The Ability of Current U.S. Electric Industry Structure and Transmission Rules to Accommodate High Wind Energy Penetration

Robert Gramlich and Michael Goggin

***Abstract*—This article highlights the current situation for wind integration in the U.S. and compares it with the ideal conditions for wind integration. The optimal conditions for integrating large amounts of wind energy at low cost are identified as the following: a large electric balancing area with access to neighboring markets, a robust electric grid, short-term electricity generation markets, flexible generation and load, the effective integration of wind forecasts into utility operations, and flexible transmission services. The article then presents the current state of affairs in the U.S. electric industry and explains how it falls short of each of these ideals.**

***Index Terms*—Power systems, Power transmission, Transmission lines, United States, Wind energy**

I. Introduction

In recent years, wind generation has become a mainstream utility scale energy source. In 2007, wind generation accounted for 30 percent of new installed capacity in the U.S. In parts of Europe wind is providing 10 to 20 percent of annual electricity needs. There is a rapidly expanding body of research and experience with integrating wind into electric power systems around the world. This research and experience is sufficiently developed to indicate both the importance of electric industry structure, rules, and infrastructure, and the particular types of structure, rules, and infrastructure that integrate the most wind energy while maintaining reliability. In this paper we describe this "ideal" structure and compare it to current electric industry structure in the U.S. in order to assess the country's ability to integrate large amounts of wind, as well as the magnitude of electric industry reforms that will be required.

II. Wind Integration in the U.S.

A. The Optimal Market Structure for Wind Energy

Wind energy has four characteristics that affect how it is integrated into power systems: 1) its variability, 2), its near-zero variable cost, 3) the difficulty of forecasting its output precisely, and 4) its remoteness. These characteristics can be better accommodated in some market structures than others. The ideal market structure for wind integration has been documented by various publications [1], [2]. The ideal market structure includes:

1) Larger Balancing Areas and More Access to Neighboring Markets:

A number of studies have documented that wind integration costs are significantly lower in large balancing areas. Larger balancing areas provide more opportunity for excess generation in one region to be offset by shortfalls in generation in another region. This effect is true even for systems without wind energy. However, this effect is often even more pronounced for wind energy, as variations in wind output tend to be less correlated over larger geographic regions. A wind integration study conducted in the U.S. state of Minnesota in 2005 found that consolidating the state's four balancing areas into a single balancing area would reduce the requirement for regulation services by 50% [3]. In addition, a larger balancing area provides a larger pool of flexible resources that can be used to accommodate variations in electricity supply or demand. The ability to export power to neighboring regions is particularly useful during minimum load situations in regions with many must-run generators, as it allows excess power to be exported to nearby regions that can use this power.

2) A Robust Electric Grid:

An important asset for allowing power flows to neighboring regions is an electric grid with robust regional interconnections. Regional transmission planning processes with effective processes to allocate the costs of new transmission tend to result in more transmission capacity being built between neighboring regions. The Western Governors Association Clean and Diversified Energy Advisory Committee evaluated a "high renewables" case and found that it required 3,578 line miles of transmission above the 3,956 line miles required in the reference case, at a total cost of $15.2 billion for transmission to serve all the generation in the high renewables case [4]. Transmission is currently constraining wind development as interconnection queues continue to be filled up and a lack of available transmission capacity continues to limit deliveries [5].

3) Shorter-term Generation Markets:

Grid integration studies have also found that electricity market design can have a significant impact on the cost of integrating wind. A March 2007 study of wind integration

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costs in the Northwest U.S. calculated that ten-minute markets would reduce wind integration costs by 40-60% compared to hourly markets [6]. Similarly, the presence of five-minute markets in California plays a large role in keeping incremental load following costs for higher wind penetrations at approximately zero [7]. This is because wind output tends to be relatively constant over ten-minute periods of time, although it can vary significantly over the course of an hour. In regions with hourly markets, significant deviations in wind output over the course of an hour often must be accommodated through the use of regulation services, which are typically the most expensive type of ancillary services.

4) More Flexibility in Generation and Load:

Wind integration studies have also found that electric grid systems with more flexible generators tend to have lower integration costs. For example, systems with large amounts of flexible hydroelectric and natural gas generation will tend to have lower integration costs than systems with inflexible generators such as nuclear and coal power plants. In fact, the study of California's grid calculated that the load following cost for integrating wind energy is essentially zero, in part because of the large available stack of flexible generators in the state [7].

In the future, smart grid technology offers significant potential for electric load to be dispatched just as generators are dispatched today. Plug-in hybrid electric vehicles that are attached to the grid using smart grid technology also have significant potential to provide demand-side flexibility in the future.

5) Wind Forecasting Effectively Integrated into System Operations:

Integrating wind forecasts into system operations can also significantly reduce the cost of accommodating wind energy on the electric grid. Without a reliable forecast, in regions with large amounts of wind energy grid operators would have to maintain significant reserves to accommodate potential variations in wind output. Reliable wind forecasts allow system operators to significantly reduce their uncertainty about future wind output, and wind forecasting techniques available today have a very high degree of accuracy. The California grid study found that the use of existing wind forecasting techniques reduced grid integration costs by $4.37/MWh [7].

6) More Flexible Transmission Services:

Although the U.S. electric grid is highly congested during a small number of hours per year, for the majority of the year only a fraction of available transmission capacity is used. In addition, wind plants tend to produce the most electricity during these off-peak times. As a result, there are significant opportunities for wind energy facilities to use spare transmission capacity outside of peak times. It is also possible to dynamically rate transmission such that more is made available when wind blows and cools the transmission lines, allowing more transfers. In the ideal electric system, such options would be made available to transmission customers including wind generators.

B. General Structure and Diversity of the U.S. Electric Industry

The US electricity industry is extremely diverse. There is significant variation in ownership structure, market rules, regulatory oversight, geographic size of operation, grid topology, transmission planning approaches, transmission services, level of local/state/federal jurisdiction, and transmission infrastructure. Compared to the ideal market structure from a wind industry perspective as described in the previous section, current market structure ranges from fairly good to poor. This section provides an overview of the US electric industry and the next section compares the specific structural features with the ideal structure and transmission rules for integrating wind.

1) Ownership Diversity:

The U.S. electric industry is made up of diverse types of entities. There are investor-owned utilities that own generation, transmission, and distribution assets. There are local government-owned utilities, ranging from some large entities on a scale close to the size of larger investor-owned utilities to hundreds of smaller municipal systems that are dependent on the market for wholesale purchases and the host utility for transmission. There are rural electric cooperatives that are consumer-owned and either buy power from Generation and Transmission cooperatives or from other utilities or independent power generators. There are Public Utility Districts that receive preference power from federal Power Marketing Administrations. Independent Power Producers (IPPs) now own approximately 40 percent of the generation assets in the country.

2) Transmission and Energy Market Diversity:

Approximately two-thirds of the country's transmission system is operated by Regional Transmission Organizations (RTOs) or Independent System Operators (ISOs, which are similar in function but usually smaller). Other parts of the country have large vertically integrated utilities that operate most of the system. Other regions, including much of the middle of the country where the best wind resources are located, have small, balkanized systems with weak links to each other and to urban load centers.

There are some very large Balancing Authorities and some very small. There are some with peak loads over 100 Gigawatts and some under 100 Megawatts. Generally the ISO and RTO areas have the larger balancing areas. The middle of the country where a lot of wind resource is located tends to have smaller areas.

Some regions coordinate transmission plans in a centralized fashion. The ISOs and RTOs tend to do this. Other regions have less coordinated transmission planning. Many utilities tend to focus their planning efforts on local generation to serve local load, without much consideration for opportunities to access more distant resources or to coordinate with neighbors on joint resource plans.

Transmission services vary considerably between RTO/ISO-operated areas and non-RTO/ISO areas. In RTOs, transmission service spans the region of the RTO/ISO footprint so it is a one-stop shop for transmission. Transmission rights are financial in most cases, not physical, which provides more flexibility for variable resource generators to pay for the transmission they use as opposed to paying to reserve capacity all day every day. Outside of RTO/ISO areas, transmission services follow FERC pro forma tariffs, require physical reservations, and are provided in a way so that customers who want service across the assets of multiple owners must pay multiple "pancaked" transmission rates.

3) Regulatory Oversight Diversity:

Electric utilities have many masters. Investor owned utilities typically have 80% of their assets regulated by state public utilities commissions, and 20% by FERC which regulates wholesale transmission and power sales. Municipal utilities are overseen by the governments of which they are a part, and do not file rate cases with regulators. Cooperatives are overseen by boards made up of their consumers. The Department of Energy has almost no jurisdiction or authority over the electric industry. DOE's role changed only recently with the Energy Policy Act of 2005 granting DOE a role in designating transmission corridors, but this policy is unproven and has had no effect to date. While DOE houses the Power Marketing Administrations including Bonneville Power Administration in the moderately windy Pacific Northwest and the Western Area Power Administration in much of the very windy Great Plains, political control of these agencies lies more with the Congressional offices that represent their customers. With U.S. electric utilities reporting to so many different entities, it is very difficult to move the industry towards the greater regional coordination and planning that is needed for many purposes.

4) Varying Degrees of Competition versus Regulation:

Public policy has also affected U.S. electric utilities in very different ways. The push in the 1990s for open competitive wholesale markets led to many changes towards the ideal structure from a wind industry perspective, namely larger regional open competitive wholesale markets. There was also a push for retail competition in a number of states. As a result, there are investor-owned utilities in restructured states and regions that own assets in these sectors but face competition in generation and in serving load. There remain, however, many fully integrated utilities that have no competition at the retail level and almost no competition in generation. Political support for competitive reforms has substantially waned due to the California energy crisis and rate shock in some states that have retail competition and retail rate caps expired at a time when costs were high. Policy makers generally do not distinguish wholesale competition from retail competition, so even though large regional competitive wholesale markets would benefit reliability and efficiency, they have lost support due to political opposition to markets in general.

C. Comparison of Current Status with Ideal Electric Industry Structure and Operations

In this section we compare today's structure and rules with what is needed for high wind penetration scenarios. We rate each category on a 1 to 10 scale, with 1 being a structure that accommodates no more wind and 10 being a structure that can accommodate obtaining 20 percent of electricity from wind (and higher in some regions), consistent with a study AWEA is conducting evaluating a scenario in which 20% of U.S. electricity comes from wind by 2030.

1) Larger Balancing Areas and More Access to Neighboring Markets:

Large regional power pools serve approximately two-thirds of the load in the U.S. Each of these ISO/RTOs has a one-stop shop for transmission service, larger than average balancing area size, accommodation of bilateral contracts for short and long distance trading, and a real-time energy balancing market. However, the RTO or ISO is not always operating a single control area, and inter-utility and inter-regional trade is hampered by infrastructure limitations and "seams" (artificial barriers created by different rules). A paper by the Utility Wind Integration Group summarizes market design features of the ISOs and RTOs operating in Texas, California, New York, New England, Mid-Atlantic, Midwest, South Central, and Canadian provinces Alberta and Ontario [8]. On matters of scheduling, imbalance settlement, ancillary services markets, wind forecasting, capacity calculation, and capacity recognition, none of the RTO/ISOs address all design features fully. Most of them have limited operational control and limited markets and forecasting capability. We give these operators a score of 5 out of 10.

In the Pacific Northwest, there are a number of separate balancing areas and pancaked transmission rates. The Northwest U.S. has 19 independent balancing authorities, the smallest of which has a peak capacity of only 90 MW [1]. The recently announced Northwest Wind Integration Action Plan [9] would improve the situation significantly by increasing coordination of these areas. Inter-utility trade and trade with the California market is active but limited by infrastructure and seams. We give this region a 2 now, with the potential for improving to a 4 if all of the recommendations of the action plan are implemented.

Other than the parts operated by the Midwest ISO, the Interior West and Upper Midwest are composed of a large number of utility areas. Some of these are medium-sized and have a market structure that can integrate more wind, although many are smaller systems that have very limited capability for additional wind integration. There are significant opportunities to trade from windy areas with rural cooperatives and federal Power Marketing Administrations to urban load centers with investor-owned utilities, but significant infrastructure and seams barriers present major obstacles to such trade. We give this region a score of 1 out of 10.

2) A Robust Electric Grid:

Transmission limitations are beginning to have significant effects on the development and operations of wind plants in the U.S. Wind sites with good transmission access are becoming more difficult to find. Some locations in the US currently experience wind curtailment and negative electricity prices, which are signals from the system operator effectively penalizing generators for producing at times and places where transmission overloads are occurring.

In general, Texas has better transmission infrastructure than other regions. Its policy of spreading costs to all users has been critical to its success in developing transmission. However, because the best wind resources in the state are located hundreds of miles west of the large urban load centers, constraints are currently emerging. An innovative pro-active transmission planning process using Competitive Renewable Energy Zones (CREZ) is expected to soon yield authorization for transmission companies to build transmission lines that would access almost 20 Gigawatts in one leading option under consideration. Colorado has a similar policy that promises to lead to significant transmission investments.

Wind projects are moving forward around the country and making use of existing infrastructure. However, interconnection queues – the waiting lists for new transmission projects that are needed to connect new generation to the electric grid – are clogged with large numbers of wind projects. This is a strong indication that large amounts of new transmission infrastructure will be required to connect most of the new wind resources that are needed to comply with state Renewable Electricity Standards.

Plans are moving forward in Minnesota for a transmission project called “CapX,” but that project will connect only 2 GW of the 22 GW in the interconnection queue from the popular Buffalo Ridge area. Similarly, California achieved support for plans to access the 4,500 MW of wind in the Tehachapi area with lines that are expected to be operational around 2011, although this development represents only a fraction of the 14 GW of wind energy in CAISOs queue. A Wyoming-Colorado intertie led by the Wyoming Infrastructure Authority is expected to provide 800 new MW of capacity connecting the valuable Wyoming wind resource to Colorado urban loads. In the Pacific Northwest, the Bonneville Power Administration is doing pro-active transmission planning with an open-season for purchasing transmission access from the windy area east of the Cascade Mountains to the populated area to the West.

The development of transmission into the Mid-Atlantic region and Southern California is more challenging. There is significant opposition to the Transmission Corridors that the Department of Energy has designated into those areas. There are significant price differences between the middle of the country and these highly populated areas, which makes investments in transmission very attractive. Local landowners and states in between the generation and the load, however, do not find the transmission proposals attractive.

Development of large inter-regional transmission superhighways would ultimately be needed to connect wind resources in the middle of the country to load centers on the coasts. While U.S. transmission investment has increased from approximately $4 billion per year early in this decade to $8 billion per year currently, more investment and forward-looking planning would be required to build networks at the higher voltage levels that can deliver scores of Gigawatts.

Given the ability to continue interconnecting wind projects with current transmission availability, the increase in transmission investment, and the progress on transmission in certain high-wind states, performance in this area is not terrible. However, compared to what is needed to continue interconnecting projects and ramping up annual wind installations, we rate performance in this area at a 3 out of 10.

3) Shorter-term Generation Markets:

Some parts of the country have markets that are close to the ideal of 5-minute markets with short advance scheduling (“gate closure”) requirements, as well as efficient ancillary services markets. The Northeastern ISOs and RTOs typically use this model.

In many areas inside and outside of ISOs and RTOs, wind is simply pooled into a vertically integrated utility’s resource mix, which works at low penetration levels. This approach does not work well if the buyer or owner is an entity other than the host utility, which is more likely to be the case as markets for wind energy grow. In most regions, scheduling is hourly and gate closure times are longer. Until recently there were “imbalance penalties” of up to $100 per MWh, but these were eliminated by FERC.

In regions with hourly markets, wind energy is often balanced with expensive regulation service as opposed to lower cost and equally effective load following service. This is like requiring the use of a Mercedes when a Honda Civic will do the job. This is one of the issues that the Northwest Wind Integration Action Plan addressed. There are a number of other inefficiencies in the operation of short-term markets that effectively raise the cost of wind integration.

A good measure of performance for a region’s use of short-term markets is the wind integration costs that have been estimated for that region. In general, studies in the U.S. calculate these costs as being in the range of $3 to $5 per MWh of wind energy, which is not excessive. However, some studies are beginning to find higher costs where designs are not as conducive to wind integration. Given the limited development of short-term markets, we score this at a 1 outside of RTOs and ISOs, and a 5 inside.

4) More Flexibility in Generation and Load:

The Pacific Northwest and Upper Midwest have significant hydroelectric resources that can provide the flexibility to integrate variable resources. However, this flexibility itself has become a scarce resource, as considerations such as fish protection and droughts limit the availability of this flexibility.

New gas-fired generation was installed in significant quantities over the last decade in all regions, and the dispatch flexibility of these turbines has helped integrate more wind. Future gas generator designs being marketed will have even more flexibility. In addition, well-functioning markets can create the incentive for generator owners to operate their plants in a way to make them more flexible. In the extreme, operators could keep all generation on-line and available if needed to balance the system and operate perfectly reliably. Decades ago before advances in load forecasting and Energy Management Systems, this is not unlike how some power systems were operated.

Demand response is being used at low levels in all regions of the U.S. There is significant policy interest in promoting demand response, but the jurisdictional split between federal regulators of wholesale markets and state regulators of retail service creates a disconnect.

A future challenge for integrating variable resources may be the large-scale development of coal and nuclear units. These units, like wind, are generally not dispatchable and thus require significant flexibility from other generators or loads.

A significant opportunity in the future will be plug-in hybrid electric vehicles (PHEV’s). The batteries in PHEVs would likely be paid for by reducing the owner’s gasoline expenses, and thus could offer cost-effective storage for the electric power system. Many PHEV’s would also be charged at night, which should provide an expanded market for the excess wind energy production that some regions experience at night. Currently, energy storage are far more expensive than dispatching flexible generation to provide balancing service.

We rate flexibility at a 2 out of 10 currently, based on the limited hydroelectric and demand side resource, and the escalating cost of gas-fired generation. More efficient energy services markets are the best policy solution to create incentives for the provision of additional flexibility.

5) Wind Forecasting Effectively Integrated into System Operations:

Wind forecasting is making great strides in the U.S. Current challenges include improving the accuracy of forecasts and integrating forecasts directly into power system operations. It is possible to integrate the wind forecast into the existing load forecast, which is provided to operators every 15 minutes for typical systems. In this way the operator would receive a net load forecast (load minus wind). However, this is not done generally.

We rate this at a 4 out of 10 based on the high quality of wind forecasting that is being done but significant needs to expand and improve its use and integration into power system and market operation.

6) More Flexible Transmission Services:

The flexibility of service varies from very good to very poor. No regions use dynamic line ratings in any significant fashion to date.

In the two-thirds of the country with RTOs and ISOs, transmission service is very flexible. Generally these entities offer financial transmission rights (FTRs) in which customers can schedule power in almost any direction at any time if they are willing to pay congestion costs, and they can pre-pay or "hedge" these costs with the FTR. Thus no physical schedule is required. These rights provide maximum flexibility for the customer. We give transmission services in these areas a 7 based on the flexibility but lack of dynamic ratings.

In the one-third of the country without RTOs, transmission service is physical and requires capacity reservations. Thus wind customers pay for transmission 100% of the time while only using it approximately 1/3 of the time. Progress was made recently by FERC by requiring Conditional Firm Service which provides access to transmission capacity when the customer is willing to forego service at certain pre-defined peak usage times, a policy that provides significant benefits for wind. In addition, FERC required transmission owners to offer re-dispatch service, which can allow wind energy to more efficiently offset more expensive generation in regions affected by transmission constraints. The value of these services is somewhat limited by the requirement that they be re-negotiated every two years, which makes project financing more difficult. We rate these regions outside of RTOs and ISOs a 2 on flexible transmission services.

D. Summary and Conclusion

Table I provides a summary of the ability of the U.S. electric system to accommodate high levels of wind penetration. With reference to a feasible national target of obtaining 20 percent of U.S. electricity from wind by 2030 (from 17 GW today to just over 300 GW then), the U.S. electric system has a long way to go. Limitations in each of these areas are already having an impact by slowing development or pushing development of wind projects into areas with poorer wind resources. Our scores average around 3 out of 10, indicating that changes must be made in the near term to integrate the next level of wind. The optimal electric system structure described in this paper would also have major benefits for reliability and for connecting any of the other low- and zero-carbon sources that are available in the U.S. It will likely take a vision articulated at the highest levels to begin moving the electric industry in the direction of these reforms that are essential for greater electric reliability and increased access to clean generation.

Table I. Summary of status of transmission and grid integration reforms in the United States.

Goal	**Policy Solution**	**Current Status**	**Score**
Larger balancing areas	Balancing area consolidation and formation of ISOs/RTOs	ISOs/RTOs have helped, but there are still a large number of small balancing areas	1-5, by region and entity
More robust electric grid	Regional transmission planning and effective cost-recovery measures	Regional transmission organizations (RTOs) have helped in some areas, although there is a severe and widespread need for more transmission	3
Short-term generation markets	Short-term markets can be implemented by balancing authorities	Short-term markets in a few regions; most have hourly markets or no market at all	1 to 5 by region
More flexibility in generation and load	Ancillary services markets that create the incentive for provision of flexibility	A few regions have adequate flexibility, while most do not	2
Wind forecasting effectively integrated into system operations	Wind forecasting implemented by the system operator	Wind forecasting operational in some regions that need it, about to become operational in others	4
More flexible transmission services	Policies that allow wind to use transmission infrastructure when it is not in use	FERC Order 890 in 2007 created conditional firm tariffs, although these tariffs not in use yet; also re-dispatch service	2 to 7 by region

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IV. BIOGRAPHIES

Robert Gramlich leads the American Wind Energy Association's work in transmission, policy analysis, and regulatory policy. He frequently testifies before state and federal agencies and he works with wind companies on the state, regional, and national levels to address transmission challenges. He recently co-authored the article "What Comes First?" on wind transmission policies in the U.S. that appeared in the Nov/Dec 2007 issue of IEEE Power and Engineering Magazine. He has been involved in electric industry analysis and policy for about fifteen years. He was the Economic Advisor for FERC Chairman Pat Wood, III from 2001 until 2005. He is on the Department of Energy's Electricity Advisory Committee. He has held positions as a market analyst in the PJM Market Monitoring Unit, the PG&E National Energy Group, the World Resources Institute and Lawrence Berkeley National Laboratory. Rob has a master's Degree in Public Policy from UC Berkeley and a BA with honors in economics from Colby College.

Michael Goggin joined the American Wind Energy Association in February 2008. He represents the wind industry on transmission matters, coordinates member input on the development of policy positions, facilitates the exchange of information between members, handles press inquiries on transmission-related issues, and advocates policy positions that advance wind industry interests. Through these activities, he works to promote transmission investment and advance changes in transmission rules and operations to better accommodate wind energy in the power system while maintaining system reliability. Prior to joining AWEA, he worked for two environmental advocacy groups and a consulting firm supporting the U.S. Department of Energy's renewable energy programs. Michael holds a B.A. with honors in Social Studies from Harvard College.