for renewable energy to the power grid, obligates grid operators to purchase this electricity and creates a fixed price ("tariff") for every kilowatt hour produced from renewables for 20 years.
- **China** has set a target of producing 16% of primary energy from renewable sources (including large hydropower) by 2020. For the electricity sector, the target is 20% of capacity from renewables by 2020, including 30 GW of wind power, 20 GW of biomass power, and 300 GW of hydropower capacity
- **The Eurpean Union under its EU** 20/20/20 mandate is committed to reducing its overall emissions to at least 20% below 1990 levels by 2020. It has also set itself the target of increasing the share of renewables in energy use to 20% by 2020., The EU policy is that it stands ready to scale up carbon reduction to as much as 30% under a new global climate change agreement when and as other developed countries make comparable efforts.

III. Key Characteristics of Renewable Resources

In general, small hydroelectric, biomass and geothermal generation are more predictable resources and their integration into both the markets and operations do not present significant problems.

PhotoVoltaic (PV) based generation is an intermittent resource most often deployed in a local context. Consequently, the reduced scale of PV generation combined with the local utilization of this power source, has not resulted in significant integration issues. While the amount of concentrated solar generation is expected to increase quite a bit over the next 15-20 years, its impact as a percentage of the overall generation mix will still be low in most OECD nations. As a result, while integration standards for the local distribution grid are required, no serious system operating issues are expected with the expansion of market penetration by the current generation of solar generation.

New wind generating facilities are the fastest renewable resource to install and interconnect to the power grid. Wind generation, however, also presents the most significant operational and planning challenges. As Figure 1 illustrates, the penetration of wind generated power is anticipated even in largely urbanized regions of the U.S. over the next decade.

Given these facts listed above, the authors have decided to focus the rest of the paper on wind-based generation, recognizing that many of these same characteristics and mechanisms (Section IV) also apply to other intermittent renewable sources of generation such as PV and tidal energy.

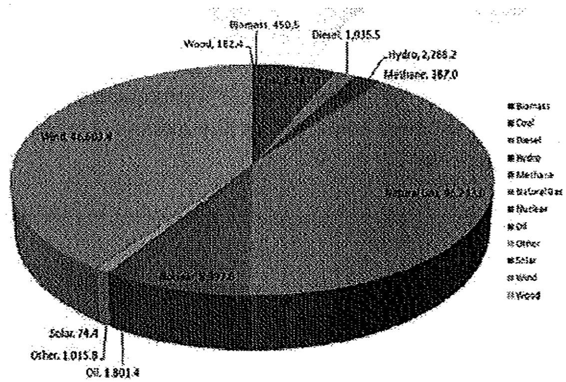

Figure 1: Active Generation in Queue for Transmission Access in PJM [9]

The challenges of wind integration at scale can be viewed as seven associated, but distinct attributes that are characteristic of intermittent wind energy sources:

- **Intermittency [1, 2]**: Wind generation energy production is extremely variable. In many places, it often produces its highest energy output when the demand for power is at a low point. During periods of favorable wind conditions it's possible that all wind projects in an area will be at their full energy output. If that happens the transmission line could become a reliability problem, and wind generation on that line would need to be curtailed.
- **Ability to dispatch**: Unlike traditional forms of generation, renewable forms of energy (especially wind and solar) will generate only when there is wind or it is sunny. When that happens it will be difficult to control their output.
- **Remote siting**: Wind projects tend to cluster mainly in rural areas not supported by strong transmission systems and remote from major load centers.. Consequently, wind projects have tended to cluster along favorable locations, often on lower voltage transmission lines.
- **Ability to Forecast**: Wind generation is difficult to forecast because it does not follow a predictable production pattern and forecast technologies are not well developed.
- **Needs lots of land space**: In general, both wind and solar need lot of land area to generate the equivalent power of one normal fossil-fired generating unit. Over time this will be a limiting factor in how much overall generating capacity can be expected from wind.
- **Still expensive**: Cost is still a significant issue with most renewable forms of generation. They are at an order of magnitude of about 10 – 50 times the cost of free venting fossil-fired generation. However with appropriate incentives, innovation in their design and/or some form of carbon taxation, it is expected that at least wind will be cost competitive within the next 3-5 years.
- **Non-Utility Owned Generation**: Possibly for the first time – major generation will be built by companies and people who do not have a utility mindset. Many of them are property or merchant power project developers. Utilities will need to understand regulation needs and implement them where they belong instead of socializing them across everyone [16]. In addition, these projects tend to get implemented much faster than conventional generation and so the interconnection processes will need to speed up.

IV. Key Mechanisms for Managing and Operating Renewable Resources

Identifying mechanisms for managing and operating renewable resources is one of the hottest areas of research in the alternative energy field [7, 8, 10].

In Figure 2, the authors present a framework that covers all aspects of planning and operating renewable resources of energy. The rings identified in the figure are the technology focus areas characteristic of wind energy integration; ranging from forecasting the generation of energy all the way to settling for the energy delivered based on a combination of the energy delivered counted against the Ancillary Services needed to support the generation. The technology would need to be supported by appropriate changes to processes and operational methods. Each aspect is discussed in the following paragraphs.

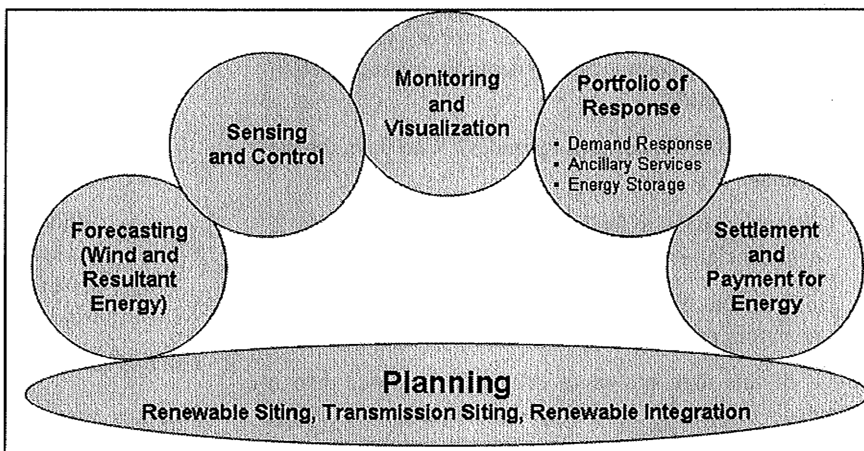

Figure 2: A Framework for Planning and Operating Renewables in a Utility Environment

A. Siting Constraints and Characteristics

The location of the wind or solar farm is a significant contributor to how it is managed and operated. Important aspects of siting include the ability to appropriately locate generation facilities at locations of high energy resource availability, provide transmission corridors for them to deliver energy from generation to load and ability to forecast how much and when they will generate power.

- **Configuration and output characteristics**: Generation from solar, wind, geothermal, etc each have specific output characteristics. Even within solar, for example, the output characteristics of different types of solar cells operate differently under different conditions. When combined in large output modes (as in a wind farm) their behavior will drive their impact to the grid under different conditions. This specific characteristic can actually be a benefit in that it can smooth out the rapid fluctuations of wind-energy output to a certain extent. Mechanisms exist to model this information into the forecasting approach so that the variability in the source can be converted into variability in the delivery of power into the grid.

- **Transmission corridors and congestion**: One of the key sticking points in the integration of renewable sources of energy in the availability and the ability to build transmission lines/corridors to bring the power from these renewable sources into the load centers. Key questions that need to be answered include:

  - What capacity value should be used to assess impact of wind on the transmission, given its intermittency?
  - Wind farms can be up and running much quicker than conventional generation. What process changes are needed to accommodate generation interconnection requirements?
  - Who pays for the network upgrades? Who pays for the studies?
  - For interconnection facilities to wind-rich areas, how is cost allocated?
  - How much firm capacity would the intermittent resources provide to meet system "Firm" peak?

  Much of this area has more of a policy aspect than a technical aspect to it. Policy mechanisms are being considered in many areas to drive towards resolution.

- **Energy Forecasting**: Wind, solar energy forecasting has been the focus of much work at several of the DOE laboratories, as well as universities for several years now. The focus currently is on forecast error and determining how these sources of generation will fit into the market models and supporting the balancing authority (BA).

  A key aspect of forecast error is a concept called the "Tail Event". A Tail Event happens when forecast errors for load and wind result in divergence of power demand and supply. Large wind power ramps in a power system (Figure 3) can create significant imbalances between generation and load resulting in grid instabilities [13]. These types of events occur infrequently but are significantly more impactful as the market penetration of wind increases[2].

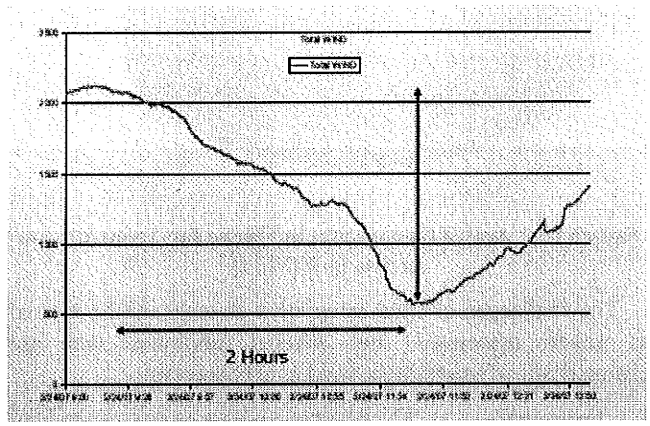

Figure 3: NREL analysis of a specific Wind drop of about 1500 MWs over 2 hrs in Texas.

Industry experience has taught us that for forecasts to be useful, they need to be:

- Integrated into the control room solutions for use by the System Operator.
- Be able to forecast the large ramp events and support high-wind warning systems.
- Include geographic aggregation to reduce aggregate wind forecast error.
- Consider load diversity and forecast into account to reduce probability and severity of step ramps or tail events.
- While specific wind turbines may have rapid start/stop times, large wind farms are spread over several miles and do not experience the same wind at the same time (Figure 3).

B. Use of Technology and Automation

Two key areas of technology and automation are being seriously considered for renewables integration:

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[2] The total wind fleet dropped ten times as much generation, ~1500 MW, but it took ten times as long, ~120 minutes. This is a dramatic drop in production, but it is not extremely fast. It was certainly not a contingency event, and therefore, was not eligible to rely upon contingency reserves. This is a large ramping event

If this event is typical, increasing the size of the wind fleet will increase the size of potential large ramping events, but it will not increase the ramp rate as dramatically. The power system must be capable of responding to the loss of wind, but the resources need not be spinning. Fast-start resources would be adequate to cover infrequent large wind events [13].

- **Hardware.** These include Synchro-phasor Monitoring units (SPMUs), Static Var Compensators (SVCs) and Flexible AC Transmission Systems (FACTS).

  SVCs and FACTS devices represent the fast-acting switching controls for both real and reactive power flow across the grid. They will provide operators with a near real-time ability to implement controlling actions in response to system challenges. However, to be effective, they will require greater visibility and transparency of grid status also in near real-time.

  Synchro-phasor technology provides time synchronized sub-second data applicable for wide area monitoring and allows the System Operator to operate the power system closer to operating margin. SPMUs take the sampling window from six seconds to 60 times per second and provide a GPS time stamp for all measurements. Phasor data will drive a new generation of monitoring, operator decision support and, ultimately, fast real-time controls to improve grid performance.

- **Software**: Control centers will see a new slate of applications focused primarily on Wide-Area Monitoring and Power System Visualization [11, 12]. As illustrated in Figure 4, such visualization tools can allow operators to enhance system status knowledge and highlight interconnection status and priorities

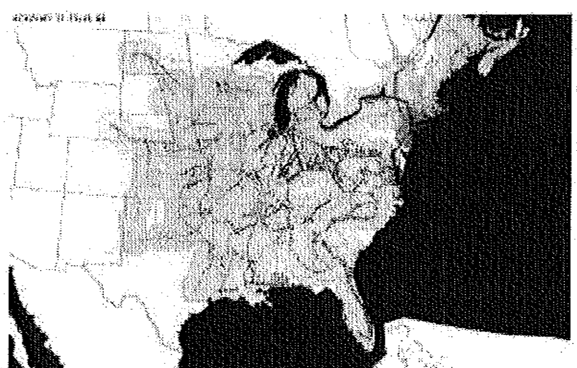

Figure 4: Sample Results of Visualization Analysis across a Wide-Area

Much of the development is focused on making the power grid operators aware of ramping requirements, comparing them to available capability, predicting the impacts of intermittent generation on congested transmission pathways, voltage levels and reactive power margins and providing re-dispatch options.

New tools are being developed to predict available frequency response and determine amount of Frequency Response Reserve (FRR) needed online as a required modification to market based unit commitment and dispatch.

C. Changes in Operational Methods and Processes

Increased integration of wind and other similar renewables-based generation will also result in the need for newer and more advanced operational methods and processes. Some techniques that merit consideration in large interconnected systems as in Europe, US, and China are:

- **Wind-only balancing areas**: Creating a virtual balancing authority across multiple control areas allows each control area to reduce their overall reserve requirements needed to support the appropriate amount of wind integration. This mechanism leverages geographic diversity both from the generation from renewables as well as load.
- **Ace Diversity Interchange (ADI):** ADI is the pooling of individual Area Control Errors (ACE) to take advantage of control error diversity (sign differences associated with the momentary generation/load imbalances of each control area). By pooling ACE, participants will likely be able to reduce control burden on individual control areas, reduce unnecessary generator control movement, reduce sensitivity to resources with potentially volatile output such as wind and allow reserve sharing across control areas
- **Second Tier Control Centers** – The continued evolution of operational methods and processes may result in a need to provide increased operator supervision to these activities. This stems from increased importance to understand probabilistic elements of the grid such as wind and load forecasts, and the availability of distributed smart resources. The System Operator will need to collect these data and formulate an optimal dispatch method which coordinates with transmission dispatch. The attention deserved by such a task implies the need for additional control room support. Whether an additional desk is added to existing transmission control rooms or a Second Tier Control Center is established to support a group of transmission control centers is unknown. However, such coordination of assets will likely be necessary.

D. Role of Demand Response

Demand response is recognized as offering near term potential for smart grid implementations. The potential benefits of managing peak loads (or generation) are substantial. Demand Response could supply valuable ancillary services such as ramping and spinning and non-spinning reserves as was demonstrated in the Olympic Peninsula pilot. The conceptual architecture for this Battelle-PNNL effort is illustrated in Figure 5, and is discussed below.

This pilot project showed that with proper value signals and automated controls, customer loads could be effectively and rapidly engaged to stabilize the aggregate load of a feeder. This virtually eliminated the need for regulation for periods lasting many hours, all without inconvenience to the consumers.

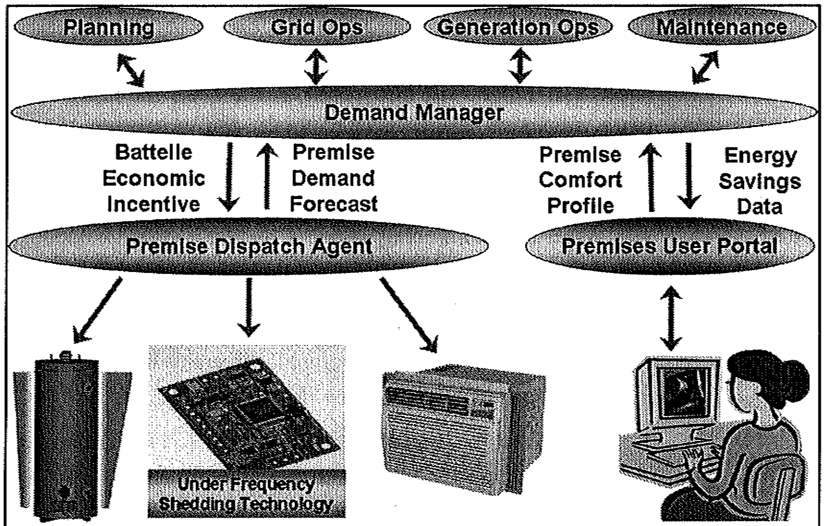

Figure 5: A Framework to Use Demand Response as a mechanism to support the System Operator

The demonstration utilized an automated premise dispatch agent that acted in accordance to previously defined customer preferences in response to 5 minute interval market signals. The trial also included very fast acting (~1 sec), autonomous, short-term load shedding in clothes dryers and water heaters to provide a stabilizing force when the grid gets into trouble or needs to support renewables [5, 6].

The Olympic Peninsular pilot demonstrated three major conclusions:

- Demand Response resources are capable of responding to ancillary service signals on short (minutes) to very short (seconds) time scales. Peak demand reductions of 16% and average demand reductions of 9% to 10% were realized over extended periods.
- The ability to measure and confirm response of resources, at least for groups of customers if not individually
- A structure for incentives can be offered to customers for short-term response.

While providing ancillary services was not a direct objective of the experiment, the observations provided an important foundation for launching a directed effort to engage demand response in providing these benefits.

E. Expanding Role of Storage

Storage forms a key part of the portfolio that will be required to support the integration of renewables. Storage is needed to manage or regulate the variable nature of wind, allowing it to be relied on a semi-firm energy resource.

Much work is being done to target operational principles, algorithms, market integration rules, functional design and technical specification for an energy storage that mitigates the intermittency and fast ramps that occur at higher penetration of renewable generation. Some of the technologies that are being studied include:

- Field experiment design and monitoring of the flywheel energy storage for existing and future renewable penetration.
- Addressing the characteristics and the role of battery storage facility and the regulatory issues to create feasible, economic applications for the battery storage devices.

F. The Need for Active Demonstrations

While the authors have presented several options which can serve as mechanisms for managing and operating renewable resources, it is important to note that both the applicability to specific locations as well as the acceptability to different operating conditions will vary. This can only be mitigated through performing continued active demonstrations of the mechanisms defined in this paper.

Active demonstrations in real-life will allow the different stakeholders to understand and validate the costs and benefits of the mechanisms.

V. Sample of Ongoing Work on Renewable Energy Integration at Various DOE Laboratories

The DOE labs are conducting ground-breaking work in the area of renewables integration. This section will present a sample of the work being done in three of the labs managed and operated by Battelle for the DOE. It is also noteworthy to mention that in some of the areas, the labs have been working together to develop common solutions.

A. Pacific Northwest National Laboratories (PNNL)

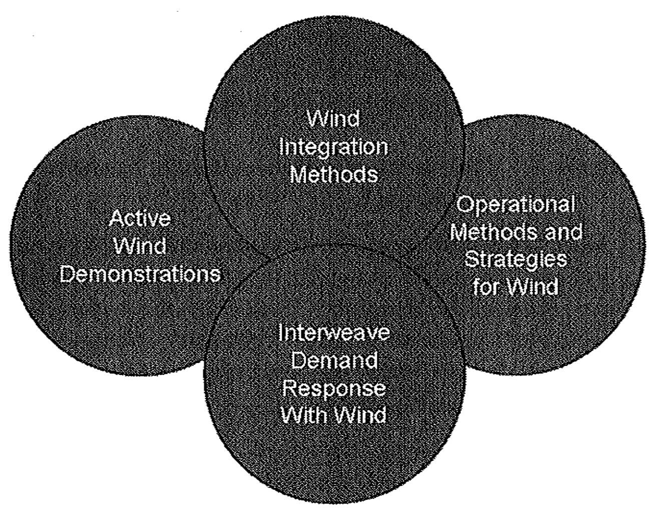

Figure 6: Key Elements of PNNL Strategy

PNNL pursues technologies that allow the United States to pursue a renewable strategy that will enable reliance on renewable energy and potentially surpass a 25% penetration level by 2025. Key elements of the strategy are provided in Figure 6.

PNNL's is focusing on technologies that have the potential to allow renewables to:

- Have a significant impact on national energy needs and green house gas emissions.
- Transform variable resources into semi-firm electricity.
- Be cost acceptable in the short run and cost effective in the long run.

Key PNNL efforts are focused on performing wind generation impact studies, analyzing wide area applications for EMS systems with energy storage to support renewables integration and finally integration of wind forecasts into operations procedures.

B. National Renewable Energy Laboratories (NREL)

Among the various labs, NREL has taken a leading position globally in the overall analysis of renewables and their impact on the Transmission and Distribution grid. NREL is playing an active role in the Utility Wind Integration Group (UWIG) as well the integration work in Hawaii, Ireland and other parts of Europe.

Much of the wind industry's technological advancement can be traced to the research conducted at NREL's National Wind Technology Center (NWTC). Funded by the U.S. Department of Energy Wind Energy Technologies Program, research conducted at the NWTC has led to the development of multi-megawatt wind turbines that produce electricity at a cost that is increasingly competitive with conventional energy sources in the marketplace. To make wind energy fully cost competitive and increase wind energy development, researchers at the NWTC are working in partnership with industry to develop larger, more efficient, utility-scale wind turbines for land-based and offshore installations, as well as more efficient, quieter small wind turbines for distributed applications.

The NREL team also performs renewables integration studies across US Eastern and Western Grid Interconnection. Fundamental to NREL's approach is the definition of wind resources and other renewables throughout the West through the concept of Renewable Energy Zones (REZs) [14]. An example of this approach can be seen in, the Texas approach of building the transmission capacity first in the right place, and then allowing the renewable developers to tie into this system. NREL has created a Zone Modeling group to identify renewable zones and a Generation Transmission work group to help analyze source to load delivery pathways.

C. Oak Ridge National Laboratories (ORNL)

Oak Ridge National Laboratory (ORNL) performs applied research and development to integrate wind and water power, among other renewable generation sources, into the nation's energy mix and accelerate renewable energy penetration into electric power systems and markets.

ORNL's current portfolio of projects includes analysis of the how load flows and markets could be impacted by the import of large quantities of wind energy to the southeastern U.S. to satisfy alternative Renewable Portfolio Standards scenarios.

ORNL is working to provide real-time wide-area situational visualization for renewable energy inputs to electric power grids, and to synthesize best practices for wind energy electrical design, including wind plant collector layouts, protective relaying and control, dynamic modeling of wind generators and harmonics analysis, and arc-flash protection. ORNL is also modeling the impacts that water availability and environmental operating constraints of small and large hydropower assets have on the ability of control areas to operate reliably with significant renewable energy penetration.

VI. Conclusions and Observations

In this paper, the authors have presented an in-depth understanding of renewables and steps needed to integrate them into the grid.

Renewables and their integration into the grid is still a new area and much of the work is in the advanced stage of being developed in the labs and being piloted around the country and the world. The overall amount of energy from renewables has not yet reached critical mass anywhere, but we suspect it will be there in the next 5-10 years. Among the forms of energy generated from different types of renewable resources, wind has the most momentum and most impacts to grid operations.

However, the authors believe that there are several steps that would be required now to prepare for the change.

To meet the objective of preparing for a critical mass of Wind-based energy generation, the authors have proposed a framework to structure the integration process. The framework is very powerful in that it allows the user to ask the right set of questions leading the process all the way from planning/design to operational integration.

There are several key takeaways from this framework:

- The right approach is a **portfolio approach** which consists of a combination of energy storage, sophisticated and high-fidelity hardware and software supported by changes to operational methods and processes.
- **Locational aspects** of renewables and their characteristics play a big role in defining the tools available for their integration. For instance the tools available to integrate renewables in North America or China will be different from those available for use in Hawaii or Ireland.
- **Demand Response** will play a key role in the success of renewables integration. Demand Response (if implemented correctly) will provide the ability to assist in ramps up and down as well as load following. This will allow the system operator to smooth out the intermittency

at least to the extent of load under demand management.

- **Storage** will play a role in smoothing the wind output curve but also help in using energy generated at one time to be used at another time.
- When forecasting, variations in both load and generation need to be taken into account to manage **tail events.**
- A wind-only **virtual balancing authority** presents a new and interesting concept to providing reserve sharing across a large area consisting of diverse load and generation characteristics.

These key takeaways serving under the umbrella of the framework provide a roadmap to assist utilities with their plans for renewable integration

VII. Acknowledgment

The authors gratefully acknowledge contributions of several dedicated and smart people of the National labs who contributed to materials in the paper through phone discussions or sending materials for use in the development of this paper. The key contributors are Ross Guttromson and Carl Imhoff of PNNL, Bob Hawsey and Brian Parsons of NREL, Travis Smith, Brennan Smith and Tom King of ORNL.

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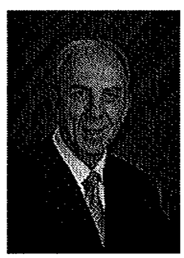
IX. Biographies

Subramanian Vadari (M'1987, SM'1993) received his M.S.E.E and Ph.D from the University of Washington in Seattle in 1986 and 1991 respectively.

Dr. Vadari is Vice President of Energy Infrastructure in Battelle's Energy Technology Global Business Unit. In this role, Dr. Vadari is responsible for maximizing the programmatic and commercial returns from Battelle investments to support the increasingly robust pipeline of innovations in the Energy Infrastructure business.

Dr. Vadari has more than 20 years of experience delivering strategic solutions to the electric utility industry focusing primarily in transmission and distribution (T&D) grid operations, generation operations, energy markets, and Smart Grid. Dr. Vadari has authored over 30 articles in a variety of areas from dispatcher training simulator development to electricity utility deregulation and the Smart Grid. Dr. Vadari is considered a Smart Grid subject matter expert, offering much-sought-after perspectives on the entire value chain of an electric utility from generation to consumption.

Prior to joining Battelle, Dr. Vadari was one of Accenture's lead partners in their T&D practice. Dr. Vadari also previously served as a lead engineer at ESCA (now Areva T&D), focusing on Power System and Deregulation applications and their delivery.



J. Michael Davis is the Associate Laboratory Director for the Energy and Environment Directorate at Pacific Northwest National Laboratory. In this role, Mr. Davis leads a team of more than 1,000 staff focused on delivering science and technology solutions to increase our nation's energy capacity; reduce dependence on imported oil; and detect, mitigate and prevent the environmental impacts of legacy waste and energy generation and use. The directorate conducts approximately $250 million in research annually for government and industry clients.

Mr. Davis has held a multitude of energy leadership roles in industry and government, including serving as the U.S. Department of Energy's Assistant Secretary for Conservation and Renewable Energy at the appointment of President Bush in 1989 where he grew the budget by $500 million within three years and received the Secretary's Gold Medal Award for charting a new market-oriented approach to federally funded research and development. He is an invited member of the National Academy of Sciences' Renewable Energy Panel as well as the NAS Committee on U.S.-Chinese Cooperation on Electricity from Renewable Resources and has provided leadership for several other energy-related organizations, including president of the Solar Energy Industries Association and chairman of the National Hydrogen Association.

Mr. Davis has a bachelor's degree in Civil Engineering from the US Air Force Academy and a Master's degree from the University of Illinois in 1970.