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Review of the Western Wind and Solar Integration Study (WWSIS) by NREL and GE Energy

Posted by Stephen Balogh on December 6, 2010 - 10:21am

(The post below is from Steve Balogh, a contributor on TOD since 2006 writing on sustainability issues under the name Baloghblog. He is a graduate student at SUNY-Syracuse and is a research associate working on energy systems for the Institute for Integrated Economic Research)

This post presents a critical review of the Western Wind and Solar Integration Study (WWSIS) published by NREL and GE Energy earlier this year. The goal of this multiyear study was to determine the feasibility of incorporating large amounts of wind and solar energy into the Western U.S. and determine the effects of doing so.[i] An earlier Department of Energy study, *20% Wind Energy by 2030*, found that in order for the continental U.S. to achieve 20% as a whole for wind energy consumption, 25% would have to be produced in the Western Interconnection. The authors of the WWSIS study conclude that it is possible (with a few caveats) to absorb and manage highly variable production from high penetrations of wind and solar energy, up to 30% wind and 5% solar. This post provides an overview of the assumptions and models used in the study, reports major findings, and considers what may be flaws inherent in the NREL/GE Energy efforts. (An executive summary of their project, models, and findings can be found here, and the full study here.)

Background

The WWSIS study area consists of land in 5 states in the U.S., the "West Connect" group of utilities, Wyoming, Colorado, New Mexico, Arizona and Nevada (WY, CO, NM, AZ, NV) which are in the Western Interconnection in the United States. The Western Interconnection includes nearly the western 1/3 of the U.S. from Washington down to California, and its eastern border includes the states from Montana to New Mexico (see figure below).

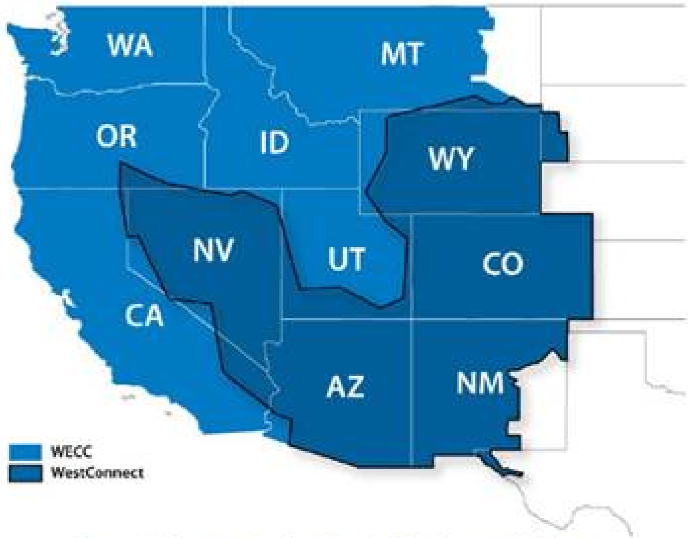

Figure 1.1 Geographic Footprint of WestConnect Utilities

Modeling Assumptions

Our analysis of the study begins in the modeling assumptions. The authors conclude that 30% wind, and 5% solar integration in the West Connect region is possible – even at high (20%) penetrations of renewable energy in the greater Western Interconnection – if the following conditions are met (p. ES-3):

1. Substantially increase balancing area cooperation or consolidation, real or virtual;

2. Increase the use of sub-hourly scheduling for generation and interchanges;

3. Increase utilization of transmission;

4. Enable coordinated commitment and economic dispatch of generation over wider regions;

5. Incorporate state-of-the-art wind and solar forecasts in unit commitment and grid operations;

6. Increase the flexibility of dispatchable generation where appropriate (e.g., reduce minimum generation levels, increase ramp rates, reduce start/stop costs or minimum down time)

7. Commit additional operating reserves as appropriate;

8. Build transmission as appropriate to accommodate renewable energy expansion;

9. Target new or existing demand response programs (load participation) to accommodate increased variability and uncertainty;

10. Require wind plants to provide down reserves.

Another important assumption is that the new wind and solar generating capability will be added to the existing power plants, and those scheduled to be added by 2017. The current generating capacity (renewable and non-renewable) of the western interconnect is [184 GW with a capacity margin of 22%] (total unused capacity available at peak load as a percentage of capacity resources). According to the EIA, this is expected to rise to 204 GW by 2013 with a capacity margin of nearly 30% (see table below). At the proposed maximum integration of wind and solar (30%/5%), along with an additional 20% outside the study area within the Western Interconnect, 75.4 GW of nameplate wind capacity and 13.3 GW of solar will be added. Although the net capacity addition will be smaller due to the lower capacity factors of renewable electricity generation (capacity factor assumptions: 31.6% Wind, 15% Solar, 90% CSP), according to my estimates, this still represents a substantial increase in capacity margin to the system.

Table 1: Total (Thermal and Renewable) Electricity Generating Capacity

Western Interconnect	Maximum Generating Capacity	Capacity Margin
Current	184 GW	~22%
EIA Projected (2013)	204 GW	~30%
EIA Projected+WWSIS Proposed: 30% Wind / 5% Solar	293 GW	~39%

Challenges to the study’s assumptions:

According to my analysis, the assumptions highlighted in bold text above are the ones that present the greatest challenge to the feasibility of the project. The NREL authors readily admit in most cases that these issues will be difficult politically and technically (but maintain that they are not impossible) to overcome. Let's look more closely at these assumptions, and examine how the system as it currently operates differs from this proposed.[ii]

1. Renewable energy capacity added on top of proposed and existing capacity

The authors are able to disregard the periods of extreme underproduction, even if these periods are infrequent, by assuming that we will continue to add traditional thermal (fossil fuel) generation equal to the amount needed to meet demand without renewable energy. This is consistent with one of the key findings of my dissertation research to date: that in order to increase generation capacity of renewable energy from stochastic sources, traditional, controllable sources of electricity generation must be maintained sufficient enough to provide 100% of the demand, if the renewable energy sources are producing 0%.

2. Grid Network Integration

The scenarios assume that the patchwork of over 100 independently managed grid sections can be neatly combined into 5 large grid regions. This goes hand in hand with the assumption that the current delivery system that includes dedicated or reserved transmission lines would be eliminated and replaced with a barrier-free transmission grid open to any suppliers. All generation would need to be economically dispatched, and managed across several states, e.g. if there is overproduction from higher than forecast wind in WY, flexible generation in combined cycle plants could be turned down in NM if that were the nearest and most economical option (p. ES-17). During extreme variations in wind production, grid stability would be dependent on absorption of excess wind, or ramping up of power plants in the greater Western Interconnection. At several times in the report, the importance of the greater interconnection to the feasibility of the West Connect projects is stressed. During at least one week in April, the authors admit (p. 310):

> the high, variable, wind output dominates the net load ... leading to several hours of

negative net load[iii] during the week. Combined-cycle generation is almost completely displaced, and significant levels of coal generation are displaced by wind and solar generation. Nonetheless, the system can operate through this challenging week with balancing area cooperation. Without balancing area cooperation, operations during the week would be extremely difficult, if not impossible, for individual balancing areas.

Because of the assumed balance area cooperation (and other assumptions), the authors highlight that at 30% penetration, only 0.5% of wind energy production would need to be curtailed.

3. Coal plants are able to be operated as load-following plants, substituting for higher cost natural gas plants

The study also assumes that coal powered power plants can be, and will need to be operated in a very flexible manner, at times operating at only 40% of nameplate capacity. While this may be consistent with emergency operating levels, the rapid and frequent increase and turn down of coal power plants over a long period of time is an untested use of their capabilities and is expected to increase operating expenses and maintenance time (p. 104, 141). This repeated cycling of coal power plants would increase the cost of electricity from coal, while at the same time, revenues earned by coal plants are expected to decline due to decreased operating times.

4. Maintaining spinning reserves to deal with infrequent extreme changes is cost-prohibitive. Load management will be used because it is more economically feasible to do so.

The authors conclude that maintaining enough spinning reserves[iv] to deal with infrequent extreme changes in wind and solar output relative to demand is not cost effective, and that demand response programs (load management) should instead be incorporated. However, the authors do not delve more deeply into this issue, nor propose which businesses or loads would be available to be curtailed at a moment's notice, only stating that even high economic incentives for demand control would be cheaper than maintaining high percentages of spinning reserves. Unlike the current system of peak load shedding or load-shifting (which mostly takes place during peak loads in the summer, or during periods with the highest energy prices), the episodes where there are rapid decreases in wind and solar production are often not coincident with large increases in demand, meaning that those participating in the demand-side management would need to be much more flexible, and available to cut back loads at all hours of the day at any time of year. Equally, wind and solar do not result in short or periodic disruptions, but rather in extended over- and undersupply situations. This relative unpredictability creates negative economic implications (equipment utilization and workforce flexibility).

5. Expansion and development of renewable energy capacity will be a coordinated process

Also inherent in the study is that the expansion of renewable energy, especially wind, will be a coordinated effort whereby each state progresses to a similar penetration level. The authors admit in the study that individual states with large increases in wind penetration face multiple hours per year of overproduction (p. 55, for example). If the other states were not progressing as quickly as others, or if individual states where wind power capabilities are higher decide to seek a higher penetration level of wind, it may result in a disruption of the balance of electricity production and result in the curtailment of wind energy during periods of high wind production. If a state outside the study area, take California for example, decided to raise their R.E. capacity higher than the 20% modeled in the WWSIS, the challenges to integrate high levels of R.E. in the study area may become too great to overcome.[v] The authors do run an alternative scenario where new wind capacity is built in the best available wind resource areas, and interconnections between states are constructed – this scenario also assumes a even higher level coordination of development.

6. Other modeling issues

Models by definition are simplifications of a system (**Hall et al. 2000**). In the WWSIS the authors examine interstate transmission costs, but chose not to include and examine the cost of building intrastate transmission lines to handle the increased remote generation by wind or solar farms (p. ES-7). The sunk costs, economic or energetic, were also ignored for the purposes of this study but should be examined with more scrutiny in future studies, as proposed.

7. Electricity Storage

In the "give credit where credit is due" category, I'll point out the study's examination of high capacity storage's role in an electrical grid with high levels of renewable energy. The authors reach the same conclusion as I have - that large scale storage as a means of capturing excess wind and solar power and releasing it during times of need is not economically feasible, nor is it as helpful as initially suspected in filling production gaps. The authors use pumped hydro storage as their example storage system – pumped hydro being the most inexpensive form of storage, and having high turn-around efficiencies over long periods. According to the authors, even with perfect forecasting, the units were still much more expensive than just adding additional flexible generation from natural gas. Pumped hydro storage was not able to take advantage of price arbitrage during the day. Quoting (p. 281):

> At the 30% penetration level, the [annual operating] value [of pumped storage] jumps up significantly, but is still only $3.8 million/year of operating value. This translates to roughly $380/KW which, even with a generous capacity value, is still more than $1000/kW below the cost of a new [pumped storage] facility. Even perfect foreknowledge of when the prices will spike and drop does not seem to provide sufficient value to justify adding any new storage facilities.

Short term storage in concentrated solar thermal plants does show some promise. PV solar production begins to decline just as the afternoon demand peak begins; however, CSP with storage allows these plants to produce power through periods with the highest demand. CSP storage benefits saturate at approximately 6 hours, and add 10% to operating revenues (p. 285). This, however, only partially mitigates the high cost per MWh from these plants in comparison to traditional thermal generation and even wind.

8. Plug-in Hybrid Electric Vehicles

The authors also examined the load effects and storage capabilities of Plug-in Hybrid Electric Vehicles (PHEV). Starting from a dubious assumption, that PHEV would only be charged at night, and then only during the hours of 11 p.m. to 6 a.m. the authors conclude that PHEV do increase the value of renewable energy by 50 cents per MWh, but also find that (p. 289):

> Adding the PHEV demand did not significantly change either the unserved or the spilled energy.

9. Other interesting findings:

- Large solar and wind drops tend to be more coincident across wide areas than large rises (p. 86)
- Distributing the wind generation capacity as a percent of state demand, rather than based on the best suited sites within the multistate area, compounds issues of over and underproduction. For example to meet 30% of Arizona's annual demand from wind power would require a much larger installed capacity than if the wind were installed in Wyoming where wind resources are greater. In Arizona this would mean that wind production would push the minimum net load (demand minus wind minus solar) below current observed minimum levels for 45% of hours in the year. And the highest minimum net load is 5 GW (wind and solar output is 5 GW higher than demand). (p. 55)
- For the entire study area at a 30% level of annual wind production, the minimum net load (load minus wind minus solar) would be below the current minimum load of 22,169 MW for 57% of the year (p. 53). The authors report "there is nothing inherently critical about this minimum load threshold. The system may be able to operate well below this load level, but it simply serves as a reference point for illustration." How much "well below" the observed minimum load level that can be tolerated remains to be seen. Our contention is that coal plants are much less flexible than assumed in this study. What is not debatable is the fact that the minimum net load hour for the year (modeled after 2006 wind conditions) reaches -2,914 MW. This means that wind and solar production, alone, in this hour, produced an excess 2,914 MW – this without considering any other base load plant that might be operating (nuclear, base load coal, etc.). This is nearly 3 GW of electricity that must be exported and absorbed outside of the system (see figure below).

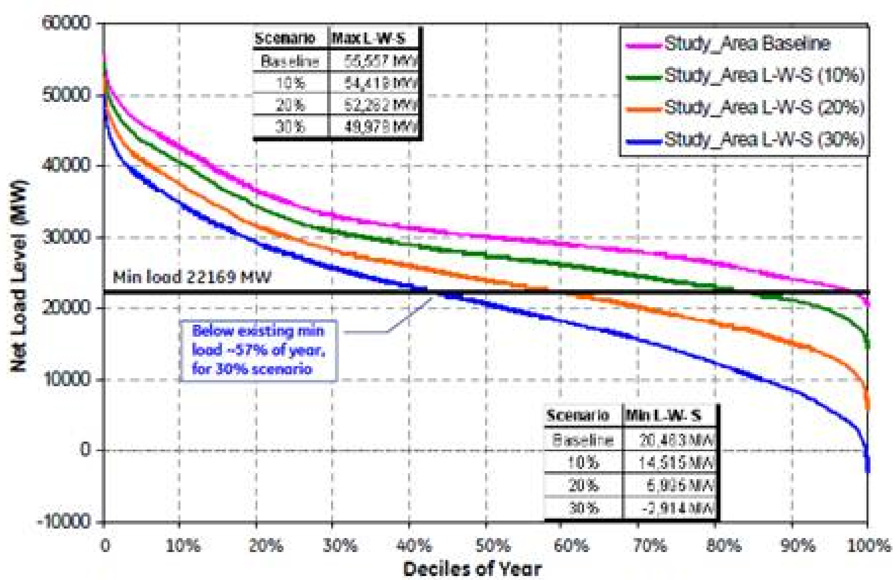

Figure 4.16 Study Footprint 2006 Net Load Duration for the In-Area Scenario

10. Accuracy vs. Precision

One final issue that must be raised is the issue of accuracy versus precision. Very precise values are given for the amount of wind consumed/curtailed/exported, as well as precise dollar amounts for costs and savings (although they have been rounded, only a single value is given). It is understood that decision makers like to have solid numbers to judge whether a project should move forward or not. However, it seems reasonable, given the highly variable nature of wind and solar production, as well as the inherent variation in electricity generation and consumption itself, that the predicted values should be presented as a range, or confidence interval, rather than a specific estimated number.

Conclusions

The NREL/GE Energy WWSIS study appears to be built on several questionable assumptions, each allowing the modeled system (of up to 30% wind/5% solar in the West Connect within the great Western Interconnect) to withstand the inherent difficulties of large scale renewable integration. The primary issue, consistent with my dissertation research[vi], is that the authors assume that we can afford to massively overbuild the capacity of the system, adding the large percentages of renewable generation on top of newly built and existing plants. This allows one to be able to ignore the hourly or sub-hourly periods with extremely low output from renewables, as well as the days or weeks at a time during the summer when wind production is well below yearly average output levels. An ample reserve is at the ready to step in when renewables perform poorly. Secondly and equally important, the authors assume that coal plants, which have traditionally run in a base load capacity, will be able to be operated very flexibly – on par with combined cycle gas plants. This allows the authors, on one hand, to state that electricity prices will be kept low, because we will still be able to burn less expensive coal as our primary non-renewable source of electricity (instead of having to switch to more expensive natural gas), but also to claim increased upside flexibility in the system to deal with periods where wind and solar output decrease rapidly and reserves need to be brought on line. Next, like previous studies, the authors assume that there is an "away" to export excess generation to during times of overproduction. By assuming that the greater Western Interconnect is available to absorb excess production (by economic dispatch and regional grid management), the authors assume minimal to no curtailment in wind production needed in periods of overproduction. If on the other hand balancing is limited to smaller areas, the authors admit that the system might not be stable.

It is my opinion that this study is far from conclusive in its assertion that very high penetrations of wind and solar electricity generation are feasible in the Western Interconnect. Although the authors of the study performed a very detailed analysis, it is one that I feel is based on technological, bureaucratic, and political optimism.

Endnotes:

[i] The WWSIS is the sister product of a study that began in 2008 and was completed in January 2010, on the feasibility of adding 20-30% wind energy to the Eastern U.S. electrical grid (EWITS).

[ii] I do not assume in general that technological or political progress is not possible or feasible. My objection lies chiefly with the methodology used in this study. I feel that the results would be more telling if the authors had first examined the issue from the current state of technology and cooperation, and then modeled the required changes needed to attempt to operate an electrical grid with over 1/3 of generation from wind and solar power.

[iii] Net load is defined as demand minus wind minus solar

[iv] Spinning reserve: Spinning Reserve is the on-line reserve capacity that is synchronized to the grid system and ready to meet electric demand within 10 minutes of a dispatch instruction. Spinning Reserve is needed to maintain system frequency stability during emergency operating conditions and unforeseen load swings.

[v] California has just adopted a 33% renewable energy standard for electricity production by 2020 (see here and here for details). This standard does **not** allow renewable electricity production by utilities in other states to count towards the 33% level – all production must be from California utilities.

[vi] My prior research at IIER found that in large scale integration of wind energy, to maintain

grid stability, capacity in traditional controllable sources of electricity generation – equal to the maximum demand level – must be maintained in order to avoid supply/demand mismatches. This principle applies to both small scales (state or country level) to large scale multi-nation grid systems.