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Analysis of Sub-Hourly Ramping Impacts of Wind Energy and Balancing Area Size

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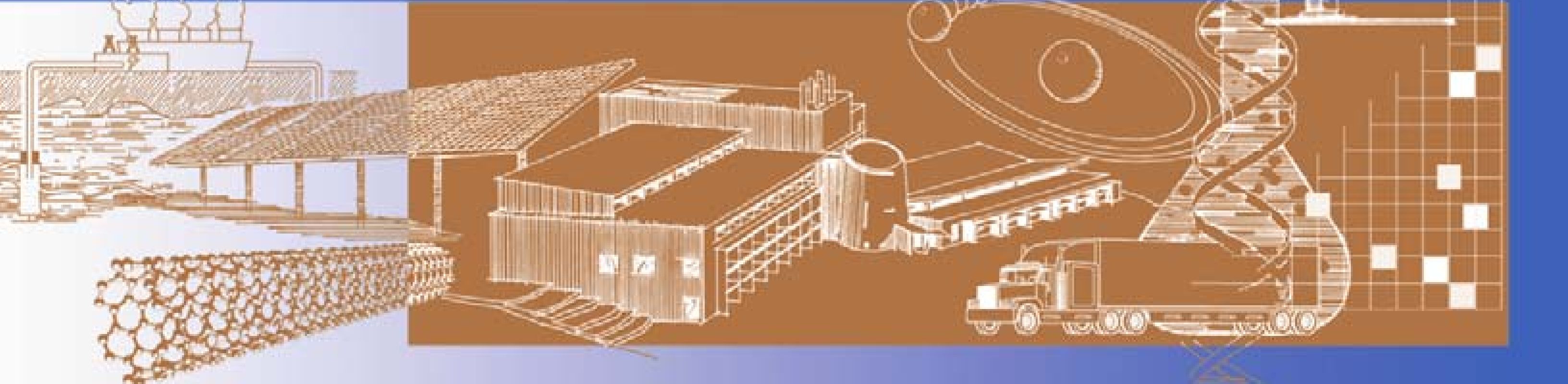

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An Analysis of Sub-Hourly Ramping Impacts of Wind Energy and Balancing Area Size

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Abstract

Pooling loads and resources into a larger balancing area (BA) holds the promise of allowing additional wind to be integrated into the system at lower cost. There are a number of ways that this type of pooling could occur, including consolidation of BAs, or various cooperative approaches. In prior work, we analyzed the impact of combined BA operations on ramping requirements, based on hourly data. We showed that ramping constraints can cause a spike in costs that would not be reflective of the energy cost. We also showed that sub-hourly energy markets can provide strong economic signals to generators on the margin that can provide ramp response with little or no cost.

In this paper, we analyze sub-hourly ramping requirements and the benefit of combining BA operations with significant wind penetrations. Our analysis at the sub-hourly level indicates that there can be significant increases in the ramp requirements compared to hourly, and yet these can be better managed by either a fast energy market or by a combined approach to operations. Our data from four BAs show that 5-minute combined load and wind ramp in excess is about 700 MW and can be avoided altogether by a combined approach to BA operations. We analyze high-quality wind power data from a mesoscale numerical weather prediction model, along with synchronized load data. We compare the sub-hourly and hourly ramp savings, and show why integration costs are lower when BAs can manage wind cooperatively, as opposed to separately.

Introduction

The use of wind energy has increased dramatically in the past several years. At the end of 2007, the United States had nearly 17,000 MW of operating wind capacity. Many regions of the country will likely see significantly more wind plants this year, and for the foreseeable future. Accompanying this increase in wind development, there are a number of initiatives that are designed to enhance the flexibility of the existing power system, in part as a result of anticipated wind development. One example is the ACE Diversity

Interchange (ADI) pilot project underway in the West. The Northern Tier Transmission Group began this project to assess the feasibility and potential benefit of ACE (area control error) sharing among the participants. The project has attracted significant interest and additional participation around the West. The project pools ACE signals from multiple balancing areas (BAs), and sends AGC (automatic generation control) signals based on the reduced requirement that is based on the combined requirements for system balance. This constitutes what might be called a virtual control area in the second-to-second time domain in which it operates.

In the Pacific Northwest, the Northwest Wind Integration Forum has developed a series of recommendations to help manage the additional variability and uncertainty that wind will bring to systems operation over the next several years, assuming that the projected 5,000-6,000 MW of wind is actually developed. Among the recommendations, the participants called for increased cooperation among Balancing Authorities to provide additional flexibility: "Short of actual control area consolidation, the two most significant steps toward realizing this benefit are the development of expanded wholesale markets for control area services and greater operating reserve sharing."[1]

In other work[2], we describe how large electricity markets and BAs can help integrate wind energy. Smith et al[3] conclude that more wind can be integrated into the power system if additional flexibility can be developed in the balance of system, and that BA consolidation, either real or virtual, can also help with wind integration.

The North American Electric Reliability Corporation (NERC) has launched the Integrating Variable Generation Task Force (IVGTF) which is developing recommendations to ensure reliable grid operations with the expected growth in variable generation resources such as wind. Although it is too early to tell with certainty what these recommendations will be, early discussions include recommendations to ensure additional ramping capability either through modifications of existing generation, new generation, or transmission and market mechanisms that can tap existing physical flexibility that may be unavailable to system operators because of scheduling restrictions.

Against this backdrop of significant interest in new flexibility and larger BAs (real or virtual) to help integrate wind, we examine the underlying potential for reducing physical ramping requirements in systems with significant wind energy penetrations in this paper. Combining two or more BAs is an institutional function, although some forms of virtual control area consolidation can be accomplished administratively. However, the pooling of the requirements for flexibility serves is an extremely powerful aggregator that can reduce the requirements for ramping capability and reduce costs for all participants. In our analysis we do not differentiate between real and virtual consolidation, because either

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[1] The Northwest Wind Integration Action Plan, p 12. Available at http://www.nwcouncil.org/energy/wind/library/2007-1.pdf.

[2] Kirby, B. and Milligan, M. *Facilitating Wind Development: The Importance of Electric Industry Structure*, 2008. NREL Technical Report NREL/TP-500-43251. Available at http://www.nrel.gov/docs/fy08osti/43251.pdf

[3] Smith, J.C., Milligan, M., DeMeo, E., and Parsons, B., *Utility Wind Integration and Operating Impact State of the Art*, IEEE Transactions on Power Systems, Vol. 22, No. 3, August 2007.

one can reach the same result. Since there may be other reasons to maintain separate BA operations, we do not recommend any particular form of consolidation other than the physical pooling of flexibility requirements on the power system.

There are three aspects of ramping capability: whether it physically exists, whether it can be utilized when needed, and whether it will increase cost when it is utilized. Figure 1 shows an example of a system that has sufficient capacity to meet a fast ramp, but in order to meet the ramp, a peaking unit must be utilized. In this case, the baseload unit has an energy price of $10/MWh, but is unable to increase output quickly enough to meet the ramp. The peaking unit is brought online at a price of $90/MWh to meet the ramp. If the marginal unit sets the energy price in a market, the energy price rises during the ramping period because the online base unit is not flexible enough. Had the ramp been sustained during a longer period of time, for example 8:00 AM until 1:00 PM, the base unit could have met the ramp requirement, and the energy price would have remained at $10/MWh. This example points out that ramping can be extracted from the energy market, but at times the energy market may not be able to provide the ramping capability. In a system with a significant wind penetration, this ramp scenario could be exacerbated, necessitating even more ramping capability at an even higher price. In the analysis that follows, we show that one source of flexibility can be tapped by simply re-drawing the boundaries of the BA. This can reduce or eliminate excessively large ramping needs, and allow for more economic wind integration.

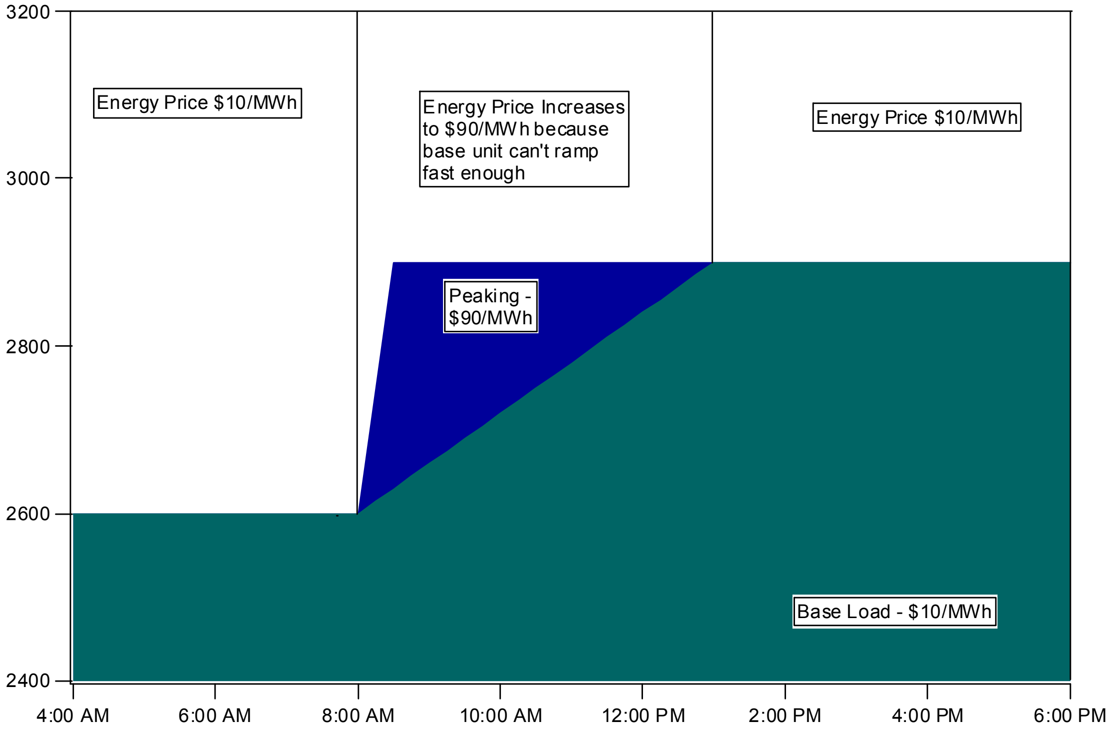

Figure 1. In some cases, there may not be sufficient online ramping capability even though there is sufficient capacity.

Analysis of 5-Minute Data from the Minnesota Study

In this paper we extend the analysis of Milligan and Kirby (2007),[4] which analyzed hourly data that was used in the Minnesota 20% Wind Integration Study.[5] To extend the analysis, we utilized 5-minute load data, along with synchronized 5-minute wind power data that covered approximately nine months. A full year of data was not available for analysis. The Minnesota study assumed that BA consolidation would occur in the state before 20% of all electricity would be supplied by wind. All within-hour variability was assumed to be managed in-state, and the MISO energy market could be tapped to help manage hourly variability.

Because of the assumption of BA consolidation, we were able to obtain data for load and wind that was broken down by the different areas, and then combine the data as would be seen by a system operator after consolidation. In fact, the expansion of the MISO market in Minnesota has occurred since the time of the wind integration study.

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[4] Milligan, M., Kirby, B., *The Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration*. Presented at WindPower 2007, Los Angeles, CA, June 3-6, 2007. Pre-print available at http://www.nrel.gov/docs/fy07osti/41809.pdf.

[5] EnerNex Corporation, Final Report – 2006 Minnesota Wind Integration Study, Vol. I. Minnesota Public Utilities Commission, St. Paul, MN. Available at http://www.uwig.org/windrpt_vol%201.pdf.

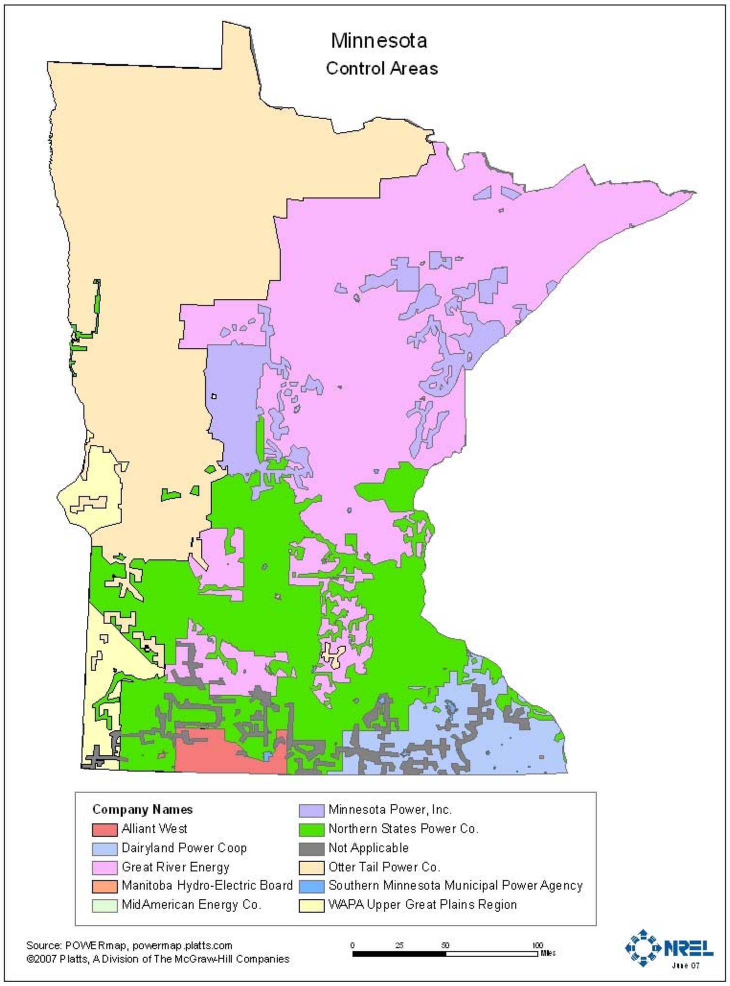
Minnesota
Control Areas

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Figure 2. Data for Great River, Minnesota Power, Northern States Power, and Otter Tail Power were used in this analysis.

Wind Impacts in the 5-Minute Time Scale

Power systems are built to accommodate the rather extreme variation that can occur in customer load. Power system operators have procedures for scheduling generation that help manage this variability. As a starting point for our analysis, Figure 3 illustrates the load (upper panel) and the 5-minute changes in load (bottom panel). The 5-minute ramp requirements are generally small, but have some significantly large values, as indicated in Table 1. The table also summarizes the ramp requirements of the combined system including wind.

Table 1. Ramp characteristics with and without wind

	Maximum/Minimum 5-Minute Ramp	Average Up/Down 5-Minute Ramp	Standard Deviation Up/Down 5-Minute Ramp
Load	1571 / 1332	19.6 / 19.6	35.8 / 31.4
Load and wind	2054 / 2617	21.6 / 21.6	39.1 / 36.4

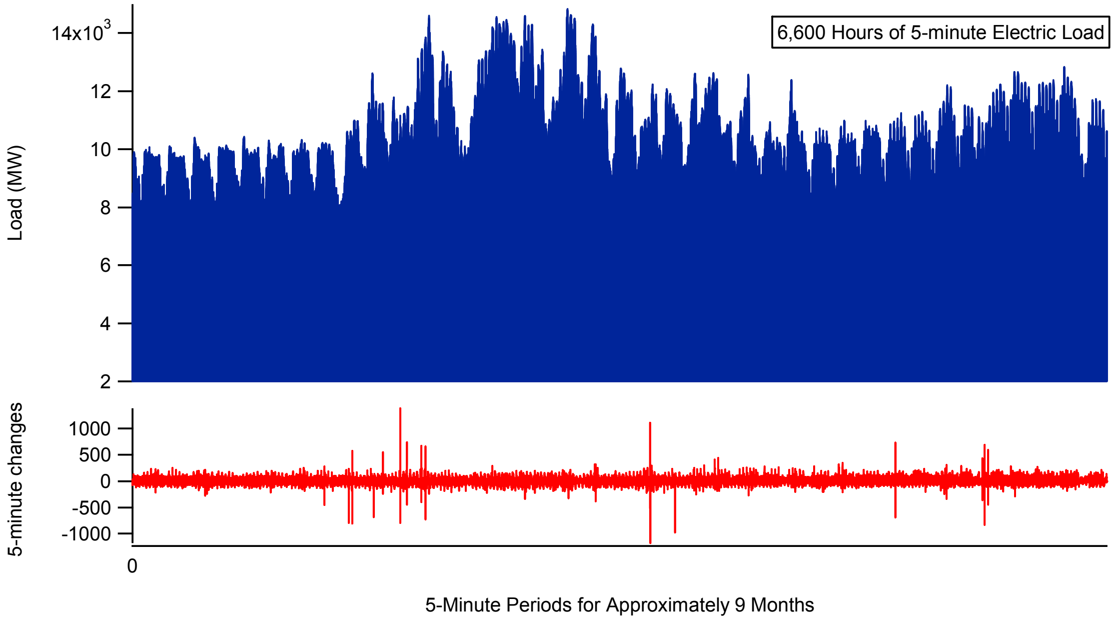

Figure 3. Five-minute load for the four combined BAs shows considerable variation

We utilized the 5-minute load and wind power data from the 25% (by energy) wind penetration case from the Minnesota study. This is a very large wind penetration, and the impact on system requirements can be easily seen when Figure 3 is compared to the wind case that is depicted in Figure 4.

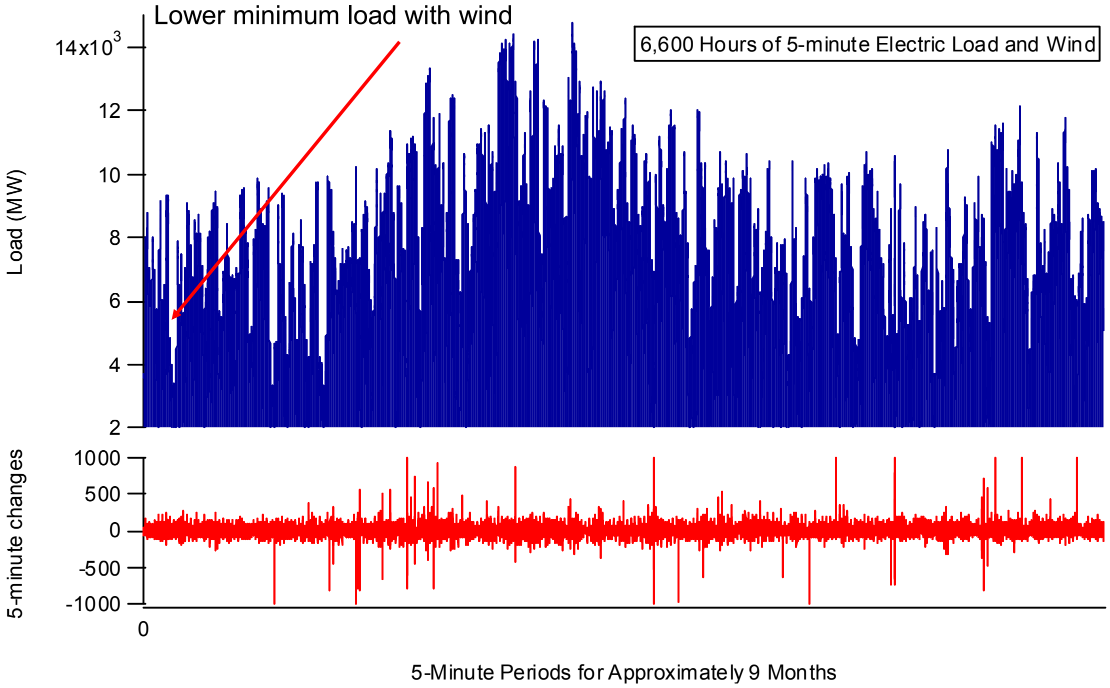

Figure 4. High wind penetration has an impact on system ramping requirements and required turn-down levels for other generators.

Figure 4 shows the load-less-wind that must be balanced by the remaining generation fleet. One key assumption underlying the graph is that there are no binding transmission constraints that would prevent all of the generated wind power from serving load. This net load clearly has a larger variability than the no-wind case. The upper panel of Figure 4 indicates a need for a significantly lower level of minimum generation compared to the no-wind case.

The figure also indicates a larger level of ramp requirements than the no-wind case. This is well known from the large number of integration studies that have been performed over the past few years.

Another view of the lower turn-down capability can be easily seen in a duration curve that compares load alone with wind. This appears in Figure 5 below.

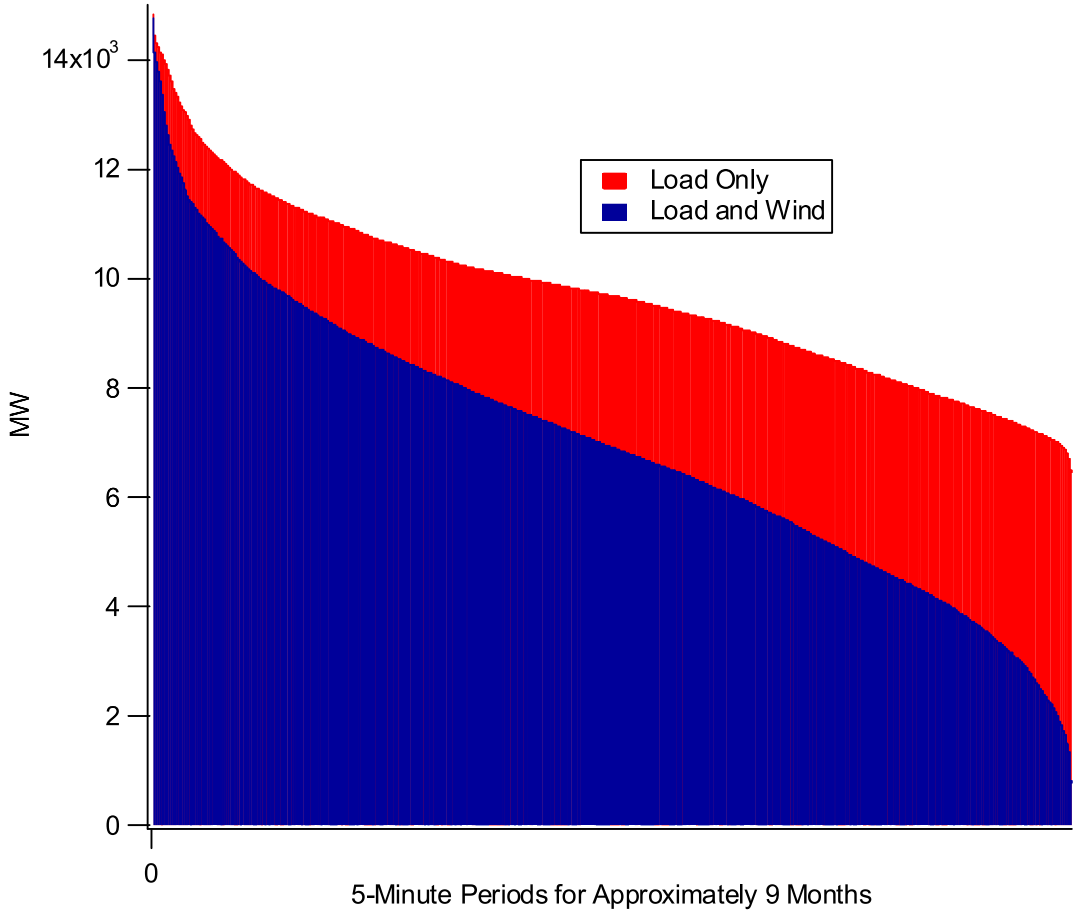

Figure 5. The lower turndown level required from the balance of system is illustrated by this set of duration curves.

The key implication is that with this large penetration of wind energy in the power supply, baseload units will be displaced because they will be unable to sustain the lower level of output that is required, either on an economic basis, a physical basis, or a combination of both. The closely related corollary is that the optimum generation mix for a system with a large wind penetration is different than the required mix under business as usual. The demand for exported energy will mitigate this required change in generation mix to the extent that it is present.

Impacts of Balancing Area Consolidation on Ramp Requirements

In our hourly analysis (2007), we illustrated the potential impact of BA consolidation on hourly ramp requirements. Qualitatively, the results in the 5-minute time scale are similar, although the quantitative results differ. The key benefit to BA consolidation is that some of the ramp requirements from different BAs will net to zero. As an example, Figure 6 shows the separate ramping requirements for the four BAs; blue shows the separate up-ramp requirements, green shows the separate down-ramp requirements. These are netted out and shown in yellow. The lower panel of the graph shows the ramping that could be eliminated under a consolidated BA scenario. Because of the canceling effect, the ramp savings are symmetrical, and so the red trace in the bottom panel of the graph shows the total ramping that can be eliminated in the consolidated scenario.

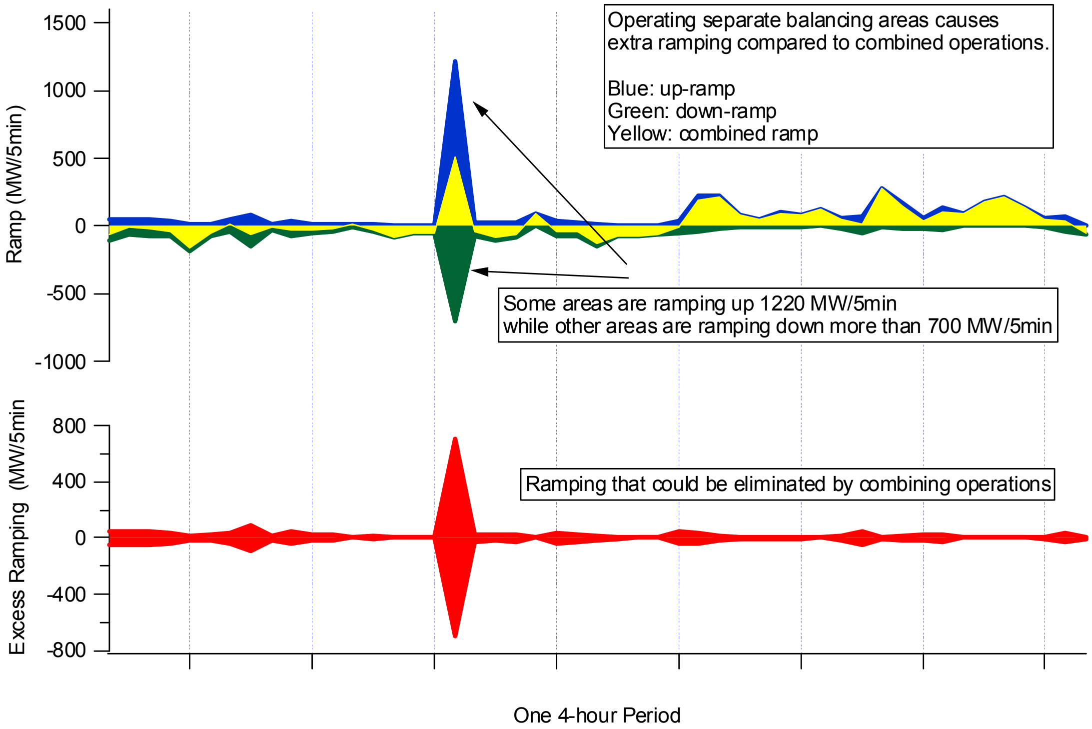

Figure 6. When BAs consolidate, some up-ramps in one area can be netted with down-ramps in other areas, reducing overall physical ramp requirements.

The full 9-month period for which we have data is shown in Figure 7. The graph shows the excess ramping that would be required with separate operations. Conversely, the graph can be interpreted as showing the symmetrical ramp savings that would result with combined BA operations. This graph shows the benefit in the system without any wind. Adding a large wind penetration will increase this benefit significantly.

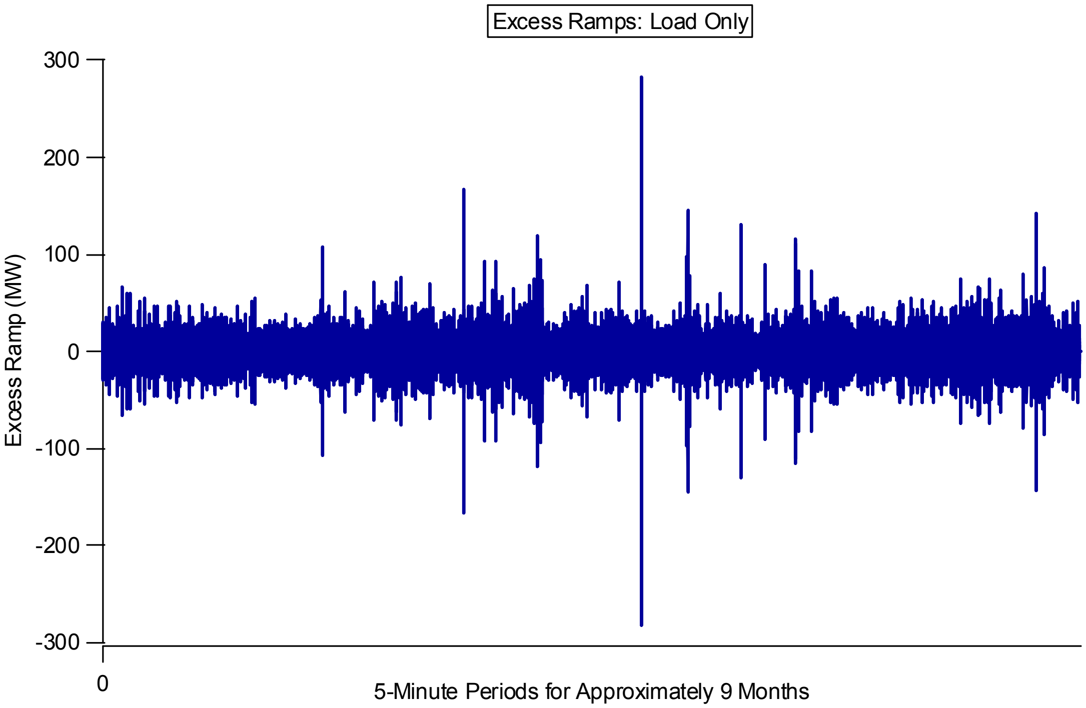

Figure 7. Excess ramping for the full 9-month period that occurs with separate BA operations.

The wind case is illustrated in Figure 8.

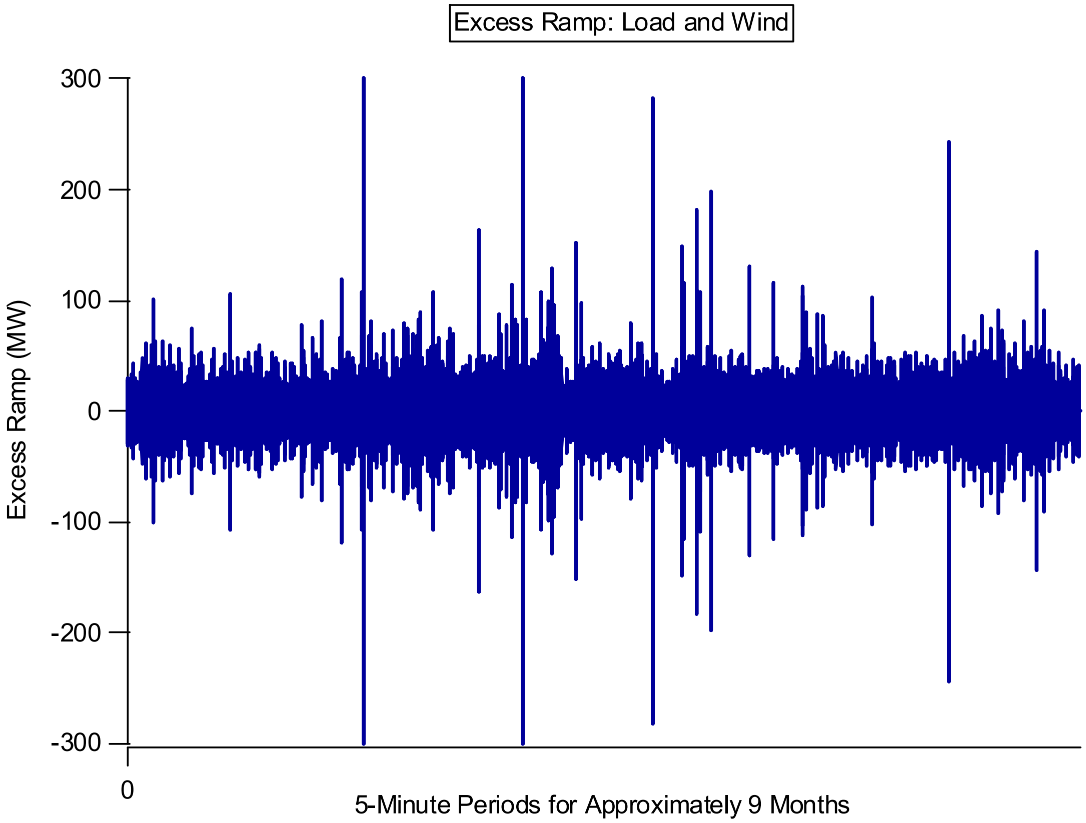

Figure 8. Excess ramping increases with high penetrations of wind. Some high ramp requirements have been clipped from the graph (see Table 1).

The excess ramping with a 25% wind penetration by energy is higher than in the no-wind case. But in both scenarios, BA consolidation reduces ramp requirements.

To obtain a view of the difference between the no-wind case and the wind case, Figure 9 shows (red) the ramp savings that would result in the no-wind case, along with the ramp savings in the wind case (blue).

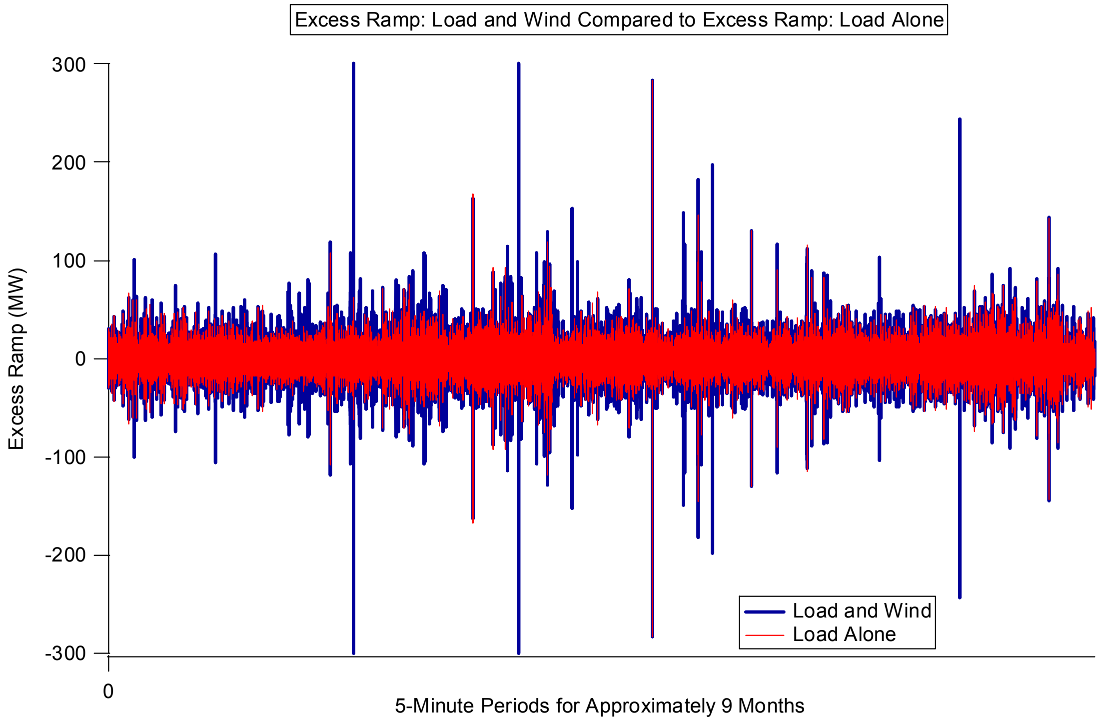

Figure 9. The wind scenario shows an increase in ramp savings that result from BA consolidation.

Collecting results from the no-wind and wind cases of ramp savings, Figure 10 shows the total excess ramps for the various cases. The first two bars show the MW-5 minute excess ramp totals in the no-wind case (not consolidated vs. consolidated BA cases) and the third and fourth bars show the MW-5 minute comparison with the 25% wind scenario. It is clear that BA consolidation benefits systems with or without wind, but that the benefit is larger with a significant wind penetration. On a percentage basis, combined operations results in a 22.4% reduction in ramping requirements without wind, and a 23.8% reduction in the wind case.

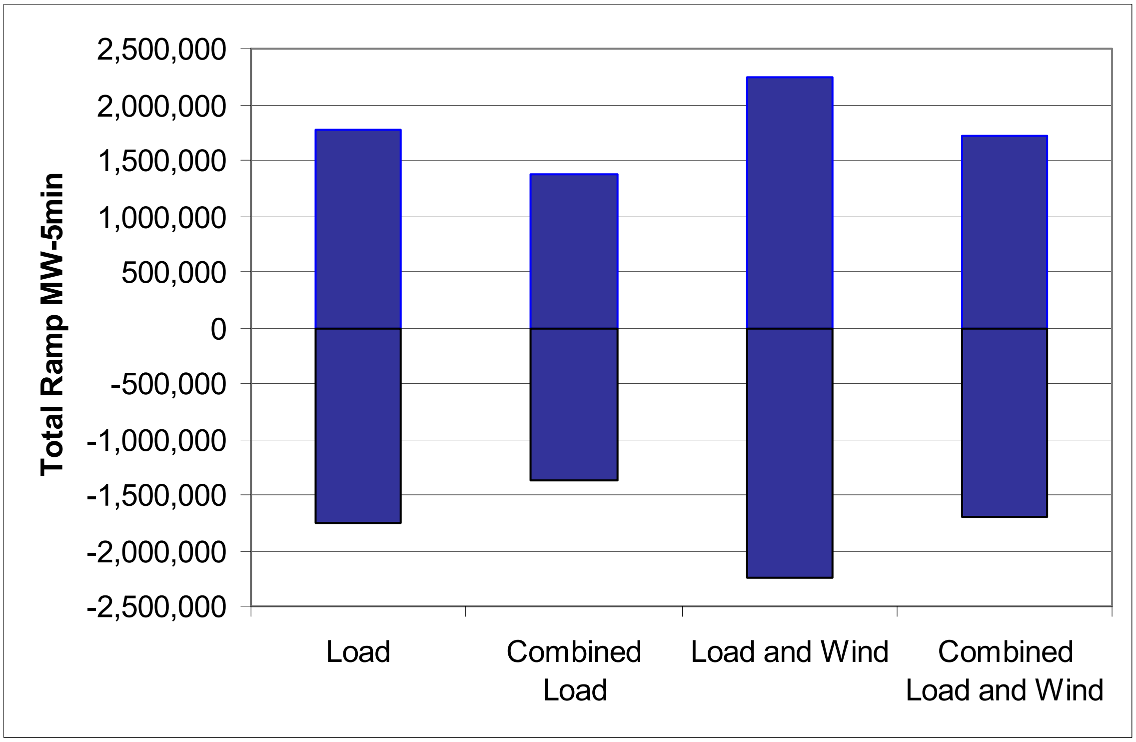

Figure 10. Excess ramping from the no-wind and wind cases, measured in MW ramps per 5-minute periods (MW-5 minute)

In many hours, the excess ramping with separate operations is relatively small. But there are a few very large ramp events that can be eliminated with combined operations. Figure 11 shows the excess ramp for the top 1000 hours. As before, the excess ramp is symmetrical because of the canceling effect of up-ramp and down-ramp requirements when operations are consolidated. The lower panel shows that the excess ramp stabilizes at just under 100 MW (both positive and negative). But the inset in the upper panel magnifies the top 10 hours, and shows that ramp requirements in the range of 200-700 MW per 5 minutes can be eliminated with combined operations in the wind case. Even without wind, the inset shows that nearly 300 MW of excess ramp can be eliminated in the no-wind case.

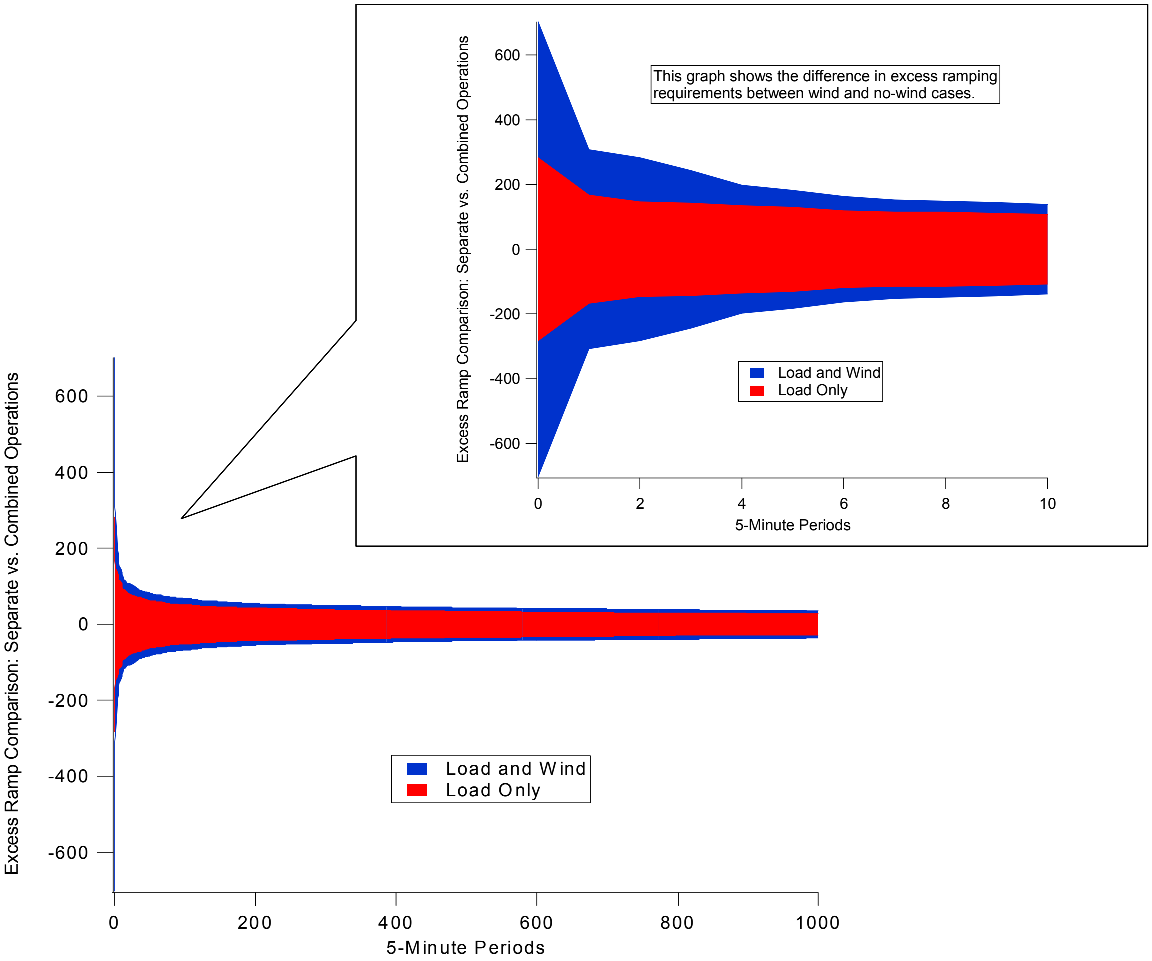

Figure 11. Combined operations can offer a significant improvement on tail events: large but infrequent ramps.

Returning to Figure 1 where we see the potential impact of ramp constraints on system cost, it seems clear that even if the scenarios such as that depicted in the figure are limited in number throughout the year, combined operation can eliminate excessively large ramp requirements that could either increase cost (for a limited number of hours), or more significantly, compromise system reliability. The large tail-events (infrequent but large ramps) are a significant part of the story, but it is also clear that there is a benefit, albeit smaller, that accrues over many more hours of the year.

Comparison to Hourly Ramping Reduction

It is useful to compare these 5-minute results to hourly results. Because we did not scale the loads to the 2020 level in our previous work, we cannot directly compare to what we reported in our 2007 paper. However, we have re-calculated the benefit in the hourly time frame using the same assumptions as for the 5-minute cases reported here. A comparison of the 5-minute results and the hourly analysis appears in Figure 12. To allow for comparison, the results are shown as a percentage reduction in overall ramping requirements that would occur with BA consolidation. In the 5-minute time scale, consolidation reduces ramp requirements in the load-only case by more than 20% (both positive and negative), compared to a 4.4% reduction in the hourly time scale. For load and wind together, there is a 23.8% reduction in bi-directional ramping requirements in the 5-minute time scale, compared to a 10.2% reduction in hourly ramping requirements. This result is not unexpected since load movements are highly correlated over longer time frames (all BAs experience a morning load ramp up, for example). Five-minute load movements are not well correlated. Wind is less correlated in both time frames. Consequently, BA consolidation has greater benefit for load at the 5-minute level than at the hourly level.

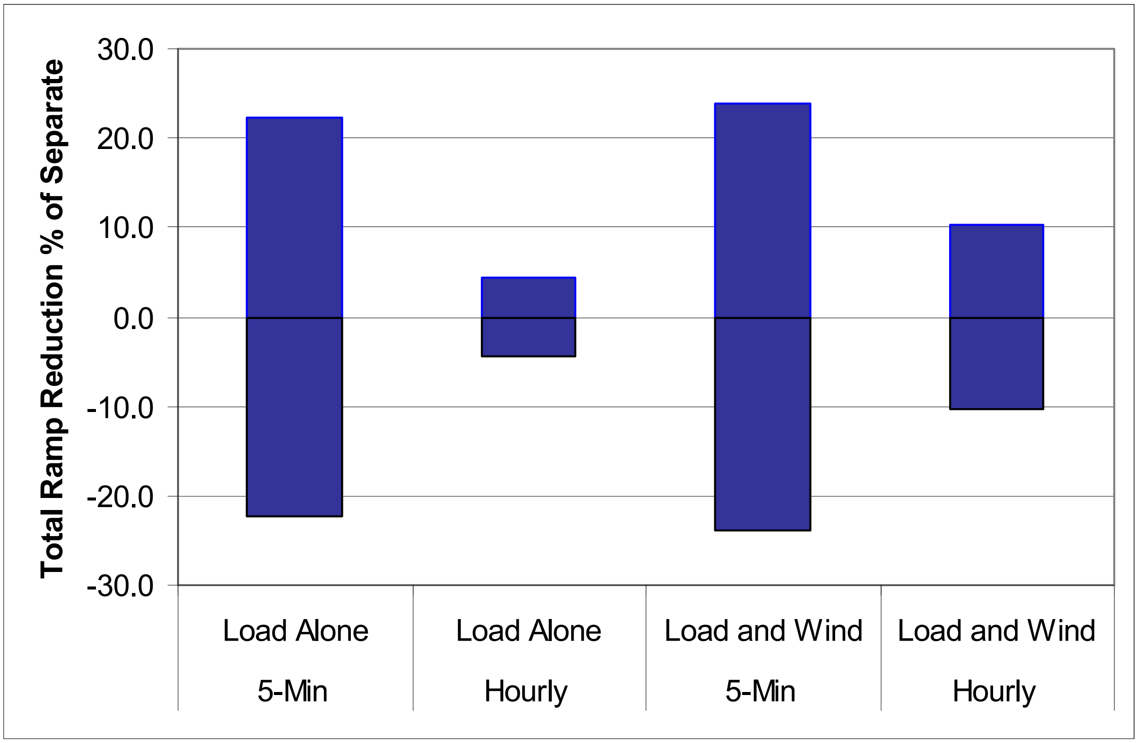

Figure 12. Five-minute excess ramping exceeds hourly excess ramping, both for load alone, and load and wind together.

Conclusions

BA consolidation, whether real or virtual, can reduce the ramping requirements for systems with and without wind. Not surprisingly, this benefit is larger when there is a large wind penetration than if there is no wind. Similarly, the benefit of consolidation is higher in the 5-minute time scale than in the hourly time scale, both for the wind and no-wind cases.

Consolidation is an institutional function, but can result in the reduction in physical requirements of system operation. This reduction could lead to a reduction in the need for fast-ramping generation, or at least in the need to deploy such generation. During periods of very fast ramps when load and wind are changing in opposite directions, it is possible that market costs are driven very high because combustion turbines or other expensive, flexible resources may be needed for short periods of time. Consolidation can reduce, or perhaps even eliminate, this need.

As wind penetration rates increase in the United States and around the world, there will be an increasing need for system flexibility. That new flexibility can come from a variety of sources, depending on the relative economics of the potential choices. Real or virtual BA consolidation is one important source of flexibility, and will improve the electrical system's ability to accommodate higher wind penetrations more reliably and economically.

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