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Do Wind Forecasts Make Good Generation Schedules?

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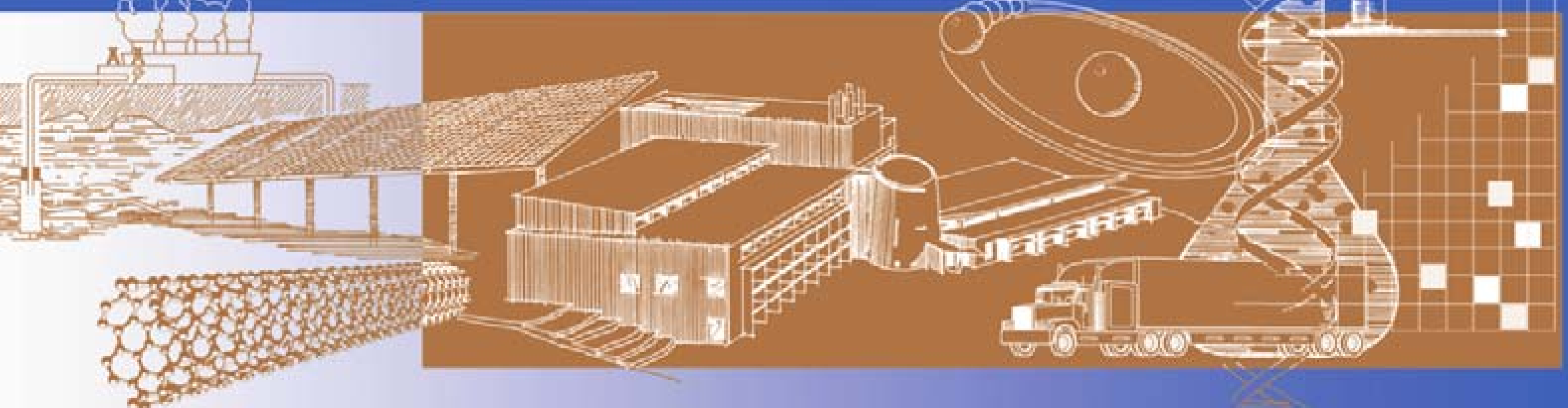

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Abstract

As the penetration of wind energy continues to increase and become a central piece of the energy mix in the United States, it will become increasingly important to consider ways to more efficiently operate power systems to accommodate significant amounts of such a variable resource. Improvements in wind forecasting methods and techniques will clearly play an important role in efficient operations, however, it is not clear that an unbiased joint forecast of load and wind represents the most economic operating point for the balancing authority (BA). Asymmetries in the wind forecast error, combined with asymmetries in costs of accommodating forecast errors suggest that the BA may most economically position itself slightly long or short with respect to the unbiased forecast. An early paper by Milligan, Miller, and Chapman[1] identified the asymmetrical economics associated with wind forecast errors. This asymmetry implies that the economic exposure of over- and under-forecasting are not balanced. If this asymmetrical exposure is not recognized by the system operator, this would likely result in unnecessary costs to the power system, and ultimately, consumers. An approach that would result in cost-minimization would recognize the asymmetry of forecast error costs, and position the system at an economically optimal point where the potential economic consequences of forecast errors are balanced. The implication is that the balancing area should position itself slightly long or short based on expected capacity needs and costs. Another consideration in determining the optimal balancing

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[1] Milligan,. M. Miller, A., Chapman, F., Estimating the Economic Value of Wind Forecasting to Utilities. American Wind Energy Association Proceedings. Washington, D.C. 1995.

position is whether the wind energy is used within the balancing area or exported to another area. Energy market scheduling conventions can needlessly increase the wind balancing area's regulation requirements without providing a compensating decrease in the load balancing area's reserves. This economic inefficiency can be eliminated once it is recognized. This paper provides a detailed discussion of these issues, and illustrates with specific examples. Using these examples, we show why neutral wind forecasts may not be the best generation schedules for wind power plants, and how intra-area schedules should be treated to avoid imposing non-productive reserve requirements.

Wind Schedules and Forecasts

BAs (control areas) purchase energy for the next market period. This market period may be as short as 5 minutes (as in California) or as long as an hour (as in the Pacific Northwest). When markets are fast, the within-market-period regulation service that is required is typically quite small. For slower markets of up to an hour, the BA cannot extract capacity movements within the hour from the economic dispatch, and must instead use relatively expensive regulating capacity for within-hour balancing. In the discussion that follows, we provide an example from hourly markets, but the principles would also apply to faster markets.

The within-hour balancing can be split into up-regulation and down-regulation services. Up-regulation is the provision of increased generation to meet unexpected increases in net load-plus-wind, and down-regulation instructs a generation reduction to respond to unexpected decreases in net load-plus-wind. In systems with significant wind penetrations, the within-hour movements required of the generation fleet will be larger than in the no-wind case, all else being equal.

Regulation is typically considered a capacity service, with the up-regulation and down-regulation energy netting to zero. It is common practice for system operators to position the regulating unit so that its average output during the market period is near the midpoint of its operating range, enabling it to respond to random increases or decreases in net load. The quantity of up-regulation is therefore countered by the quantity of down-regulation. This is reasonable when regulation is used to compensate for the small random minute-to-minute variability of aggregate system load. The situation is more complex, however, when market intervals are long (an hour, for example) and regulation is used to compensate for sub-hourly trends as well as for random minute-to-minute movements.

Figure 1 illustrates symmetrical balancing for a hypothetical balancing area. The prescheduled generation on economic dispatch ramps up before the start of the operating hour so that it is in position to approximately match net load during the hour. The example shows part of a morning load rise, so that the economic dispatch units begin another upward ramp at the end of the hour to position the system for the following hour. For the hour in question, the load fluctuates, requiring the movement of other regulating units to achieve system balance.

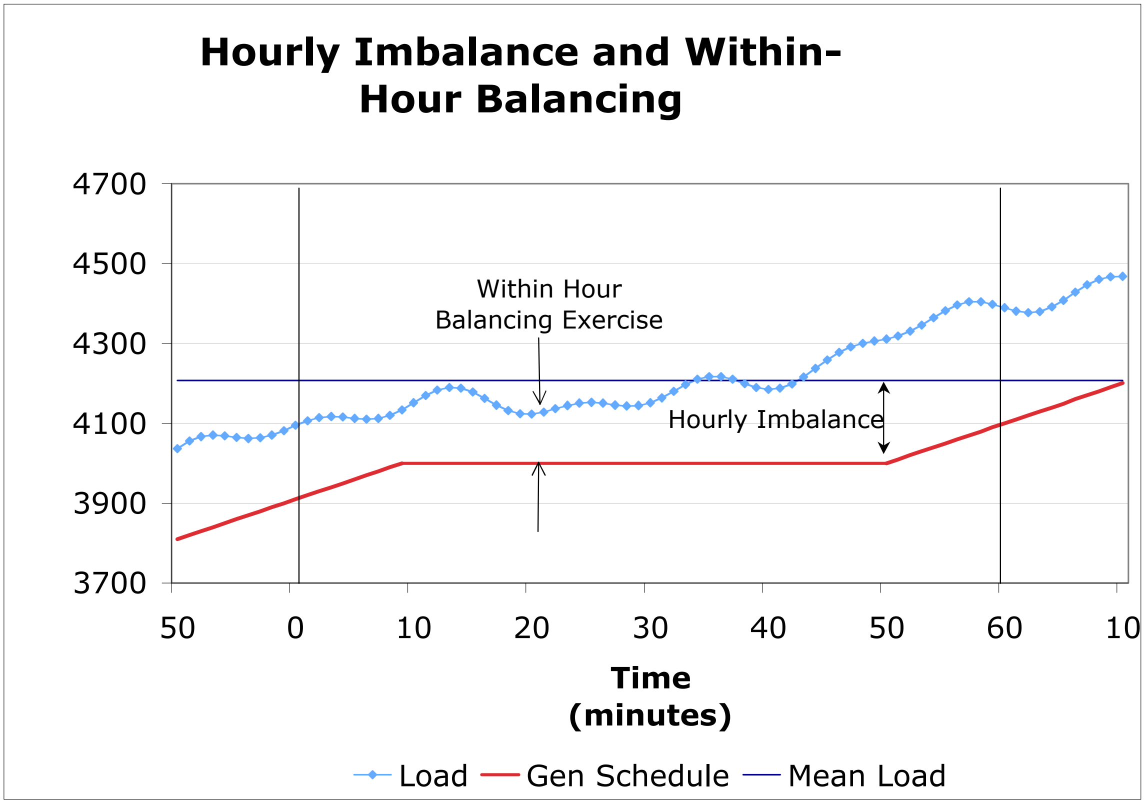

Figure 1. Symmetrical balancing within the hour.

There is frequently a significant difference between the price of up-regulation and down-regulation at different times of the day. As a result, there may be economic advantages to scheduling the within-hour balancing on an asymmetrical basis. In the second example, the need for up-regulation during the load rise is nearly eliminated where it turns out to be an especially expensive service. Instead, additional energy imbalance is purchased for the hour so that the only type of required regulation is down-regulation. This is illustrated in Figure 2.

Energy imbalance can be used to convert up-regulation capacity into down-regulation capacity and visa-versa. For example, additional up-regulation capacity can be purchased inexpensively at night. Generation that is operating at minimum load is capable of swinging up fairly cheaply. In general, positioning the system is an optimization problem depending on the relationship among the prices of additional hourly balancing, up-regulation, and down-regulation, as well as the shape of the forecast error distribution. These relationships typically differ between light load hours and heavy load hours, and an economic procurement decision is primarily based on these price relationships.

For a closed system that includes all loads and generating resources, these arguments may not hold as generation must meet load at all times within the hour. However, wind projects often hold schedules across control areas to entities that must hold incremental and decremental units to accommodate changes in wind output. Since the schedules do not exactly match the wind through the operating periods, the BA holds reserves that are somewhat duplicative of those held by the receiver of the wind schedules. Biasing wind schedules allows the BA to more economically share reserve requirements with the receivers of the wind schedules.

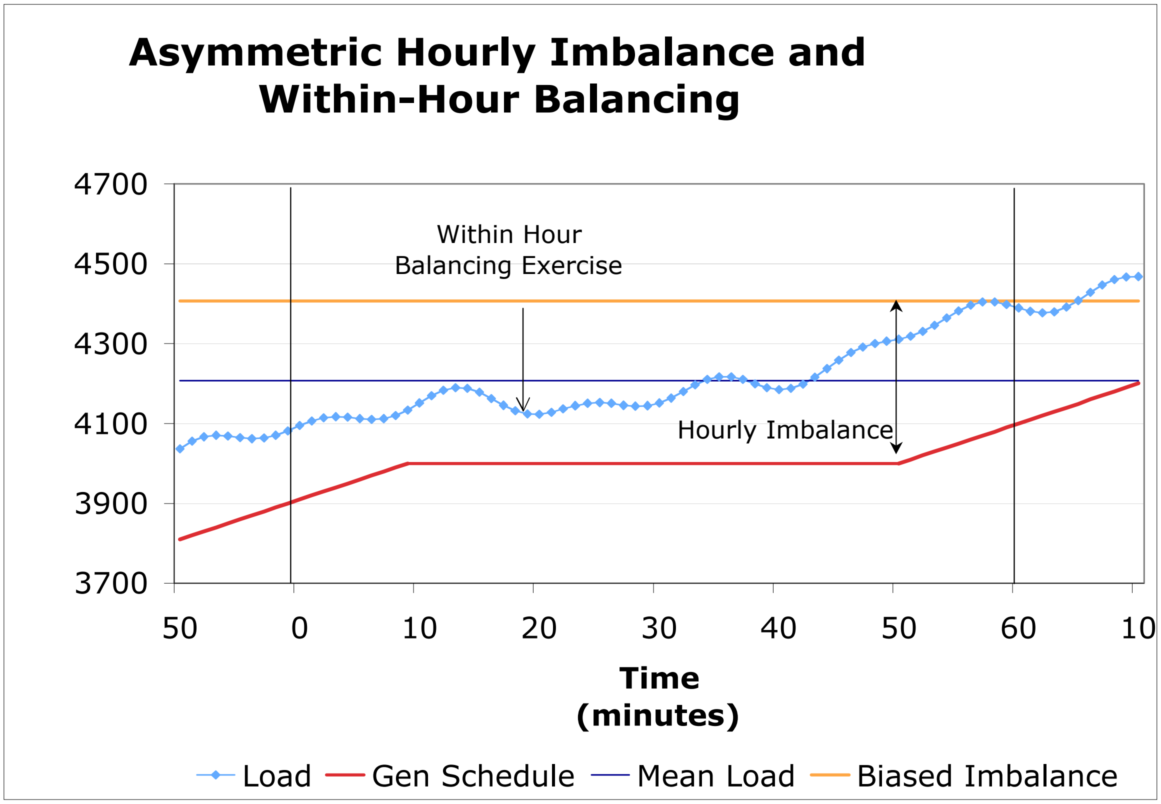

Figure 2. Asymmetrical balancing within the hour.

The asymmetry problem implies that BAs consider purchases and sales of power to reduce the cost of procuring up-regulation and down-regulation for balancing system load net of wind. Figure 3 presents results from a simple spreadsheet model that chooses an optimal schedule from a given set of regulation costs and market price for power. The example shows optimized schedule amounts for an expected net system demand of 2,500 MW with a normally distributed error that has a standard error of 50 MW. The market purchase/sale price of energy for the hour is $50/MWh, and the cost of down-regulation was fixed at $20/MWh. The optimization shows that a BA purchase, or sale, that effectively moves the system away from the unbiased expected 2,500 MW demand is necessary for optimum economic efficiency. The optimization process was repeated for a range of up-regulation costs. In the example, the optimum schedule is the same as the unbiased schedule when the market price for power is equal to half the difference between the up-regulation and down-regulation services. Note that for the purposes of the simplified optimization example, the regulation costs include both opportunity and incremental costs of holding and dispatching reserves, expressed on a cost per megawatt-hour basis.

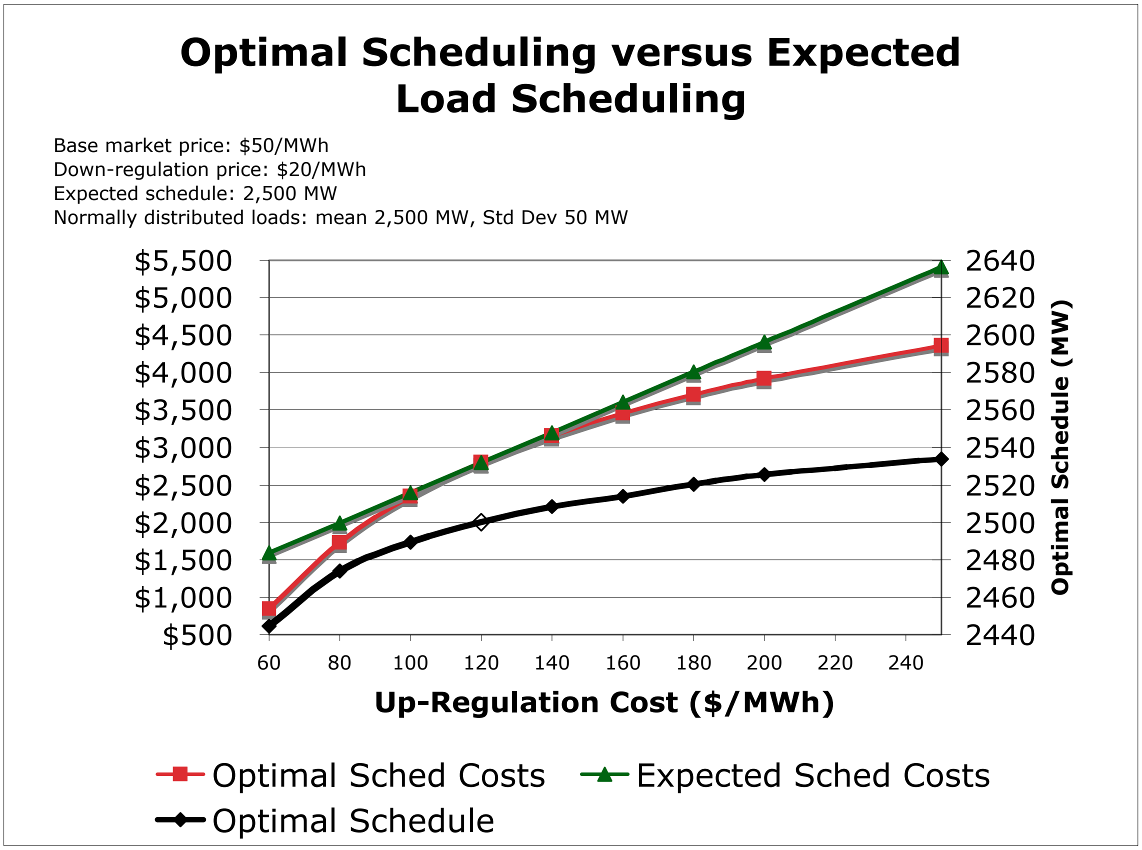

Figure 3. Optimized scheduling costs versus unbiased scheduling—optimum schedule is unbiased (2,500 MW) when the up-regulation price is $120/MW-hr.

The price difference between up-regulation and down-regulation can be significant for several reasons. Regulation costs are dominated by the opportunity costs the regulating generator incurs when it withholds capacity from the energy market. During peak hours, the cost of providing up-regulation may be based on the lost opportunity the regulating unit incurs when it withholds output from the energy market in order to provide up-regulation. If the regulating unit is the marginal unit, it incurs little cost.[2] The regulating unit is typically not the marginal unit, however, because automatic generation control (AGC) is not included on every unit. Down-regulation costs can be associated with the fuel savings of a more efficient resource already operating at maximum capacity and the opportunity it loses to sell energy when it is regulated down. Conversely, on low load hours, there may be higher costs associated with down-regulation services if all operating units are at or near minimum generation points. Typically, hydro systems will operate in such a way as to have significant amounts of down-regulation available on heavy load hours, and up-regulation on low load hours, but will much less frequently have an abundance of regulation in both directions at the same time.

[2] Regulating units do incur inefficiencies when they regulate both as throttling losses and because the base point ID often shifted away from the most efficient operating point. These costs are typically less than the opportunity costs.

Biased wind schedules may also be useful in reducing the incremental reserves needed to accommodate wind. Generally, the additional reserve requirement stems from periods when the wind deviations from schedule exacerbate the need for reserve used for following load. For example, the wind may suddenly fall off during the morning load ramps, increasing need for other generators to offset more than would otherwise be needed. Figure 4 shows an example in which the wind dropped off during the morning load ramps. If wind schedules based on persistence were replaced with a schedule of, say, 85% of persistence, there would have been minimal need for additional reserves due to the wind on morning hours.

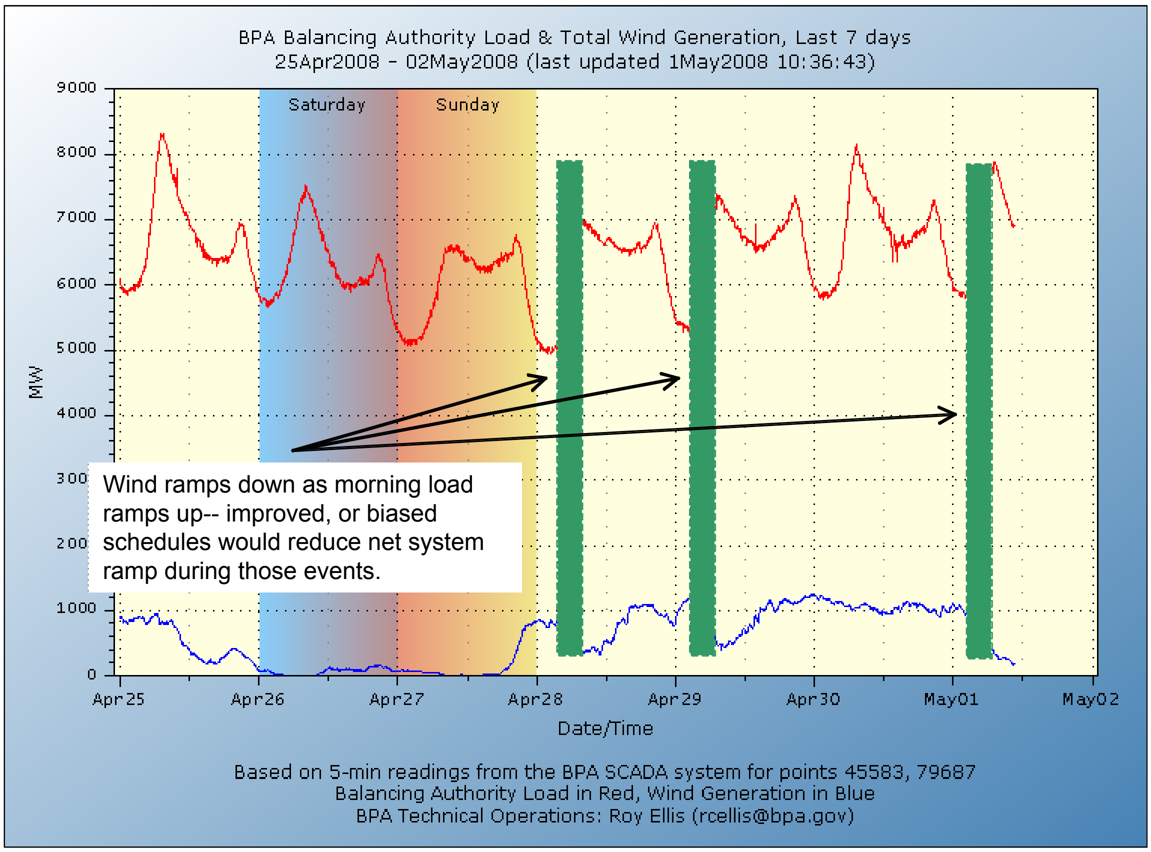

Figure 4. Biasing wind schedules downward from persistence would have reduced incremental reserve requirements for wind in these three recent events on the Bonneville Power Administration (BPA) system when wind fell off during the morning load ramp.

Impact of Inter-Balancing Area Wind Energy Transfers

The previous section showed that a balancing area may be able to bias the wind forecast and reduce its regulation requirement. However, that will result in a duplication of reserves that are held by the host and the receiver balancing areas. In this section, we generalize that discussion and show the impact that wind has on balancing area requirements under alternative scenarios: wind that is delivered within the host balancing area, and wind that is delivered to an outside balancing area.

Excess balancing capacity (regulation and intra-hour balancing) can also be required when a wind plant is not located in the same balancing area as the load it is serving if the energy market clearing interval is long (an hour, for example).[3] This excess balancing requirement neither reduces the balancing requirement in the load balancing area nor does it increase power system reliability – it is simply wasted. Figure 5 shows the simplified daily capacity requirement for a balancing area where load is increasing in the morning. Figure 6 provides a similar simplified illustration of the balancing area capacity requirement when wind is providing energy to a flat load within the balancing area.

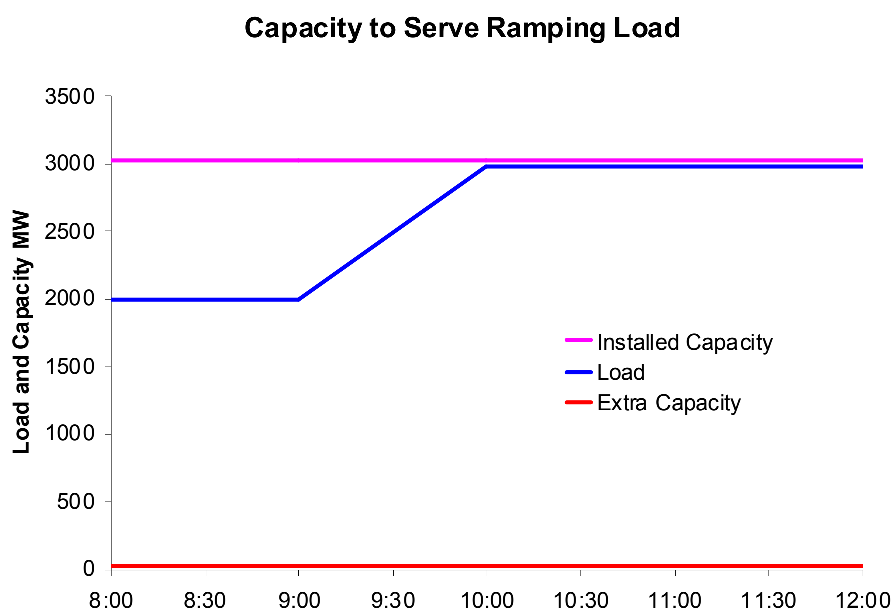

Figure 5. Daily capacity requirement for a balancing area serving a rising load.

[3] Kirby & Milligan, "An Examination of Capacity and Ramping Impacts of Wind Energy on Power Systems, 2008." Electricity Journal. To appear.

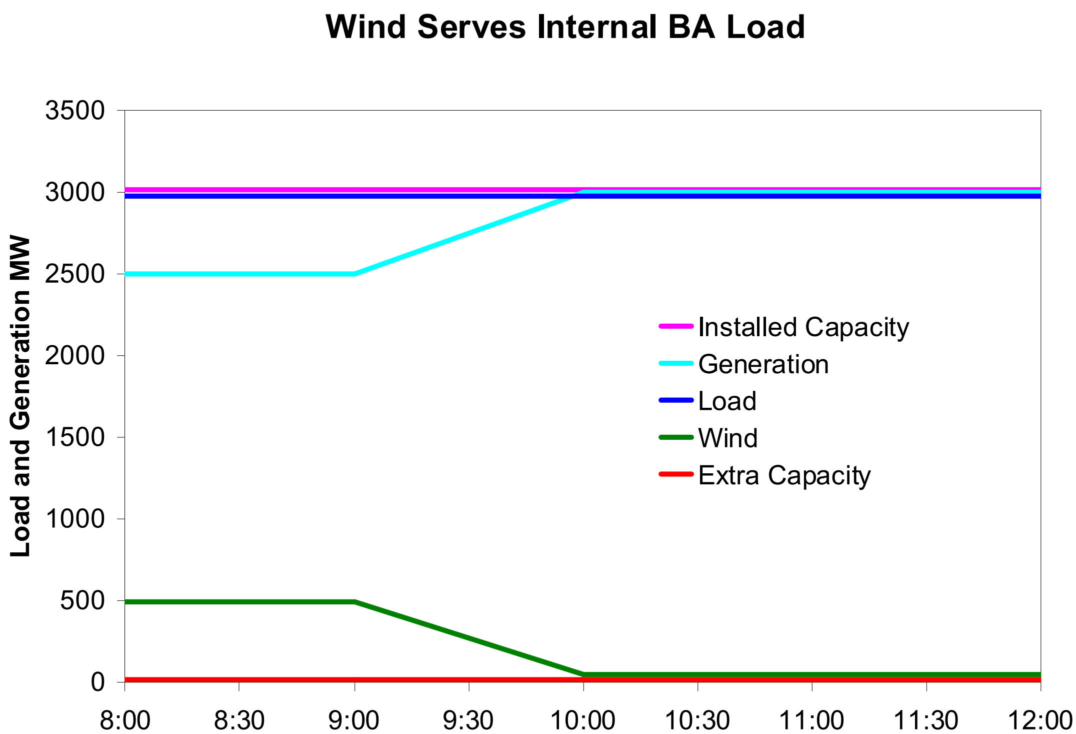

Figure 6. Balancing area capacity requirement when wind supplies load within the balancing area.

Note that the wind down ramp does not increase the balancing area's capacity requirements above what was required simply to serve the load. The conventional generation has to ramp to compensate for the change in wind generation, but no additional conventional generation capacity is required. The situation is different, however, when the wind energy is being sent to an external balancing area with inflexible scheduling rules as shown in Figure 7. When the wind drops by 500 MW at 9:30, the balancing area is obligated to continue delivering scheduled energy until the start of the next market interval; 10:00 in this example. The wind host balancing area requires 500 MW of increased regulation reserves, or other slower reserves. Interestingly, the load balancing area gets essentially no benefit from the wind balancing area carrying the extra reserves as illustrated by Figure 8. The load balancing area still requires enough capacity to serve the load. The load area generation must ramp up at 10:00 when the wind schedule drops. Had the wind been physically located within the load area, the generation would have had to ramp up at 9:30 instead. The 30-minute delay does not reduce the reserve requirement, and likely does not change the character of the reserve either. In fact, requiring hourly scheduling increases the stress on the conventional generators for two reasons (in addition to increasing the amount of reserves required in the wind balancing area). First, the conventional generators are required to move in two directions; up and then down in this example. Second, ramping speed is likely increased. The ramp to the new scheduled wind level, which occurs at the top of the hour, always occurs over 20 minutes in the Western Electricity Coordinating Council (WECC) area and over 10 minutes in the east. The actual change in wind output may have occurred over a longer interval. So the second ramp is likely faster than the first.

There is little or no economic benefit, and no reliability benefit, from the wind balancing area holding the excess reserves. The wind host balancing area could instead continue to provide the minute-to-minute regulation requirements of the wind plant, but pass the sub-hourly ramping requirements to the load balancing area at much lower cost. Alternatively, the wind plant could be dynamically scheduled to the load balancing area, but this might not be as economical for either system.

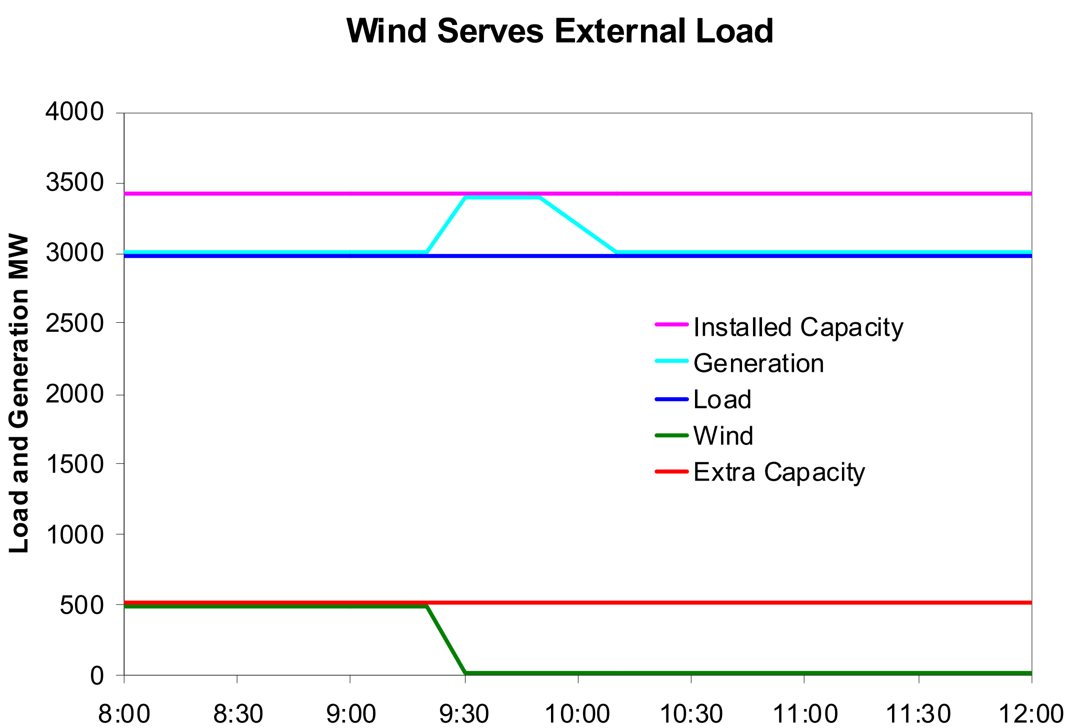

Figure 7. Extra reserves are required when the wind plant is supplying load in another balancing area.

Viewed from another perspective, the wind plant in the example discussed above has a put-option on the receiving balancing area. The wind plant has essentially the same 'put-option' on the host balancing area – this double counts the reserve requirement because each balancing area is liable for the associated reserves. Both the host balancing area and the receiving balancing area have to be prepared for sudden shifts in the wind. Forcing both balancing areas to hold reserves to cover the same shift in wind output causes costs to be much higher than they would be otherwise; one put-option is cheaper than two.

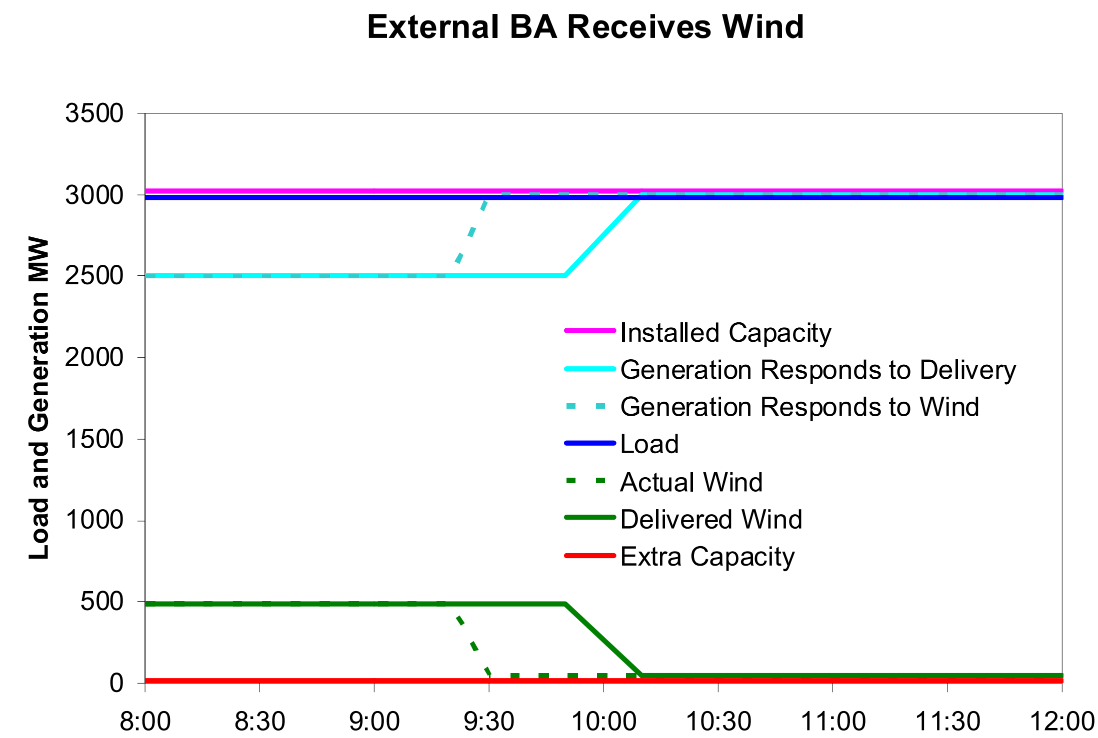

Figure 8. The load balancing area reserve requirements are not reduced when the wind area holds excess reserves.

Conclusions

As systems add wind resources while meeting increasing environmental constraints, power system optimization will likely become a greater concern, with greater economic consequences. BAs need to consider adding energy purchases and sales to their list of resources in order to maximize the economic efficiency of their power systems and minimize the cost of procuring ancillary services. Large wind energy penetrations will increase the variability that must be managed by the system operator. In some cases, it may be advantageous for the BA to use a biased wind schedule, but that results in an equivalent put-option on the receiving balancing area. Shorter market periods, dynamic schedules, or other mitigating approaches will reduce or eliminate the excess reserves when wind is delivered outside the host balancing area.

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Energy market scheduling conventions can needlessly increase the wind balancing area’s regulation requirements. This economic inefficiency can be eliminated once it is recognized. The paper provides a detailed discussion of these issues.

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