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Integrating Wind and Solar Energy in the U.S. Bulk Power System: Lessons from Regional Integration Studies

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Introduction

With the pace of renewable energy development in the United States increasing, questions are arising about how to integrate higher penetrations of renewable energy into the bulk electric power system. Weather-induced variability of renewable energy sources, such as wind and solar, can pose challenges for electric power systems. While they are designed to handle variable loads, power systems may require some operational changes to handle the additional variability of renewable resources.

Two recent studies sponsored by the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) have examined the impacts of integrating high penetrations of wind and solar energy on the Eastern and Western electric grids. The Eastern Wind Integration and Transmission Study (EWITS), initiated in 2007, examined the impact on power system operations of reaching 20% to 30% wind energy penetration in the Eastern Interconnection. The Western Wind and Solar Integration Study (WWSIS) examined the operational implications of adding up to 35% wind and solar energy penetration to the Western Interconnect. Both studies examined the costs of integrating higher penetrations of variable renewable energy generation into the grid as well as transmission and operational changes that might be necessary as a result.

This paper identifies key insights from these regional studies. The studies share a number of key findings, but other results vary due to differences in grid operations and markets, the geographic location of the renewables, and the need for transmission.

Study Methods and Assumptions

Both the Eastern and Western studies used production cost models to examine scenarios of variable renewable energy penetration. Each study relied on a technical review committee of power system industry stakeholders to review inputs and assumptions. Key objectives and design elements of each study are detailed below.

Eastern Wind Integration and Transmission Study

EWITS modeled four scenarios of high wind energy penetration representing different levels of wind development in the Eastern Interconnect by 2024. The study provided data on: 1) the amount of wind generation required to meet 20% of the electrical energy demand in the East in 2024, and 2) for each scenario, possible transmission development scenarios for delivering energy economically. EWITS examined the following scenarios.

- A **Reference Scenario** that approximates the current level of wind energy development in addition to the expected level of near-term development considering project interconnection queues and state renewable portfolio standards (RPS) requirements. The wind energy in the reference scenario equals about 6% of the 2024 projected load requirements for the Eastern Interconnection.
- **Scenario 1, 20% penetration** assumes onshore wind with a high capacity factor utilizing high-quality wind resources in the Great Plains and development of other good wind resources in the eastern United States. The 20% scenarios would call for about 225,000 megawatts (MW) of wind generation capacity, about a tenfold increase from current levels.
- **Scenario 2, 20% penetration** assumes both land-based and offshore wind, shifting some wind generation from the Great Plains to other areas in the East and assuming some East Coast offshore wind.
- **Scenario 3, 20% penetration** assumes local development with aggressive offshore wind development. More wind generation is moved east toward load centers, with the offshore wind assumptions representing an upper bound of offshore development by 2024.
- **Scenario 4, 30% penetration** assumes aggressive on- and offshore development. Meeting the 30% energy penetration level uses a substantial amount of the available higher quality wind resource,

including substantial offshore wind. The 30% scenario equals about 330,000 MW of total wind capacity.[1]

Western Wind and Solar Integration Study

The WWSIS modeled several scenarios of wind and solar energy penetration in 2017 to determine potential impacts on grid operations. While WWSIS is not a transmission planning study, it did examine a number of options for expanding interstate transmission in the West. The study specifically examined: 1) several scenarios in which wind and solar energy penetration reached 11% to 35% of energy needs, 2) several scenarios reflecting possible differences in the geographic locations of the wind and solar development, and 3) a number of sensitivities to assess the impacts of fuel costs, reserve levels, storage, balancing area size, and other factors. WWSIS included three scenarios of possible development patterns to examine the impacts and tradeoffs between 1) resources with low capacity factors that are close to load and 2) remote resources with higher capacity factors that require long distance transmission to meet loads.[2] The four levels of wind and solar energy penetration assumed for the study scenarios were:

- The **Preselected case** assumes wind and solar capacity installed by the end of 2008, which is equivalent to 3% wind and solar in the study footprint and 2% wind in the rest of the Western Interconnect.
- The **10% case** includes 10% wind energy and 1% solar energy of total annual load in the study footprint covering the WestConnect transmission region[1] (about 11,000 MW), with the same fraction in the rest of the Western Interconnect (about 23,000 MW).
- The **20% case** assumes 20% wind energy and 3% solar energy in the study footprint, with 10% wind energy and 1% solar energy in the rest of the Western Interconnect.
- The **20/20% case** assumes 20% wind energy and 3% solar energy in the WestConnect study footprint (about 23,000 MW), as well as in the rest of the Western Interconnect (about 25,000 MW).
- The **30% case** assumes 30% wind energy and 5% solar energy in the study footprint (about 36,000 MW), with 20% wind and 3% solar in the rest of the Western Interconnect (about 53,000 MW).

Shared Lessons from Eastern and Western Integration Studies

These studies shed light on the operational changes required to accommodate higher penetrations of renewable energy generation on the U.S. electric grid. We focus here on findings related to the level of penetrations that can be managed, integration costs, the impact of operational issues such as balancing area size, use of forecasting, scheduling and dispatch frequency, use of demand response, and the ability for wind and solar to contribute to resource adequacy.

Higher penetrations of variable renewable generation are manageable

How much variable renewable generation can U.S. power systems manage? The Eastern and Western studies found that by 2025, with operational changes and expanded transmission access, high penetrations—up to 30% or 35%—of variable renewable generation are technically feasible to integrate so that load and generation can be balanced for all hours of the year.

In the Western study, the scenarios with 10% renewable energy penetration show substantial benefits in terms of operating costs with no negative impacts on system operations. A scenario of 20% renewable energy penetration found some instances of insufficient reserves on the system as a result of forecast errors. While these instances could be addressed, it is more challenging to do so than in the lower penetration scenario. Under the 30% penetration case, load and contingency reserve requirements are met only if the wind and solar forecasts are perfectly accurate.

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[1] WestConnect includes Arizona, northern California, Colorado, Nevada, New Mexico, and Wyoming, see http://westconnect.com/aboutwc.php, accessed August 23, 2012.

Both the Eastern and Western studies found that annual operating costs are lower because of fuel and emissions savings (assuming carbon has a value) that result from increased levels of wind and solar energy on the system. In the Western study, the high renewable penetration case reduced annual operating costs by 40%, or $17 billion in 2009$, compared to the reference case. In EWITS, the high renewable energy case reduced the annual production costs by 10% ($69 billion in 2009$), compared to the reference case.

Larger balancing areas and geographic diversity of renewable resources are preferred to minimize impacts

Both the Eastern and Western studies as well as other recent studies3 show that large operating areas and sufficient transmission access are effective measures for managing wind energy. Larger operating areas provide benefits of reducing the variability of the wind and solar when it is spread over a larger geographic area and providing access to more resources for balancing the system. Costs can be reduced through reserve sharing over larger areas or balancing area cooperation that enables pooling of reserves.

In the 10% renewable penetration case, the Western study found system operating cost savings of $1.7 billion in 2009$ from larger balancing areas. The study compared five large balancing areas versus 106 zones in the southern part of the interconnection that are roughly equivalent to today's regions. Sharing reserves over larger regions results in significant efficiency and costs savings even without wind and solar on the system.

Aside from merging smaller balancing authority areas, several other ways to achieve balancing area cooperation are already being implemented or considered in the Western United States, where small balancing areas are relatively prevalent. In the West, an energy imbalance market is under consideration and could if implemented help balancing authority areas manage variability by accessing flexible generation throughout a broader region. Implementing an energy imbalance market could substantially reduce the amount of reserves required to manage variable generation.[4]

Other mechanisms that could effectively enhance balancing area cooperation include: dynamic scheduling and the Area Control Error (ACE) Diversity Interchange (ADI), which enables participants to net out imbalances.[2] Dynamic scheduling allows generation to be controlled by a balancing authority area authority other than the one where it is physically located. This can be beneficial for wind or solar energy projects in areas with limited ability to handle the added variability. The ADI takes advantage of the fact that some balancing authority areas have excess generation while others have shortages. It enables participating balancing authority areas to net out imbalances, which increases system efficiency and reduces the amount of regulation reserves needed.

Sub-hourly scheduling and planning are preferred

Both studies reinforce the idea found by other integration studies that sub-hourly scheduling and dispatch can aide in the integration of higher penetrations of wind and solar on the grid. The Western study found that hourly scheduling as is used in areas of the West today had a larger impact on balancing needs than the additional variability introduced by higher penetrations of wind and solar. Sub-hourly scheduling and dispatch is beneficial because it reduces the reserves required by the system and reduces the movement needed by generators providing balancing service. The Western study found that with sub-hourly scheduling, the amount of maneuvering of combined cycle plants is about half of that which occurs with hourly scheduling. WWSIS also found that the use of hourly scheduling has a larger impact on resources

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[2] For additional information on ADI, see Southwest Power Pool presentation "ACE Diversity Interchange Program, April 14, 2009.
http://www.spp.org/publications/SPP%20ADI%20Implementation%20for%20MOPC%20041409.pdf, accessed August 23, 2012.

needed to provide regulation service (balancing) than the variability introduced from the levels of wind and solar examined in the study.

In the Eastern interconnect, the wholesale power markets already use 5-minute scheduling and dispatch of generation. In the East, efforts are underway to increase the scheduling frequency across neighboring markets, which is expected to help integrate wind and solar more efficiently particularly in areas with transmission congestion.[5] In the West, sub-hourly scheduling and dispatch is being explored. In particular, the Energy Imbalance Market currently under consideration would lead to an imbalance energy market with 5-minute dispatch.

Using advanced forecasting can reduce costs

Forecasting is an important tool for reducing the uncertainty associated with variable generation. While forecast accuracy is increased closer to the time of actual generation, incorporating day-ahead forecasting into the process of committing generation units can help operators mitigate the uncertainty of wind generation.

The Western study found that using advanced forecasting in the day-ahead unit commitment process would reduce annual operating costs in the Western Interconnect by up to $4 billion in 2009$, compared to not considering renewables in unit commitment. If forecasts were perfectly accurate, they would reduce annual costs by another $425 million in 2009$. While forecasts will not be perfectly accurate, this metric indicates the upper bound of potential cost savings with improved forecasting.

Demand response can be cost-effective

Demand response is one mechanism for providing systems with operational flexibility. It can be useful for assisting with the integration of variable renewable generation by helping to address large loss of generation events. The Western study compared the use of demand response and spinning reserves to meet contingency reserve shortfalls resulting from wind forecast errors with higher penetrations of wind on the system. The study found that it was more cost-effective to rely on demand response to address contingency reserve shortfalls for the 89 hours/year when they were needed than to carry additional spinning reserves for all hours of the year. WWSIS found that using demand response rather than spinning reserves saved up to $510 million (2009$) in annual operating costs.

Integration costs are manageable

Systems can incur costs due to increased balancing resources needed to manage variable renewable energy generation on the system. The costs can include the need for additional operating reserves, changes in dispatch, and new transmission. When considering renewables integration costs, it is also important to keep in mind that all generation sources have costs associated with managing them on the grid.[6]

The Eastern study estimated that the cost of integrating renewable energy is less than $5 per megawatt-hour (MWh) of wind generation, or $0.005 per kilowatt-hour (kWh), assuming large balancing areas and full regional markets. Thus, the costs for integrating high penetrations of wind in EWITS are manageable given significant operational changes and large regional operating systems.

The EWITS integration cost estimates are consistent with estimates from other integration studies. Integration costs for penetrations of wind energy up to about 40% of peak system loads are below $10/MWh and often below $5/MWh.[7] Cost estimates vary depending on calculation methodologies, market and power system operating characteristics, wind penetration levels, fuel price assumptions, and other factors.

A study by the ISO/RTO Council notes that the costs of integration vary based on the generation dispatch interval and the balancing area size. For example, Table 1 compares the difference in integration costs for areas with and without sub-hourly scheduling and dispatch. In areas with 5- or 10-minute generation dispatch, integration costs associated with dispatching units (not including transmission) ranged from $0-$4/MWh, while integration costs were $8-$9/MWh or higher in regions with hourly dispatch.[8]

Table 1: Comparison of Wind Integration Costs in Five Studies

Study Date	Study	ISO/RTO	Wind Capacity Penetration	Integration Cost: $/MWh of Wind Output	Energy Market Interval
March 2005	NYISO	Yes	10%	Very low	5 minute
Dec. 2006	Minnesota/MISO	Yes	31%	$4.41	5 minute
Feb. 2007	GE/Pier/CAIAP	Yes	33%	$0–$0.69	10 minute
March 2007	Avista	No	30%	$8.84	1 hour
March 2007	Idaho Power	No	30%	$7.92	1 hour

Source: ISO/RTO Council 2007

Renewables can play a role in resource adequacy – capacity value

While wind and solar are primarily energy resources, they can contribute to resource adequacy of the system. However, in contrast to conventional generators, only a portion of the capacity of wind and solar facilities can be relied on to be available to meet peak demand. The capacity value is to the fraction of the nameplate capacity rating of a wind or solar facility that can be considered as firm capacity. Both studies evaluated a range of capacity valuation techniques based on traditional Loss of Load expectation (LOLE) data to estimate the contribution of the wind and solar to the resource adequacy of the system.

In EWITS, wind generation was found to have an effective load carrying capability (ELCC) of 24% to 33% of the rated capacity. Additional transmission access was found to enhance the contribution of wind to resource adequacy. With expanded transmission access, the ELCC of wind generation was increased from a few to nearly 10 percentage points depending on the transmission scenario. It is important to note, however, that the analysis is based on three years of data that were available for the analysis, rather than the 10-15 years of data typically required for such analysis. Although wind generation cannot be relied upon for dispatch during system peaks, EWITS shows some probability that wind generation would be available during peak demand periods or periods when additional energy is needed to meet demand.

In the Western study, the evaluated wind generation resources were found to have capacity values of 10% to 15%. These values are relatively low because wind energy generation tends to be higher at night and during the winter and spring seasons, when system loads are not at peak levels. The study found that solar PV facilities have capacity values in the range of 25% to 30% (based on the DC rating of the PV). These values are higher than for wind but still limited because PV generates electricity during the day, but output generally declines in the late afternoon and early evening which are often peak demand periods. For concentrating solar plants with thermal energy storage, capacity values were in the range of 90% to 95%, similar to conventional generators.

Conclusion

Regional integration studies are an important means of understanding how to integrate higher penetrations of renewable generation. They build upon the extensive body of literature on grid integration and provide additional empirical evidence with respect to the needs for managing higher penetrations of wind and solar on regional electrical grids in the United States. These studies show that integrating penetrations of 20% to 35% renewable energy is technically feasible in regional grids, with added transmission and operational changes. In the Eastern and Western interconnects, operational changes, such as balancing area cooperation, sub-hourly scheduling, advanced forecasting, use of demand response, as well as increased access to transmission, can help integrate higher penetrations of variable renewable generation. Some of these changes are already underway. For example, some steps toward balancing area cooperation have been implemented in the West and faster scheduling between balancing areas is being implemented between the Pacific Northwest and California and in the Eastern markets.

However, questions remain. The second phase of these studies, now underway, is examining in greater detail issues raised by the initial studies. For example, the second phase of the Western study is examining the impacts of 1) cycling and ramping thermal plants to accommodate variability in the system and the associated emissions, 2) higher penetrations of renewable energy on the system, and 3) faster dispatch, using models that can simulate 5-minute dispatch. The second phase of the Eastern study is examining how to plan and operate the Eastern Interconnection in an uncertain future, with sensitivity analyses of load growth, fuel prices, policy drivers, and transmission expansion. Additional emphasis in the Eastern study is being placed on enhancing operational flexibility in the system, reserves analysis, regional and inter-regional impacts, and potential mitigation strategies, such as energy storage, plug-in hybrid electric vehicles, curtailment, and demand response.

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[1] For additional information on the study design, assumptions and results, see the Eastern Wind Integration and Transmission Study, prepared by EnerNex Corporation for the National Renewable Energy Laboratory, Golden: CO, revised February 2011 http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_final_report.pdf

[2] For additional information on the study design, assumptions and results, see the Western Wind and Solar Integration Study, prepared by GE Energy for the National Renewable Energy Laboratory, Golden: CO, May 2010 http://www.nrel.gov/wind/systemsintegration/pdfs/2010/wwsis_final_report.pdf

[3] See for example, Corbus, D., D. Lew, G. Jordan, W. Winters, F. Van Hull, J. Manobianco, and R. Zavadil. November/December 2009. "Up with Wind: Studying the Integration and Transmission of Higher Levels of Wind Power." *IEEE Power and Energy*, 7(6): 36–46.

[4] J. King, B. Kirby, M. Milligan and S. Beuning, *Flexibility Reserve Reductions From an Energy Imbalance Market With High Levels of Wind Energy in the Western Interconnection*, NREL Report No. TP-5500-52330, October 2011, http://www.nrel.gov/docs/fy12osti/52330.pdf

[5] ISO/RTO Council (2011). Briefing Paper: Variable Energy Resources, System Operations and Wholesale Markets, August . http://www.isorto.org/atf/cf/%7b5B4E85C6-7EAC-40A0-8DC3-003829518EBD%7d/IRC_VER-BRIEFING_PAPER-AUGUST_2011.PDF

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[7] U.S. Department of Energy, 2011. 2010 Wind Technologies Market Report, Prepared by Lawrence Berkeley National Laboratory, June. http://eetd.lbl.gov/ea/EMP/reports/lbnl-4820e.pdf

[8] ISO/RTO Council , (2007). *Increasing Renewable Resources: How ISOs and RTOs Are Helping Meet This Public Policy Objective*. October 16. http://www.isorto.org/atf/cf/%7B5B4E85C6-7EAC-40A0-8DC3-003829518EBD%7D/IRC_Renewables_Report_101607_final.pdf