Calculating Individual Resources Variability and Uncertainty Factors Based on Their Contributions to the Overall System Balancing Needs

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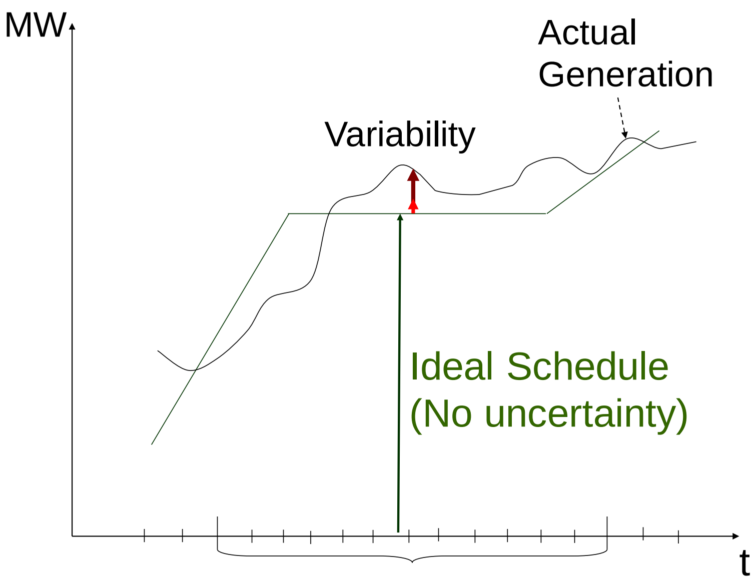
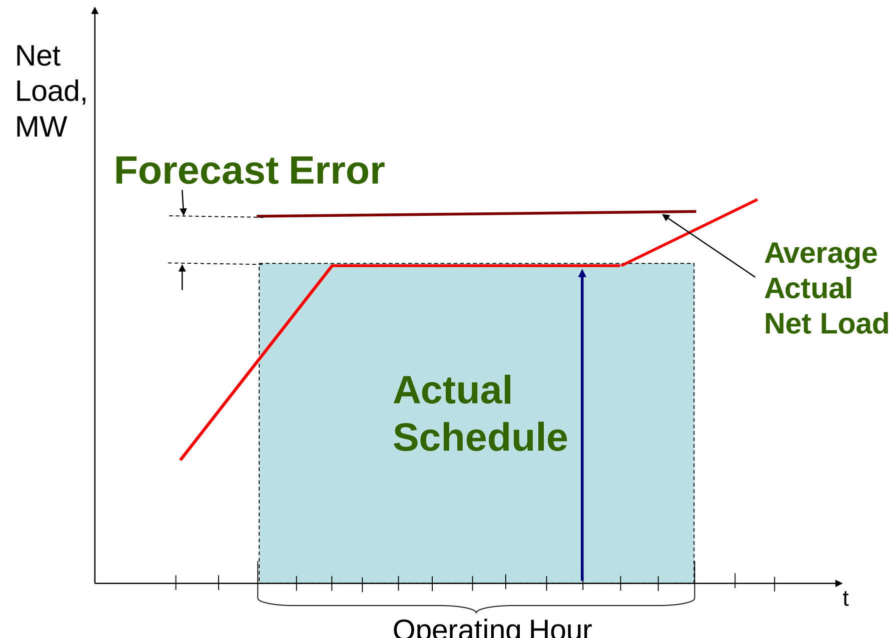
Overview

- Sources of uncertainty and variability
- Metrics to measure BAs' control performance in maintaining power balance:
  - ACE
  - CPS1
  - CPS2
  - BAAL
- Proposed method: Grid Balancing Metric
- Case study
- Conclusions

Uncertainty and Variability

- Variability
  - Is the difference between the “ideal” scheduled values within a dispatch interval and the actual variations of the balancing requirement (discretization errors)
- Uncertainty
  - Is caused by deviations of actual values from their corresponding predicted values





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Sources of Uncertainty and Variability

- Sources of uncertainty and variability:
  - Loads
  - Wind and solar generation
  - Uninstructed deviations of conventional units
  - Failures to start up
  - Load drops
  - Forced outages
- The sources include continuous and discrete processes
- All sources <u>collectively</u> contribute to balancing requirements
  - Wind and solar generation are not the only contributors
  - All sources of uncertainty interact in a statistical way decreasing the relative impact on the system balance
  - At the same time, the danger of having major system imbalances (“tail events”) remains real

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Balancing Challenges

- Reserves and the balancing effort must be sufficient to compensate for combined variability and uncertainty.
- The balancing reserves are expensive, and each BA is trying to minimize these requirements without compromising system reliability and performance.
- Various metrics (CPS1 and CPS2, DCS, FRS, BAAL, frequency limits) are NERC standards
- They check how well a BA balances its generation against load, wind and solar generation and interchange

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Area Control Error (ACE)

$$ACE_i = \Delta P_{tie} - 10 B_i \Delta F$$

interconnection frequency error in Hz

tie-line power error in MW

control area frequency bias in MW/0.1Hz

- ACE: a measure of BA performance in balancing its generation against the load and interchange variations.
- Each BA is required to reduce its ACE and keep it within certain statistical limits, established by NERC control performance standards.

Control Performance Standards (CPS1)

$$\text{CPS1} = (2 - \text{CF}) \cdot 100\% > 100\%$$

$$CF = AVG_{12-month}\left[CF_1\right]$$

$$CF_1 = \left[\left(\frac{ACE}{-10B}\right)_1 \left(\frac{\Delta F}{\varepsilon_1^2}\right)_1\right]$$

interconnection frequency error

targeted frequency bound for CPS1

frequency bias of the control area

$(.)_1$ is the clock -1-min average.

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Proposed Mechanism: Grid Balancing Metric

- The current methods for allocating the responsibility for the system balancing reserves are not effective:
  - They are not based on existing control performance standards
  - They are frequently applied to renewable resources only and ignore the other sources of uncertainty
  - They are not making any difference between “helpers” and “harmers”
  - They do not reflect the fact that random deviations are not always harmful to the system
  - They do not follow simple arithmetic rules (linearity)
- Proposed mechanism: Grid Balancing Metric (GBM):
  - Based on the CPS1 control performance standard mandated by NERC (Can be modified to reflect CPS2 or BAAL)
  - Directly linked with the current CPS1 score and interconnection frequency performance
  - Provides scientifically defined allocation factors for variability rates
  - Has easy to understand statistical interpretation
  - Is applicable for any resource, group of resources and load, or a combination of load and resources
  - The sum of allocation factors within any group of resources is equal to the group’s collective allocation factor (linearity)

Proposed Mechanism: Grid Balancing Metric (Continued)

- Proposed mechanism: Grid Balancing Metric (continued)
  - Distinguishes helpers and harmers by assigning the corresponding signs and values for contributing factors
  - Urges resources to minimize their variability and uninstructed deviations
  - Stimulates resources to support interconnection frequency and provide better frequency response
  - Helps to minimize the interconnection time error and minimize the number of manual time error corrections

Grid Balancing Metric: Definition

- Grid balancing metric for resource *i*,

$$R_i = \frac{avg_T\left(\frac{\delta_i}{-10B}\Delta f\right)}{PF_{BPA} - PF_{WI}}$$

moment-to-moment deviation of a resource *i* or a load *i* (e.g., minute-to-minute deviations)

the deviation of the actual interconnection frequency from its scheduled value

T analyzed period

frequency bias, MW/0.1 Hz

BPA CPS1 performance factor over period *T*

CPS1 performance factor over period *T*

Grid Balancing Metric (continued)

- The balancing cost *C* is allocated to a particular resource using the following formula:

$$C_i = R_i \cdot C$$

- If the cost *C* is associated with a particular subgroup of resources, it can be allocated based on the formula:

$$C_i = \frac{R_i}{\sum_{j \in J} R_j} \cdot C$$

Interpretation

$$avg_T\left(\frac{\delta_i}{-10B}\Delta f\right)=\underbrace{\mathrm{cov}_T\left(\frac{\delta_i}{-10B},\Delta f\right)}_{\substack{\text{Insentive to support}\\ \text{Inteconnection frequency}\\ \text{\& provide frequency support}\\ \text{(i.e., create negative correlation}\\ \text{between } \delta_{\mathrm{i}} \text{ and } \Delta f\text{)}}}+\underbrace{avg\left(\frac{\delta_i}{-10B}\right)}_{\substack{\text{Insentive to minimize}\\ \text{systematic uninstructed}\\ \text{deviations } \delta_i \text{ (i.e. to provide}\\ \text{unbiased schedules and}\\ \text{minimize } \delta_i\text{)}}}\times\underbrace{avg(\Delta f)}_{\substack{\text{Insentive to minimize}\\ \text{Interconnection}\\ \text{Time error}}}\rightarrow\min$$

$$avg_T\left(\frac{\delta_i}{-10B}\Delta f\right)=\underbrace{\sigma_T\left(\frac{\delta_i}{-10B}\right)}_{\substack{\text{Insentive to minimize}\\ \text{variability of } \delta_i\text{, especially}\\ \text{at the minimum system}\\ \text{load (min } B\text{)}}}\times\underbrace{\sigma_T(\Delta f)}_{\substack{\text{Insentives to provide}\\ \text{frequency response}\\ \text{and limit significant}\\ \text{excursions of } \Delta f}}\times\underbrace{\rho_T\left(\frac{\delta_i}{-10B},\Delta f\right)}_{\substack{\text{Insentive to support}\\ \text{Inteconnection frequency}\\ \text{(create negative correlation}\\ \text{between } \delta_{\mathrm{i}} \text{ and } \Delta f\text{)}}}$$

$$+\underbrace{avg\left(\frac{\delta_i}{-10B}\right)}_{\substack{\text{Insentive to minimize}\\ \text{systematic uninstructed}\\ \text{deviations } \delta_i \text{ (i.e. to provide}\\ \text{unbiased schedules and}\\ \text{minimize } \delta_i\text{)}}}\times\underbrace{\frac{TE(T)}{60\cdot \mathrm{N}}}_{\substack{\text{Insentive to minimize}\\ \text{Interconnection Time}\\ \text{Error accumulation over } T\\ \text{(and reduce the number}\\ \text{of corrections)}}}\rightarrow\min$$

Interpretation (continued)

- Fact 1: Relationship between the area control error and uninstructed deviations of resources and load variations:

$$ACE = (I_a - I_s) - 10B \cdot \Delta f = (G_a - L_a - G_s + Ls) - 10B \cdot \Delta f$$
$$= \sum_{i=1}^{M} \delta_i - 10B \cdot \Delta f$$

$$\sum_{i=1}^{M} \delta_i = G_a - L_a - G_s + Ls$$

actual generation

actual load

scheduled generation

scheduled load

Interpretation (continued)

- Fact 2: CPS1 formulation (simplified)

$$PF_{BPA} = avg_T\left(\frac{ACE}{-10B}\Delta f\right) \le \varepsilon_1^2$$

- Fact 3: Link with CPS1 standard

$$PF_{BPA} = \underbrace{avg_T\left(\frac{ACE}{-10B}\Delta f\right) \le \varepsilon_1}_{CPS1}$$

$$= \sum_{i=1}^{M} avg\left(\frac{\delta_i}{-10B}\Delta f\right) + rms^2\Delta f \le \varepsilon_1$$

$$= \left(PF_{BPA} - PF_{WI}\right)\sum_{i=1}^{M} R_i + rms^2\Delta f \le \varepsilon_1$$

Interpretation (continued)

- Fact 4: For all sources of variability (generators and loads),

$$\sum_{k=1}^{M} R_i = 1$$

- Fact 5:

$$avg\left(\frac{\delta_i}{-10B}\Delta f\right) < 0 - \text{"Helper"}$$

$$avg\left(\frac{\delta_i}{-10B}\Delta f\right) > 0 - \text{"Harmer"}$$

The “helper” improves the system performance, and the “harmer” worsens the performance.

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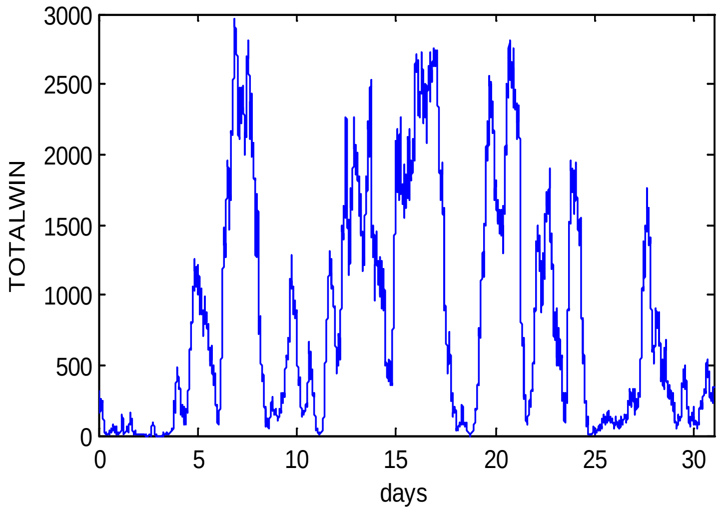
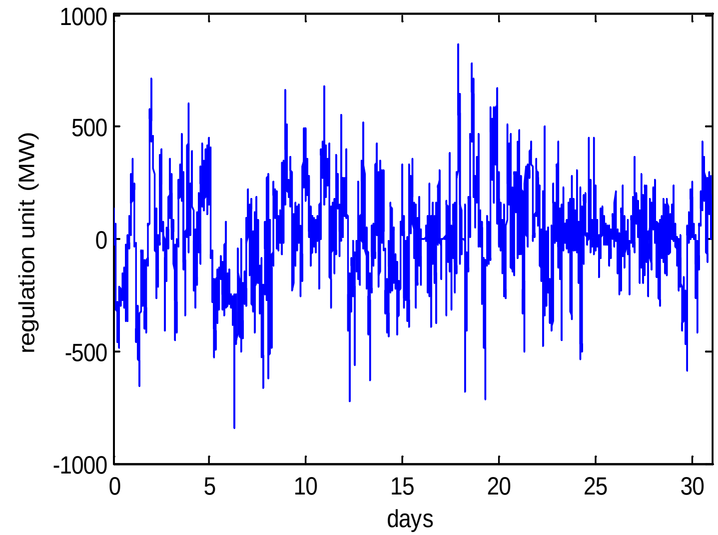
Case Study



Aggregated wind profile



Regulation unit output

The simulation was performed using a 1-month BPA historical data, where peak load and peak wind power were 9.77 GW, and 2.96 GW, respectively.

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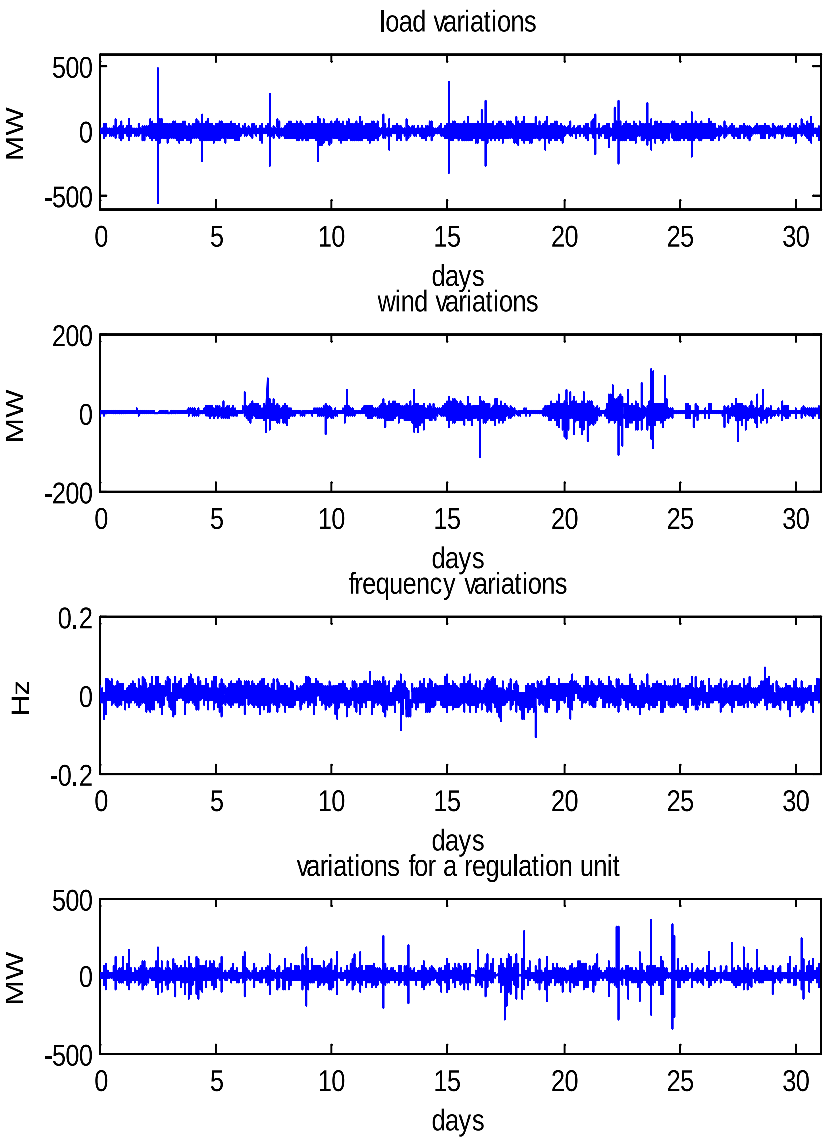
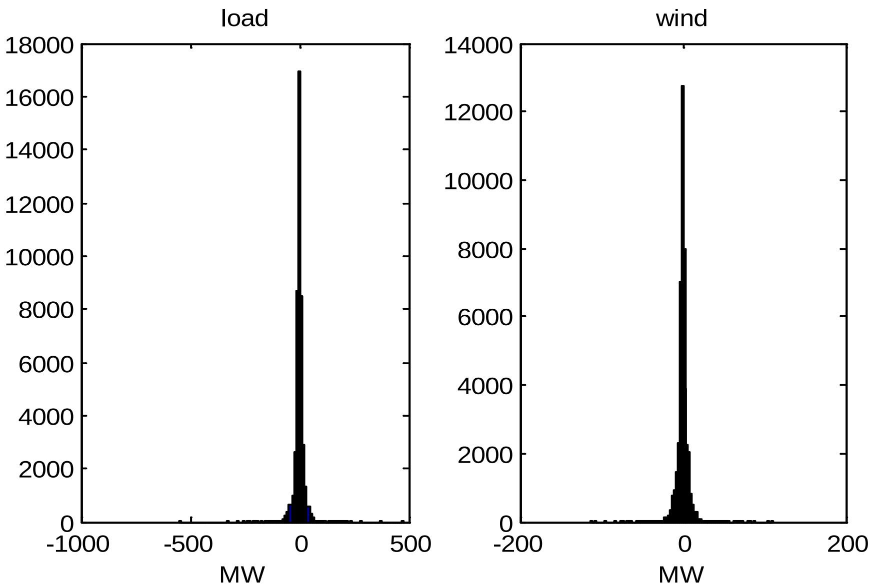
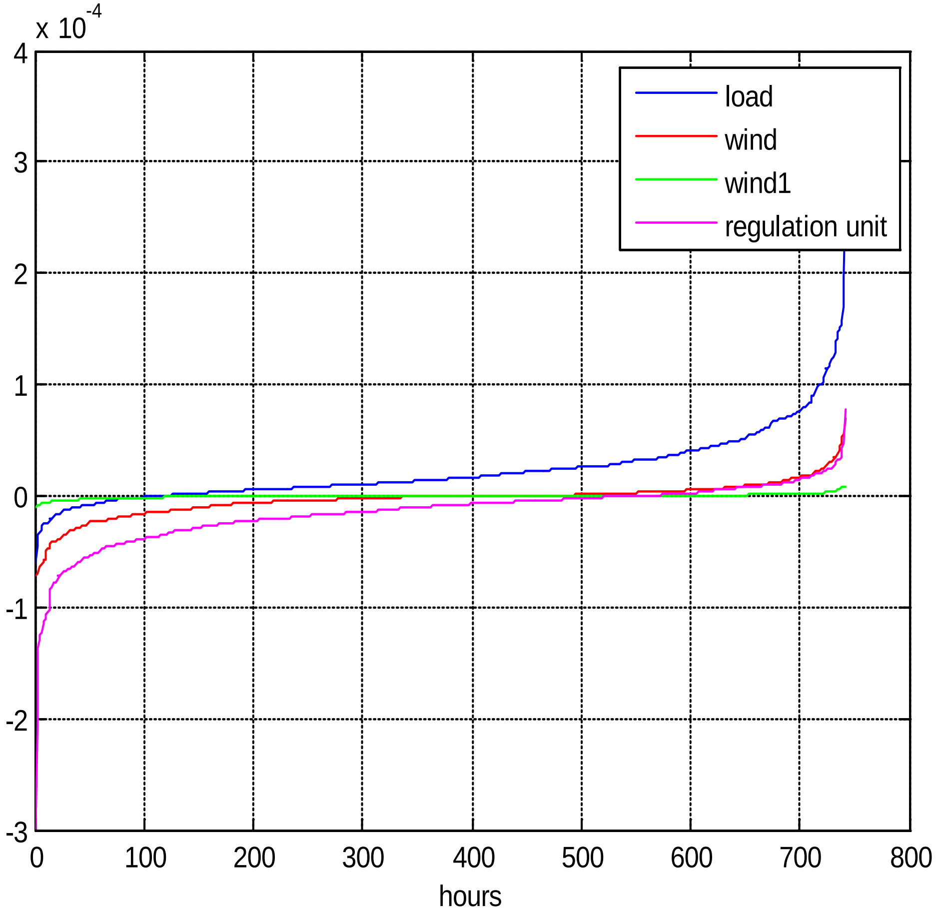
Minute-by-minute Variations





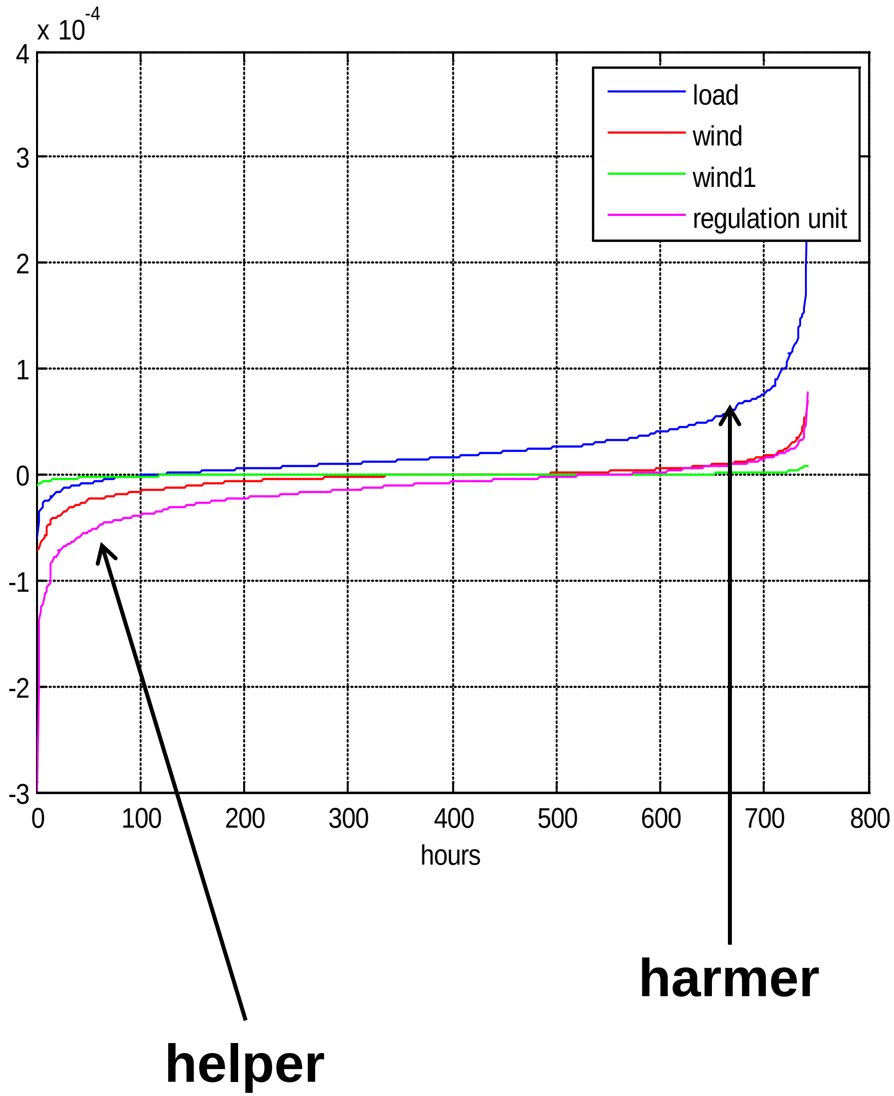
Histograms of variations

Grid Balancing Metric (GBM)



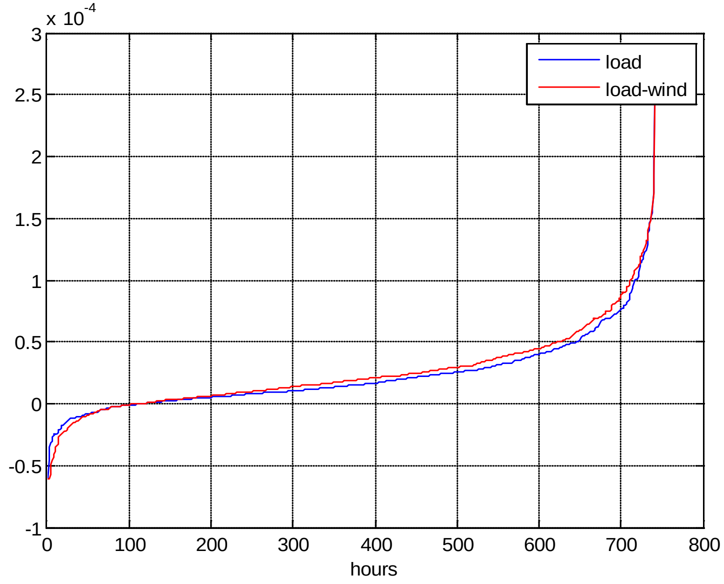
- Overall grid balancing metric for aggregated wind shows much less impact than that of system load.
- The grid balancing metric for one wind farm shows very little impact.

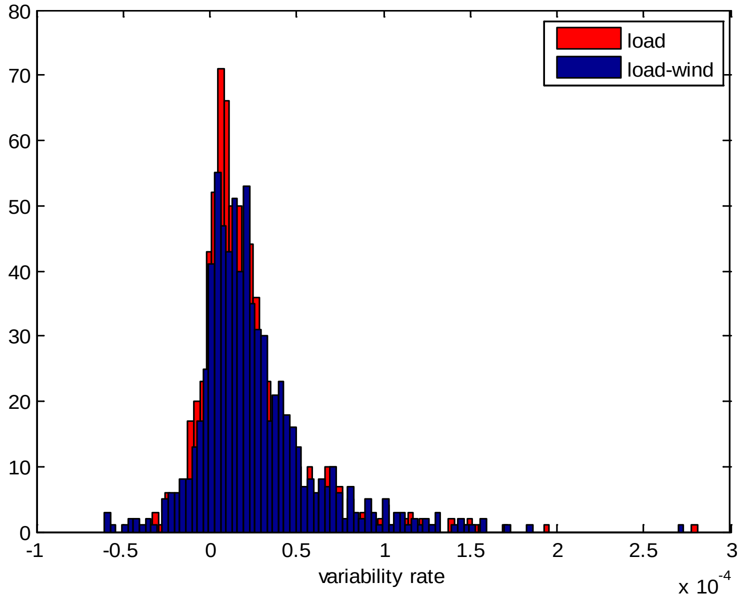
Grid Balancing Metric (continued)



- If the GBM is negative, the resource is helping the grid to maintain the frequency needed to stay close to the nominal frequency within the tolerance limits (helper).
- If GBM is positive, the resource needs resources to compensate for its variations and to regulate the frequency (harmer).
- The GBM for aggregated wind is almost symmetric around zero, which means that wind has small overall impact on the interconnection frequency variations, and sometimes even helps to balance the system.

Grid Balancing Metric for Load and Net-Load





The impact of the wind at the present penetration level is small.

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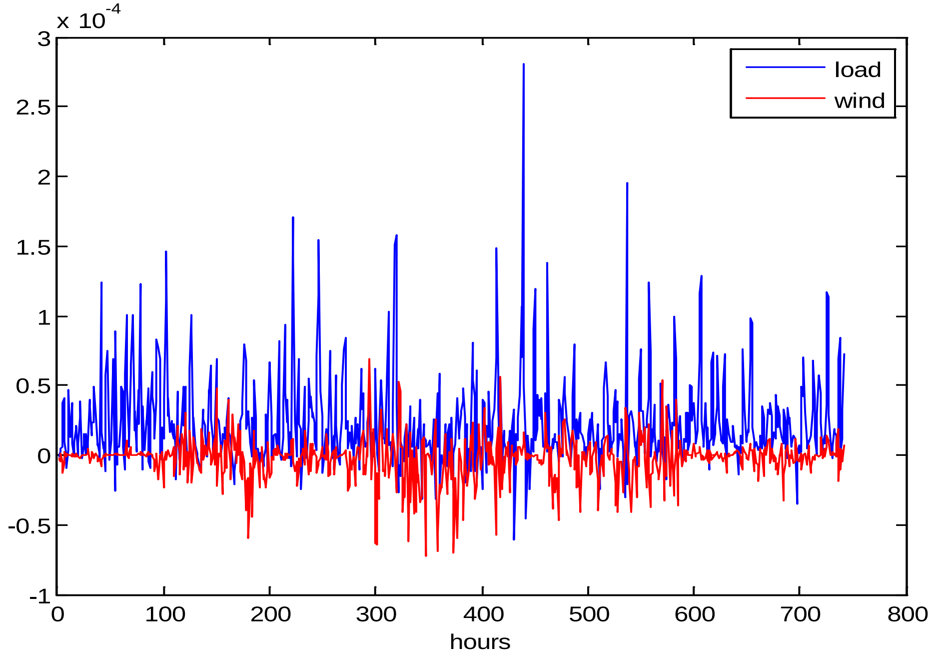
Grid Balancing Metric for Load and Wind



- When the magnitude of grid balancing metric for the wind is comparable with or exceeds that of load, it requires the operators to procure additional regulation capacity.
- This happens for a short period in the simulation (15%).
- The problem is that GBM is not predictive, so we should be moderately pessimistic when predict balancing requirements.

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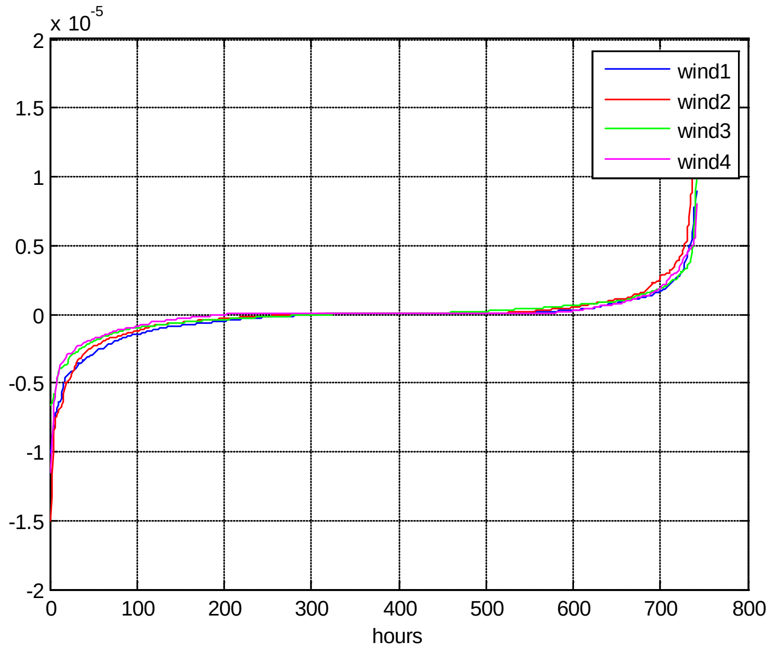
Grid Balancing Metric for Wind Farms



- The grid balancing metric is calculated for four different wind farms, and each has100-MW installed capacity.

Conclusions

- A new allocation mechanism uncertainty and variability of resources (regardless of their type) was proposed.
- Grid Balancing Metric is based on a new statistical formula.
- It has multiple advantages over the other existing approaches.
- Case study illustrates the new approach using Bonneville Power Administration data.

Thank you

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