Benefit of Regional Energy Balancing Service on Wind Integration in the Western Interconnection of the United States

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***Abstract*—Interest in various wide-area balancing schemes to help integrate wind have generated significant interest. As we have shown in past work, large balancing areas not only help with wind integration, but can also increase the efficiency of operations in systems without wind. Recent work on the Western Wind and Solar Integration Study (WWSIS) has found that combining balancing over the WestConnect footprint will increase the efficiency of commitment and dispatch at wind penetrations ranging from 10-20% of annual electricity demand, and will be essential for high penetrations and small balancing areas. In addition the Northwest Wind Integration Action Plan recommended balancing area cooperation as a method to help integrate the large potential wind development. In this paper we investigate the potential impact of a proposed Energy Imbalance Service on the ability of the non-market portions of Western Electricity Coordinating Councils (WECC) United States footprint to integrate wind energy. We will utilize data adapted from the WWSIS for the Western Interconnection. The analysis uses time-synchronized wind and load data to evaluate the potential for ramp requirement reduction that could be achieved with combined operation. Chronological analysis and ramp duration analysis quantify the benefit in terms of not only the ramp sizes, but the frequency of the potentially avoided ramps that must be managed by the non-wind generation fleet. Multiple approaches that can be used to achieve these benefits will also be suggested in the paper. We also suggest other approaches that can help achieve much of the benefit of full consolidation without requiring the physical consolidation of balancing areas.**

***Index Terms*—Wind energy, balancing area, wind integration**

I. Introduction

The existing state-level renewable portfolio standards in the Western Interconnection will require substantial renewable resources, expected primarily as wind generation. At typical capacity factors and considering annual energy consumption, potentially more than 50 GW of wind resource installation will be installed by 2020. The associated high level of variability further increases the efficiency benefit over the "traditional" economic dispatch benefits of regional market operations. This analysis indicates the extent to which pooled regional dispatch for matching generation to load mitigates the costs and improves associated reliability, particularly in scenarios with high penetration of variable output resources, such as wind.

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II. Data

The data used for this analysis was developed for the Western Wind and Solar Integration Study. This data consists of synchronized chronological load and wind power production data from the WWSIS dataset.

The weather data was simulated by 3Tier group using a mesoscale Numerical Weather Prediction (NWP) Model to recreate the weather across the western U.S. from existing atmospheric measurements and archived information about the historical weather at many locations. The data is sampled from the model and saved at 2km spatial resolution, every 10 minutes for 3 years. The wind speed data along with other atmospheric parameters were then processed to provide wind plant output at each of the saved locations.

The 30% "In Footprint" plant selection scenario from the WWSIS was used as the basis for wind plant location with 2006 data chosen for the analysis. Load profile information from 2006, derived from Ventyx Velocity Suite, was escalated to 2017 using NERC peak load and energy forecast filings from the various planning areas in WECC. We aggregated the data into regional footprints: Columbia Grid, Northern Tier Transmission Group, WestConnect, and California. Because Canada did not have a wind build-out in the study, we did not include the Canadian provinces here; however we believe that this would be a necessary step to fully understand the impact of wide-area balancing in the Western Interconnection.

The NWP model of the Western Interconnection contained geographic and temporal seams that were not possible to resolve. This resulted in unrealistic wind energy ramps near the temporal boundaries, which occurred every three days. To ensure realistic data and to maintain consistency with the statistical analysis of the WWSIS, we eliminated every third day, corresponding to the seams identified in the study.

III. Overview of the Proposed “Efficient Dispatch Toolkit”

In the Western Interconnection, areas outside of California and Alberta do not presently have a common energy market, although there is bilateral transaction activity in the region. The Seams Issues Subcommittee of the Western Electricity Coordinating Council (WECC) is currently investigating an Efficient Dispatch Toolkit (EDT) that would achieve many of the benefits of a large-scale energy market, but without a coordinated unit commitment or regulation market.

The proposed EDT would use two primary tools: an Enhanced Curtailment Calculator (ECC), which can prioritize and allocate transmission service curtailments based on service priority for power flow impacts on the grid. Both tagged and un-tagged flows (most deliveries inside balancing areas are not tagged) will be evaluated by the ECC. The ECC would pass relevant curtailment information to the second tool, the Energy Imbalance Market (EIM).

The EIM uses a security-constrained economic dispatch to provide two functions:

- Balancing Service – this service redispatches generation to balance maintain balance between generation and load. For deliveries scheduled in advance, the effect is that deviations from schedules in generator output and errors in load schedules are supplied by the market.
- Congestion Redispatch Service – this will redispatch generation to relieve overload constraints on the grid. Information provided to the EIM from the ECC ensures correct allocation of the costs of redispatch service.

The current approach that is used by WECC BAs for balancing services comes from FERC Pro Forma Tariff Schedules 4 and 9. The proposed EIM replaces part of the BA services and results in a “virtual consolidation” due to a wide-area security constrained economic dispatch that covers imbalances. The congestion redispatch service is new to the non-market portions of WECC.

The EIM design includes a feature different from most regional markets in the US where internal resources are subject to a “must offer” requirement. Instead the default operating assumption is that each market participant provides sufficient resources to cover its own obligations (as is the case today) and the regional economic dispatch is provided by any resource that voluntarily offered responsive capability, and which is cleared by the security-constrained economic dispatch process. Most transmission service deliveries would continue to use traditional reserved transmission service, but the EIM would not use pre-reserved transmission. Instead, the EIM flow would receive the lowest transmission service curtailment priority. By this mechanism, EIM flows would not displace reserved transmission service.

Unlike other regional markets where transmission service for market delivery is provided under a regional network service tariff, the EIM flows would pay an imputed service compensation after-the-fact to participating transmission providers. At this stage of development of the EDT toolkit, the specific terms for the transmission service revenue target and revenue allocation among participating transmission providers have not yet been established.

The EIM function adds some operational steps to the current practices used in the Western Interconnection today. Functionally, the operating steps for the proposed EIM track closely with the operating process established in the Southwest Power Pool (SPP) in their Energy Imbalance Service Market. Figure 1 illustrates the timeline for operation of the proposed EDT toolkit.

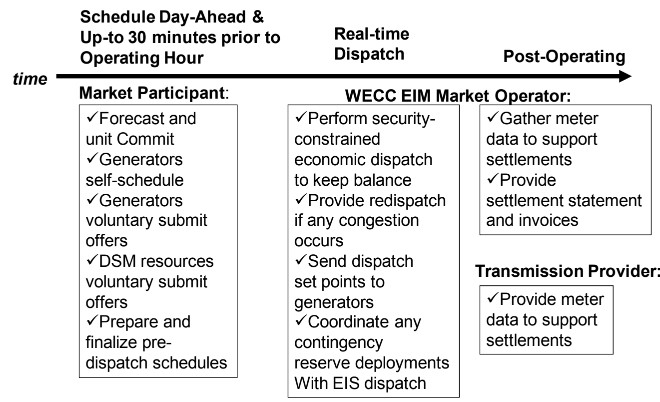


Figure 1. Operation timeline for the EIM toolkit.

The EIM would effectively implement one form of a virtual BA across the Western Interconnection (California and Alberta would not be included because they already have energy markets). Imbalances would be netted out, much as they would be in a single BA. As proposed, the EIM does not result in a coordinated unit commitment, nor does it pool regulation, which remains a service at the local balancing area level. However, the netting of energy imbalance, which would include impacts of load and wind, are expected to be significant. Figure 2 illustrates the concept, with each of the small bubbles representing a single BA. The arrows between the BAs indicate bilateral tagged energy flows that would not be precluded in the EIM. However, under the EIM, only the footprint net imbalance would need to be managed, resulting in less “pent-up” variability within the local balancing areas and less required ramping across the footprint.

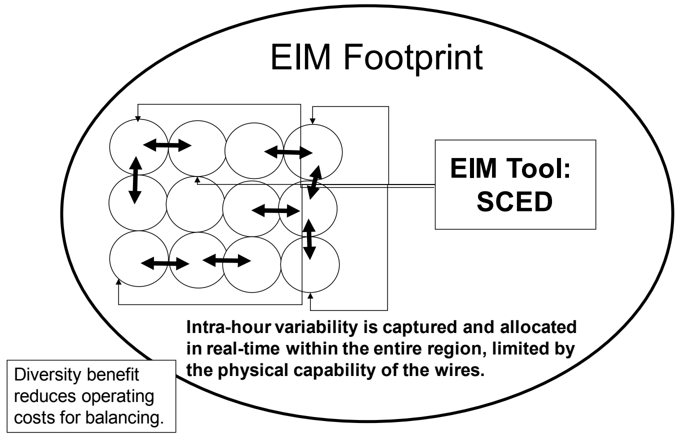


Figure 2. The EIM would effectively pool variability within the operating footprint, similar to a single BA.

IV. BASIC SCENARIO DESCRIPTION

In our analysis we examined two basic levels of aggregation, representing alternative levels of wide-area management and implementation of the EIM. The first aggregation level is based on the existing transmission planning regions within the U.S. portion of WECC: Columbia Grid (CG), Northern Tier Transmission Group (NTTG), WestConnect (WC), and California.[1] This first level of analysis addresses the impact of pooling within each of these regions, without considering the impact of a WECC-wide balancing market. The second level of analysis examines the impact of full pooling in the U.S. portion of WECC, as would be experienced with a full implementation of the EIM. We note that many other possible configurations are possible, based on which entities participate in the EIM.

V. VARIABILITY ANALYSIS

Larger operating footprints improve the ability of the system to respond to variability. This occurs for two reasons: (1) pooling of variability of loads and wind generation increases diversity, which reduces the overall variability per-unit, and (2) a broader resource mix increases ramping capability linearly. The result is that aggregation provides an increased ability to manage variability, which itself is somewhat reduced with aggregation. This principle can be applied to many facets of power system operation, and is one driver for the formation of reserve-sharing pools that reduce the total level of contingency reserve needed to maintain reliability.

Table 1 shows the peak, average, and minimum load and wind for all of WECC and the five regions. Both coincident and non-coincident values are shown. Aggregation provides a host of benefits for load as well as for wind. Aggregation reduces the peak capacity requirements for load alone. Coincident peak load is 6.2% lower for WECC than the sum of the non-coincident peak loads which each BA must support on its own. Minimum loads are also improved (raised) through aggregation: 8.6% for WECC and 17.2% for Columbia Grid. Load factor is 3.9% better for the aggregated WECC; 62.9% vs 59.0%.

Aggregation also benefits wind. Peak WECC wind is reduced by 15.3% through aggregation. WECC aggregated minimum wind is 420MW compared with zero to 43MW for the individual sub regions. WECC wind capacity factor increases by 6.1% with aggregation. Aggregating wind also reduces the maximum wind penetration. One BA in WestConnect (WAUW) has a maximum ten minute wind penetration of 784% which is reduced to a maximum of 95% for the aggregated WestConnect and a maximum 62% for aggregated WECC.

Table 1. Load, wind, and penetration levels for WECC and its five regions.

	WECC	WestConnect	Northern Tier	Columbia Grid	Canada	California
# of BAs	32	14	5	9	2	2
Load						
Max Non-Coincident	203,000	62,623	23,979	23,664	24,292	68,442
Max Coincident	190,500	60,925	23,123	23,154	24,067	68,308
Avg	119,783	33,682	15,821	14,811	17,761	37,709
Min Coincident	86,062	22,509	10,613	10,363	13,561	25,722
Min Non-Coincident	79,270	21,056	10,240	8,842	13,469	25,664
Wind						
Max Non-Coincident	72,623	26,250	10,997	11,853	0	23,523
Max Coincident	61,508	24,398	10,682	11,702	0	23,523
Avg	24,421	8,624	3,805	4006	0	7,987
Min Coincident	420	124	69	2	0	43
Min Non-Coincident	47	1	3	2	0	43
Non-Coincident CF	33.6%	32.9%	34.6%	33.8%	0%	34.0%
Coincident CF	39.7%	35.3%	35.6%	34.2%	0%	34.0%
Penetration						
Max in Area	784%	784%	181%	227%	0%	90%
Max Coincident	62%	95%	81%	106%	0%	81%
Energy	20%	26%	24%	27%	0%	21%

[1] We consider California as a single area, combining the CAISO region with other balancing areas in the state for this analysis.

VI. Reserve Analysis

One very important aspect of the variability due to wind is the impact on the reserve generation capacity that is necessary to cover the variations in the load and wind. A methodology was developed to estimate the increased requirements for regulation with wind variability in the Eastern Wind and Transmission Study (EWITS).

Short term variability is a problem since we can't fully anticipate the changes with scheduling and must cover those fluctuations with reserves. In a system with 10 minute markets or schedule updates, the best we can do is forecast a flat value for wind output for the next interval based on the past 10 to 20 minutes. The wind varies on that time scale and need to understand how it will vary during the forecast interval. With a statistical approach, we can estimate how much reserve is required if we have an estimate of the standard deviation of the variability.

The variability is a function of production level. At low levels of production, turbines that are part of a wind plant are not spinning or at very low output. At high levels of production, turbines are in the flat portion of their power curves. Changes in the wind tend to yield small changes in output. In the middle of the power curve, however, small changes in wind can yield large changes in output. The EWITS method recognizes that the short term forecast error in WTG output and thus short term variability is a normally distributed value. Through analysis, an equation can be written for the standard deviation (sigma) that variability that varies with production level.

The EWITS method determines the equation for sigma by analyzing the wind production data over some long period of time (a year or more) and calculating the standard deviation for the variability in various ranges of wind output. For each hour of production data, the standard deviation (sigma) is calculated from that equation. A component 3 time sigma is combined with a regulation component of 1% of hourly load to estimate the total regulating requirement for variability. The 3 sigma approach estimates reserve values that will cover 99.9% of all short term variability.

An additional uncertainty component due to hour-ahead wind forecasting error was calculated for the EWITS study. This component is calculated in a similar manner to the short term forecast error described above, using an equation to describe the standard deviation of hour-ahead forecast error. With that equation, the expected sigma for the forecast error is calculated based on the previous hour's production (persistence forecast). This component helps to insure the system is positioned with enough maneuverability to cover probable forecast error.

The variability (short term forecast) and uncertainty components can be combined to access the total additional spinning reserve burden due to load and wind variability. Please refer to Section 5 of the EWITS final report for full description of the methods employed.

The method described was applied to the WECC system in the following way. Reserve components were calculated for load serving balancing authority in WECC, organized by the regions Columbia Grid, Northern Tier Transmission Group, WestConnect and CISO. Those requirements take the form of an 8760 hour vector for each BA. The hourly requirement vectors were summed across the BAs for the regions and for WECC as a whole. These vectors represent the 'Before Consolidation' data. To calculate the 'After Consolidation' requirements, the wind production data is aggregated across the regions and WECC and the reserve requirements calculations repeated. This procedure was repeated for the hour-ahead forecast error component.

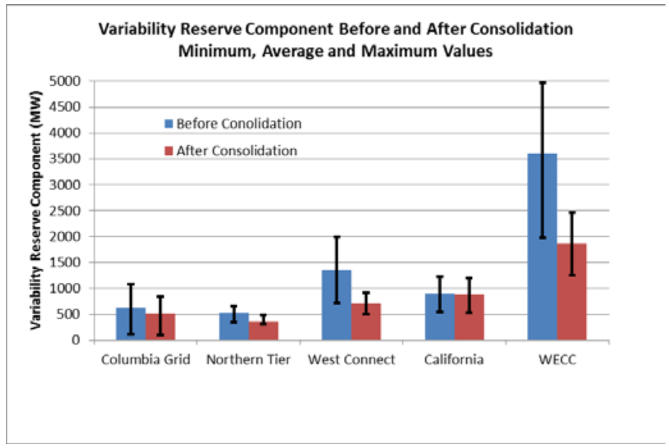


Figure 3. Impact of pooling on the variability component of reserves, using the EWITS approach.

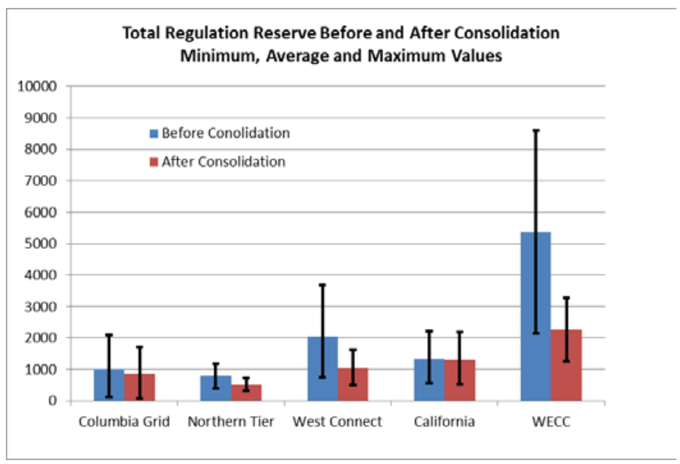


Figure 4. Impact of pooling on the regulation reserve.

The greatest benefits for the regional consolidations (virtual or otherwise) fall to WestConnect due to the wide territory and the resulting high diversity of the region, as was seen in Section V. Smaller benefits are seen for Columbia Grid where much of the wind is concentrated in one area (Montana) thus diluting the effects of consolidation. California (CISO) shows very little benefit since it already operates as a single market and only one smaller BA (LADWP) for this analysis. By far, the greatest benefit is seen for consolidation of the entire WECC territory. This is because of the wide diversity when all of the BA's are combined.

VII. Implications for Planning

System planners must assure that there is sufficient ramping capability as well as sufficient capacity to meet net load. Table 1 showed the significant capacity benefits that can be realized through BA cooperation or aggregation. Aggregation also reduces ramping requirements. Figure 5 shows the maximum and average daily peak ramping requirements for WestConnect load. Greater capacity is required for longer ramps but the increase is not linear. As expected, the peak one hour ramp is at a faster rate (greater MW/min) than the peak eight hour ramp. Figure 6 shows both the maximum ramping capacity required for each ramp duration for the year as well as the average of the daily peak ramping requirements. Interestingly aggregation reduces the maximum annual ramping requirement significantly more than it reduces the average daily ramping requirement. This is because the daily load shape is highly correlated between the BAs in the aggregation. Figure 6 shows the same ramping requirements for all of WECC.

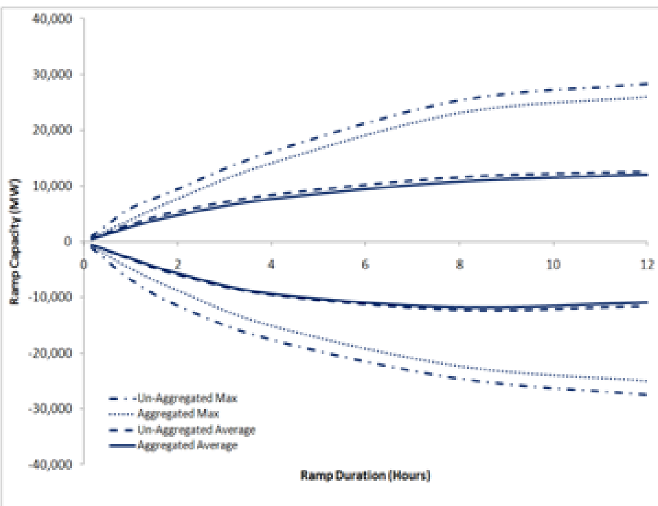


Figure 5. WestConnect load daily maximum ramping requirements.

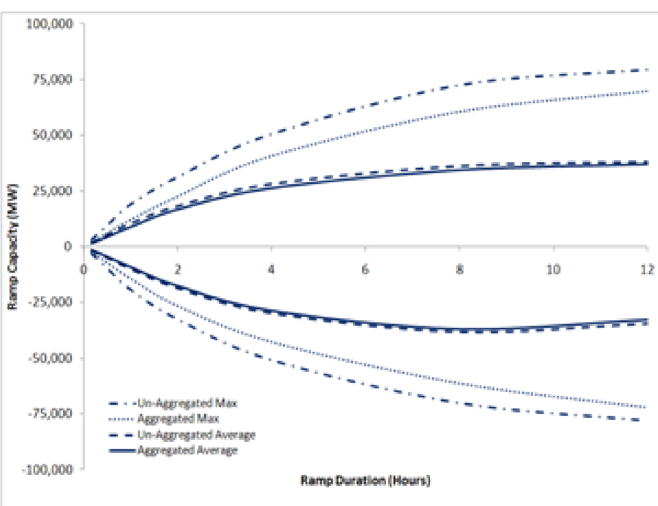


Figure 6. WECC load daily maximum ramping requirements.

Figure 7 and Figure 8 show the wind ramping requirements for WestConnect and WECC while Figure 9 and Figure 6 show the net load ramping requirements. For convenience the ramping sign convention for loads is used in all of the figures. A positive ramp represents a load increase or a wind decrease since both require conventional generation to ramp up in response. Several characteristics are apparent in both the WestConnect and WECC data. One is that the wind ramping requirements are significantly lower than the load ramping requirements. Second is that there is a greater ramping aggregation benefit for wind than for load indicating greater diversity in wind patterns than in load patterns. Third, the maximum annual ramping requirements are significantly greater for both load and wind than the average daily maximum ramping requirements. Finally, aggregation benefits remain strong for net load.

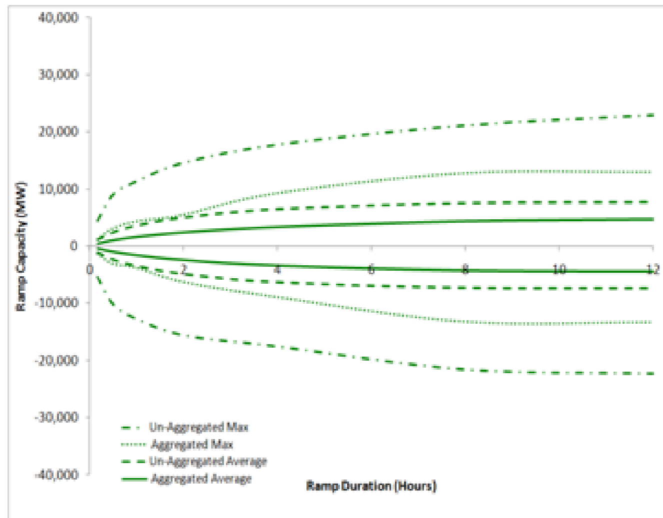


Figure 7. WestConnect wind daily maximum ramping requirements.

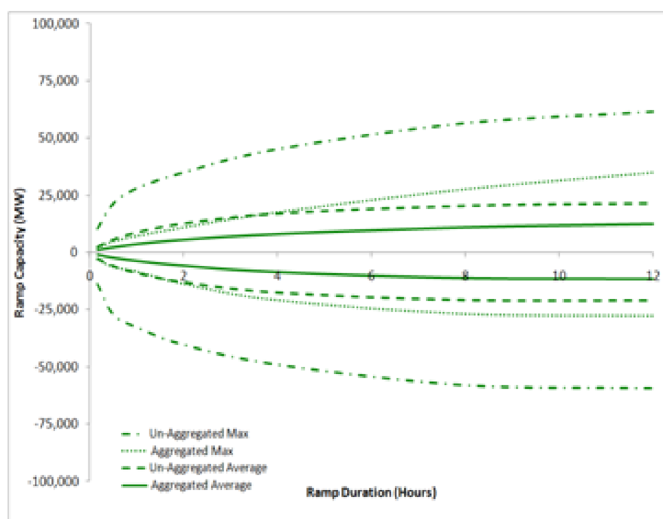


Figure 8. WECC wind daily maximum ramping requirements.

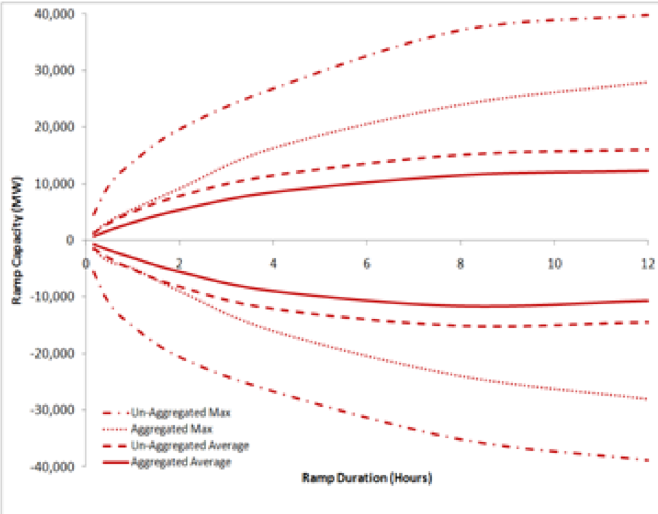


Figure 9. WestConnect net load daily maximum ramping requirement.

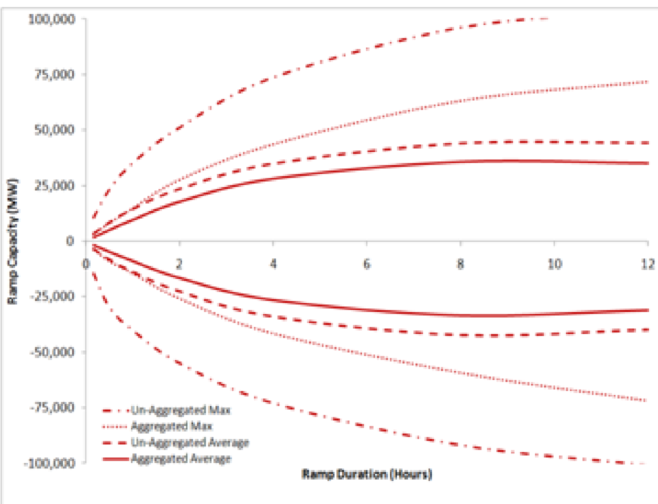


Figure 10. EDT Footprint net load daily maximum ramping requirement.

Figure 11examines how frequently four hour ramping capacity is required in the assumed footprint for EDT operations. The aggregated wind fleet, for example, ramps down (positive ramp on the graph) at a maximum of 7,913 MW/4hr or more on half of the days (50%). Without aggregation the total maximum daily wind ramp from all the BAs in the EDT footprint is 16,451MW/4hr or more on half of the days. Load ramps up at 27,013MW/4hr or more on half of the days for both the aggregated and unaggregated EDT footprint. Net load ramps up at 28,998MW/4hr or more for aggregated EDT footprint and 33,130MW/4hr or more for the individual BAs for half the days. Four hours is shown as an example, ramping requirements of all durations from ten minutes to 12 hours were computed. The reduction in ramping requirements is greatest for the few days when the highest ramps are required. This represents a significant potential savings in capacity.

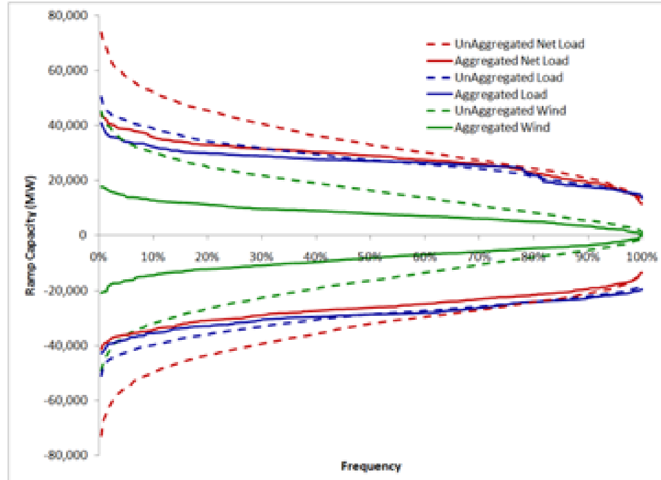
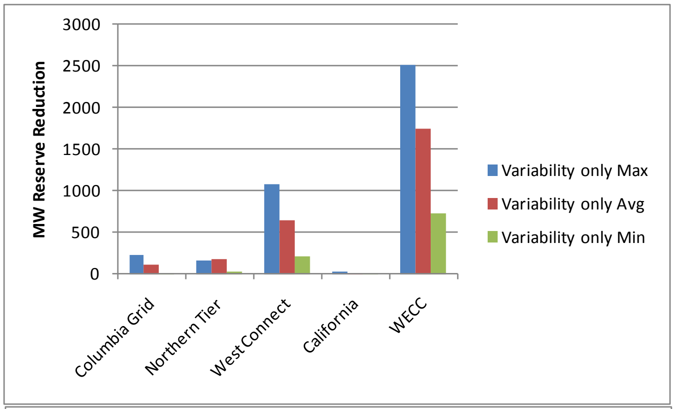


Figure 11. Assumed EDT footprint maximum daily four hour ramping requirements.

VIII. Conclusions

This analysis indicates that the efficient dispatch toolkit proposed by the WECC stakeholders holds great potential to mitigate the operations impacts associated with integration of large amounts of wind generation. The EDT effectively pools variability across the interconnection, and although it does not result in coordinated unit commitment, energy variability, both from load and from wind, is reduced. The impact on variability reserve is summarized in Figure 12, and shows a significant reduction in maximum, average, and minimum dynamic reserve levels.

Although there are a number of mechanisms that may achieve a similar reserve reduction, the proposed EDT will result in a reduction of an average of 3,101 MW of variability reserve in the West.



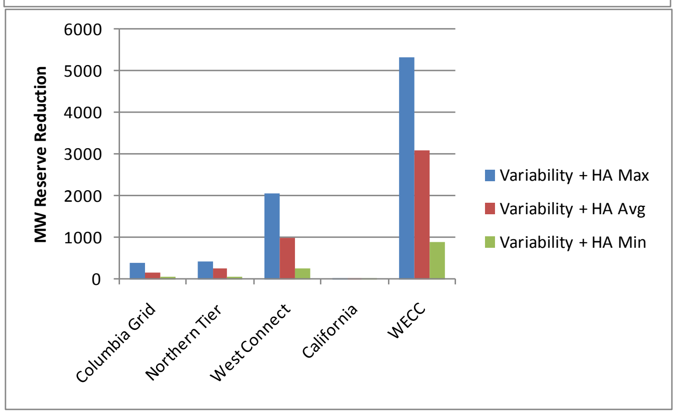


Figure 12. Savings in variability reserve.

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