NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL Variability Analysis for the Western Interconnect

Composite photo created by NREL

WECC WebEx

Brendan Kirby,
Jack King,
Michael Milligan

National Renewable Energy Laboratory

July 29, 2011

NREL/PR-5500-52430

Contents

- Study Data
- Methodology
- Analysis
- Allocation of reserve requirements

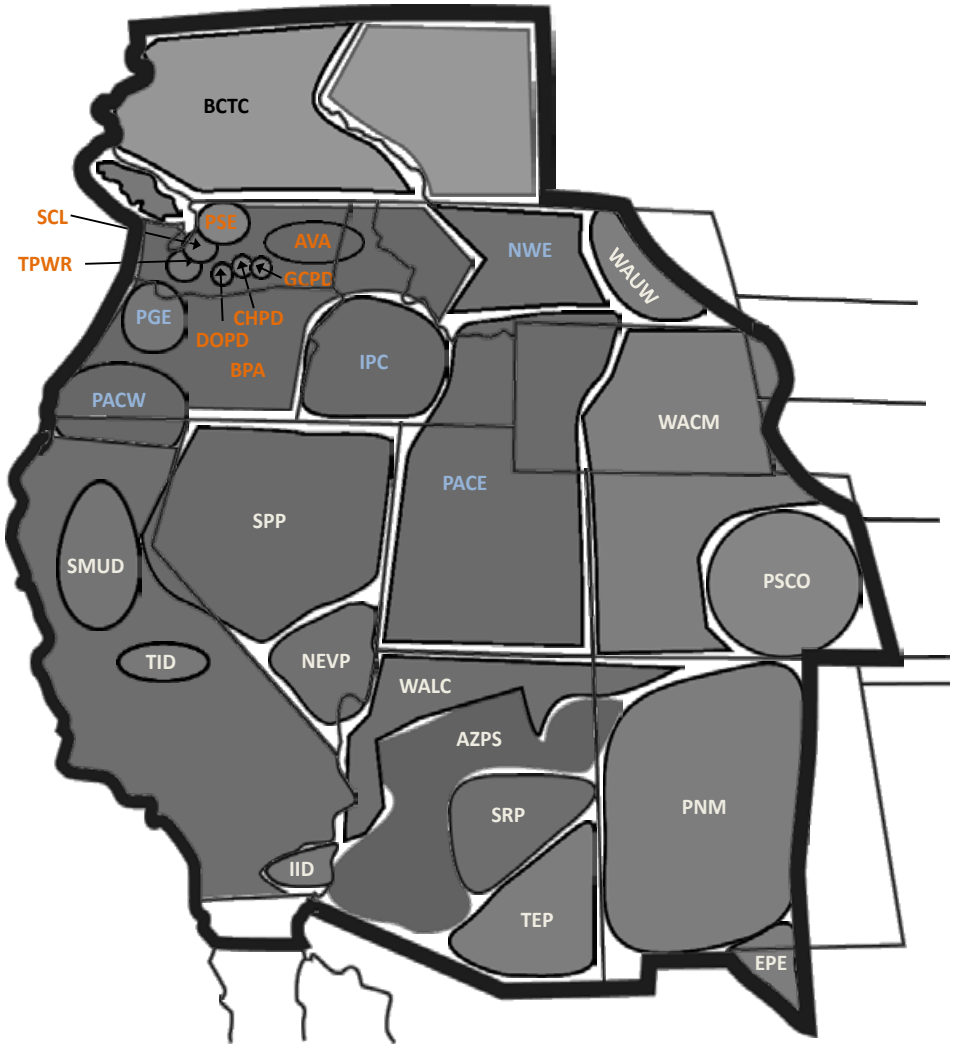
Overview

- Investigate the effects of several Energy Imbalance Markets implementations in the Western Interconnect (WI):
  - Operating reserves;
  - Ramping demand;
  - Alternative Schedu.ing
- Analysis based on aggregation of variability and uncertainty:
  - Uses available load, wind and solar data.
- Calculate the reserve requirements:
  - Estimating within the hour and hourly requirements based on historical data.
- Compared to NREL draft report, this analysis has approximately 1/3 VG.

Study Data

Model Area

- Based on TEPPC PC 0.
- Areas of the WI not already in a market structure (CAISO, Alberta).
- LADWP not included.
- Analysis at BAA granularity.
- Generation only BAAs not considered.
- 28 load and generation BAAs retained – The study 'Footprint.'
- Regions are:
  - Columbia Grid – Orange;
  - NTTG – Blue;
  - West Connect – White.



Load Data

- 2020 loads provided by WECC;
- Load shape is based on 2006 load;
- 193,700 MW in full Western Interconnect (non-coincident).
- 116,700 MW in analysis footprint (non-coincident);
- One hour load provided, 10-minute synthesized.

Wind Data

- NREL WWSIS wind dataset for 2006;
- 10-minute resolution;
- Sites identified by TEPPC 2020 PC 0;
- 29,085 MW in Western Interconnect;
- Approximately 8% of WI 2020 load;
- 18,272-MW nameplate modeled in analysis – footprint.

Solar Data

- NREL WECC Solar dataset for 2006;
- 10-minute resolution;
- Sites identified by TEPPC 2020 PC 0;
- 14,300 MW in WI;
- Approximately 3% of WI 2020 load;
- 4,568 MW nameplate in analysis footprint.

Reserve Calculations

Reserve Calculations

- Developed for the EWITS study;*
- Statistical approach based on 10-minute time series wind, solar and load;
- Method that can estimate adequate reserves to cover the short term and hour-ahead forecast error based on historical data;
- Predicts requirements based on current hour load and wind, solar production;
- Statistically combine with load regulation requirements;
- Provide 8760 vector of requirements for the production simulations.

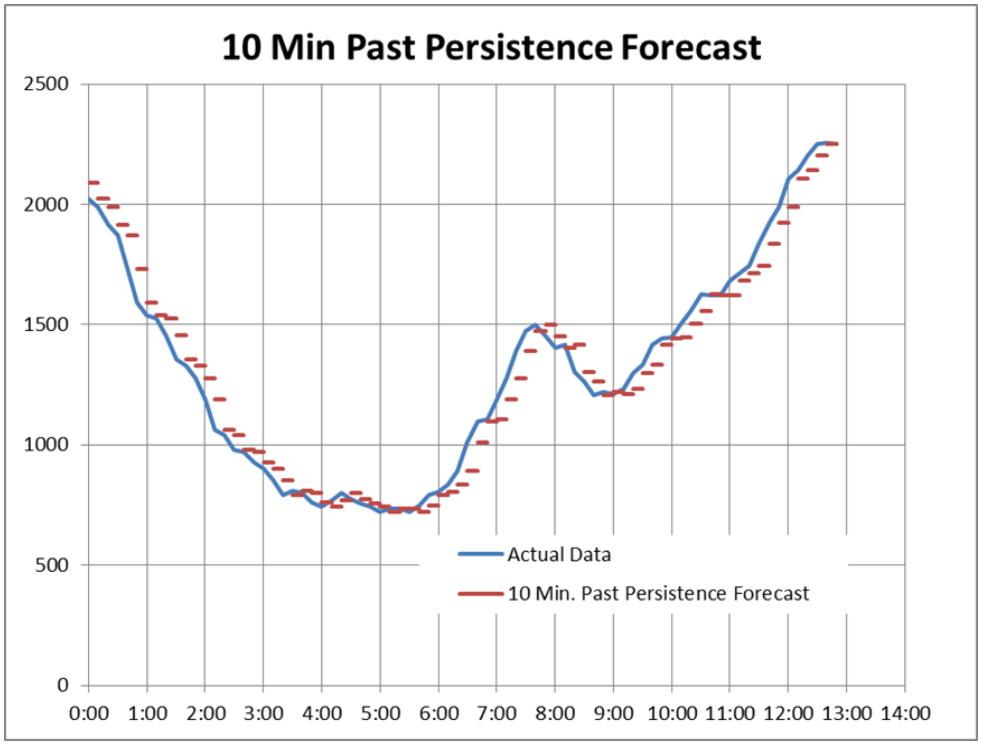
*For in-depth discussion see section 5 of the EWITS final report: http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_final_report.pdf

Reserve Definitions

- Regulation – Fast changes:
  - Due to variability and short-term forecast errors;
  - Faster than re-dispatch period;
  - AGC resources required.
- Spinning – larger, slower, less frequent variations:
  - Due to longer term forecast errors;
  - AGC not required;
  - 10-minute response.
- Non-spinning/supplemental:
  - Large, infrequent, slow moving events such as unforecasted ramps;
  - 30-minute response.

Short-Term Forecast Error - Regulation

- Based on persistence forecas;t
- Wind data is 10 minute, 10-minute delay for forecast;
- Forecast error is calculated as difference from actual to forecast.

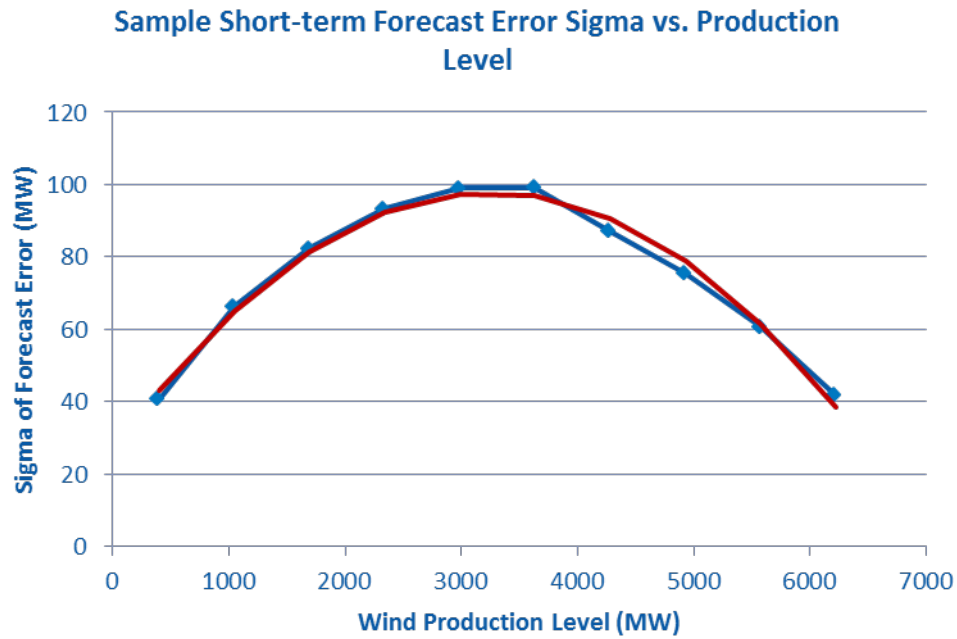


Short-term Calculation

- Measure as standard deviation of the forecast error;
- Forecast error varies with production level;
- Empirical expected error as a function of production is quadratic:
  - Low variability at low and high wind (cut-in and rated);
  - High variability in mid range at steep part of power curve;
  - Solar follows same pattern, more or less.
- Predicts the expected variability for the hour based on the intra-hour statistics, current production;
- Assumes fast dispatch, 10 minutes in this case:
  - Implication is that economic movement happen at 10-minute updates.

Calculation of Short-term Forecast Error

- Calculate and sort error by production level;
- Divide production into deciles;
- Calculate error sigma in each decile;
- Blue line is calculated from data;
- Red line is curve fit;
- Equation of the curve shown below.



$$\sigma_{ST}\,(Hourly\ Wind) = -6.72E-06 \cdot (Hourly\ Wind)^2 + 0.0437 \cdot (Hourly\ Wind) + 26.74$$

Calculating the Regulation Requirement

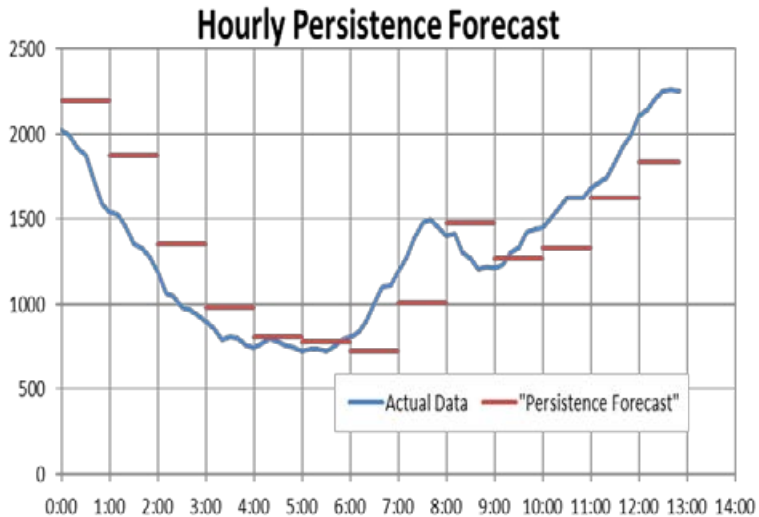
- Combine load, wind and solar components statistically assuming no correlation in this time frame
- $Regulation\ Requirement\ (With\ Wind\ and\ Solar) =$

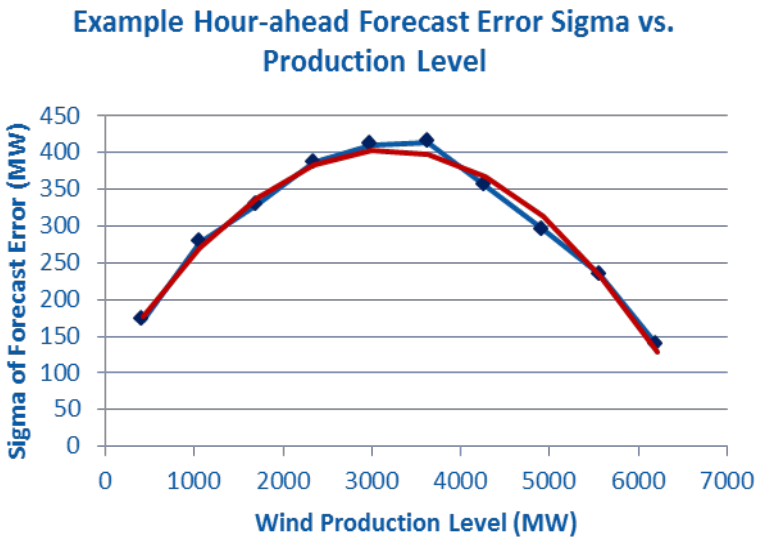
$$3 \cdot \sqrt{(\sigma_{Load})^2 + (\sigma_{STWind}\,(Hourly\ Wind))^2 + (\sigma_{STSolar}(Hourly\ Solar))^2}$$

- σ_{Load} calculated as fixed % of hourly load based on BA size
- $\sigma_{STWind}\,(Hourly\ Wind)$ calculated from previous slide
- $\sigma_{STSolar}\,(Hourly\ Solar)$ calculated from solar version
- This is 3 sigma to cover 99.7% of all short term forecast errors
- Assumed equal up and down
- Calculated for each hour of the study year

Hour-ahead Forecast Errors

- Repeat the short term forecast procedure with hour-ahead forecasting;
- Again, same procedure for wind and solar;
- Load following not included.





$$\sigma_{Hour-ahead}(Hourly\ Wind) = -2.985E-05 \cdot (Hourly\ Wind)^2 + 0.1895 \cdot (Hourly\ Wind) + 103.2$$

Spin and Non-spin Calculation

- One sigma allocated to **Spinning** category

$$Spinning\ Requirement\ (Hour - ahead\ wind\ forecast\ error)$$
$$1 \cdot \sigma_{hour-ahead}(Previous\ Hour\ Wind)$$

  - Covers 68%* of all movements less than 1 hour
  - With regulation, covers approximately 98% of 30 minute movements

- Two sigma allocated to **Non-spin** category

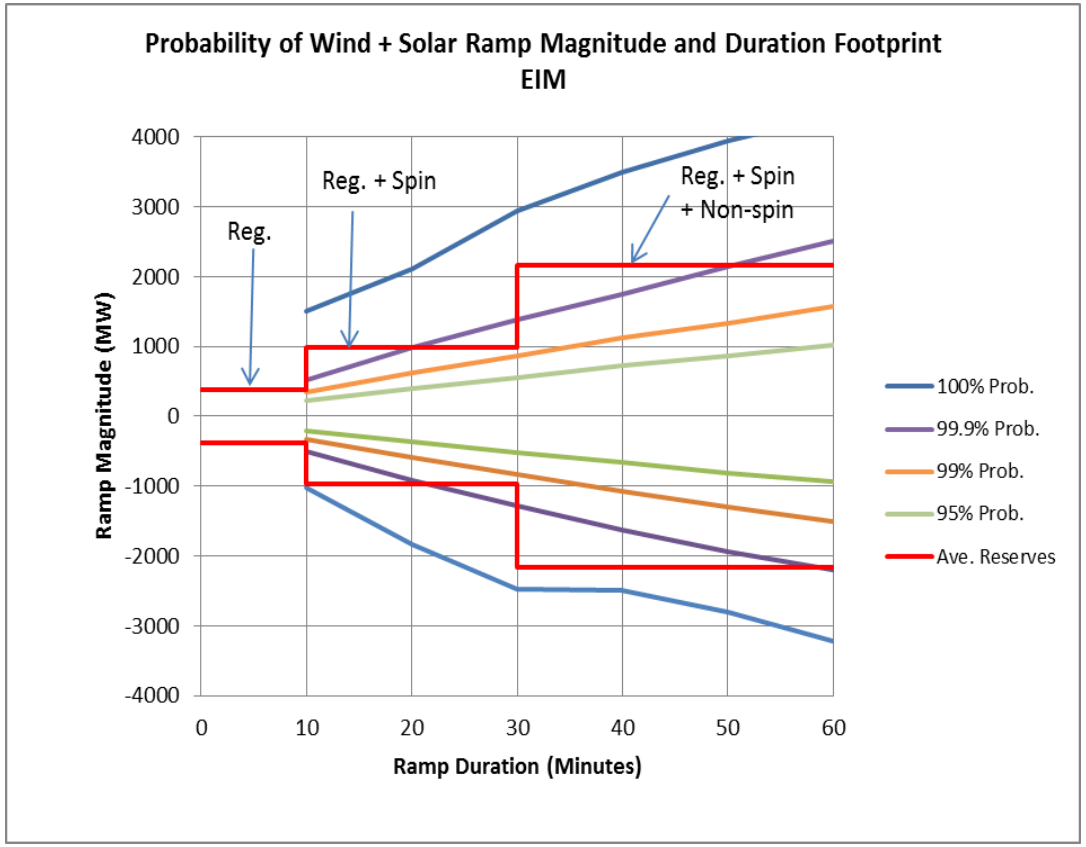
$$Non - spin\ Requirement\ (Hour - ahead\ wind\ forecast\ error) =$$
$$2 \cdot \sigma_{hour-ahead}(Previous\ Hour\ Wind)$$

  - With spin, covers 99.7%* of all movements less than 1 hour

*assuming movements are normally distributed which is slightly optimistic

Verification of Reserve Coverage

- Shows coverage of VG intra-hour movements;
- Actual ramp data from footprint EIM;
- Red line – Actual average reserve calcs from footprint EIM;
- Probability lines are z% of all ramps at x minutes are less than y MW.



Reserves Provided to E3 for Phase 2 Study

- NREL provided reserve calculations to E3 for phase 2 study;
- Slight variation in calculation of regulation component – load not included in E3 Flex;
- Does not include contingency reserves;
- Areas are slightly different from each other.

NREL	E3	Response	Notes
Regulation	Flex	AGC	E3 flex reserve does not contain load
Spin	Spin	<10 minutes	
Non-spin	Supplemental	<30 minutes	Terminology change

Analysis

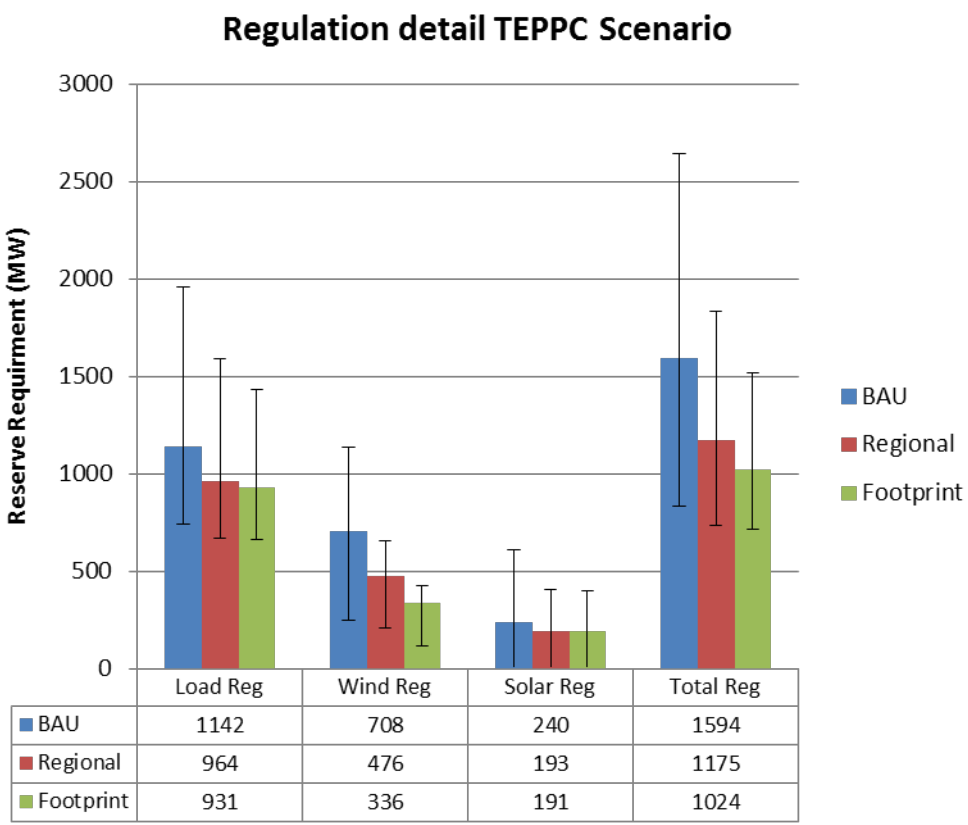
Cases

- Complete analysis includes:
  - Footprint EIM
    - All 28 BAAs participating.
  - ‘Regional’ EIM implementations
    - Columbia Grid;
    - Northern Tier Transmission Group;
    - WestConnect.
  - EIM implementations without BPA and/or WAPA participation.
  - Comparison to the Business-As-Usual (BAU) case – No EIM in place;
  - Selected results.

Footprint EIM Regulation

- Detail of the individual regulation components;
- Bars are average values, whiskers are min and max;
- 3 regional results in smaller reductions compared to footprint.

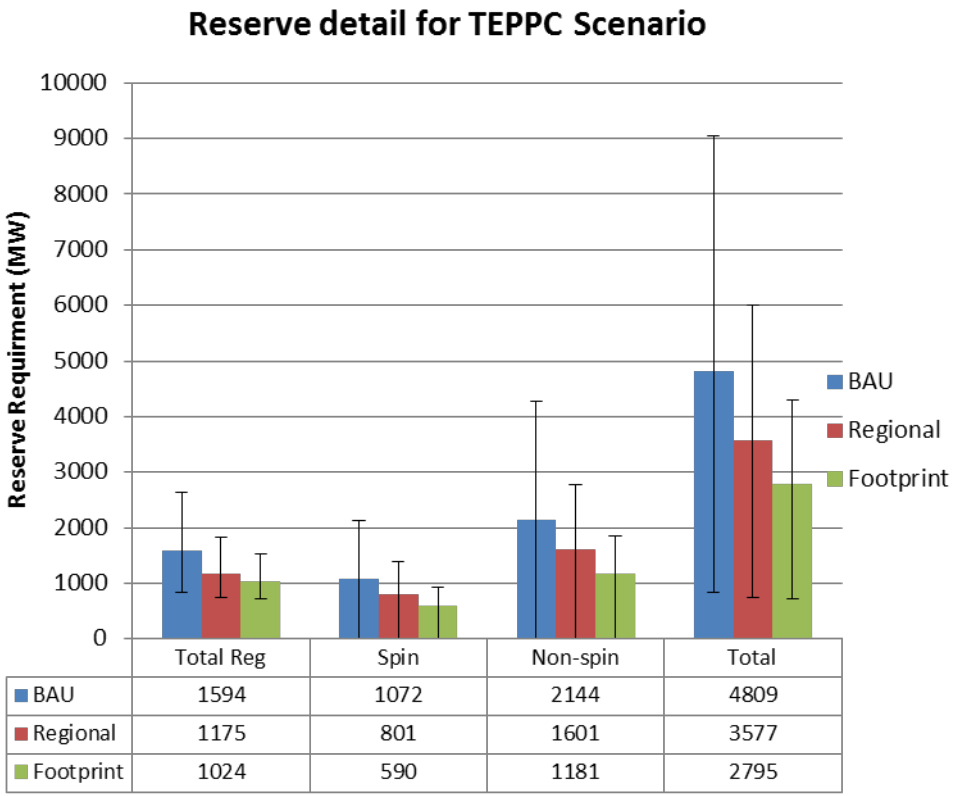
	Reduction over BAU			
	Footprint		Regional	
	MW	% Reduct.	MW	% Reduct.
Load Reg	211	18%	178	16%
Wind Reg	372	53%	231	33%
Solar Reg	49	21%	46	19%
Total Reg	570	36%	419	26%



Reserve Details for Footprint and Regional EIM

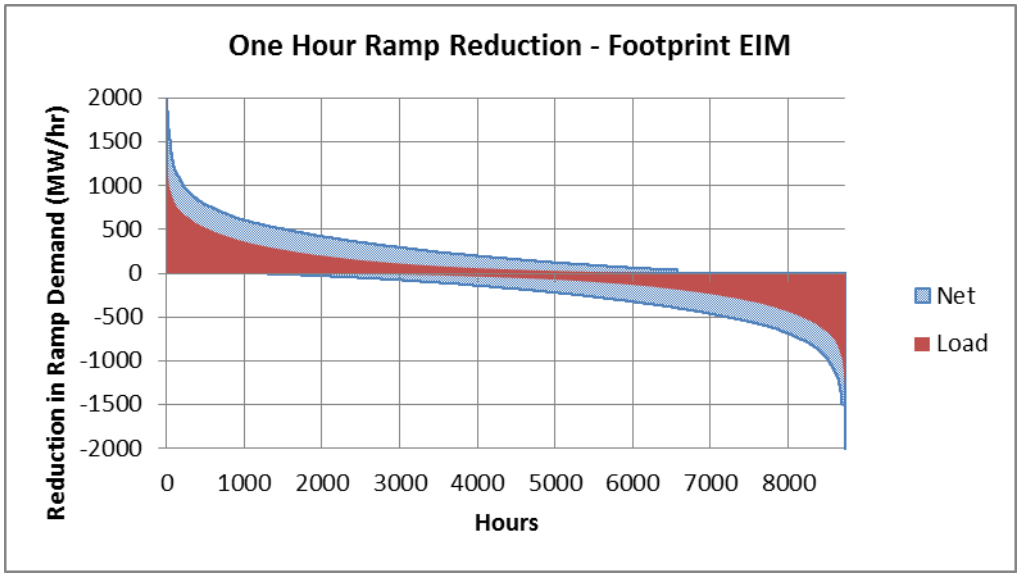
- **Up to 42% (2000 MW) reduction in total reserve requirement for footprint EIM;**
- **26% for regional EIMs.**

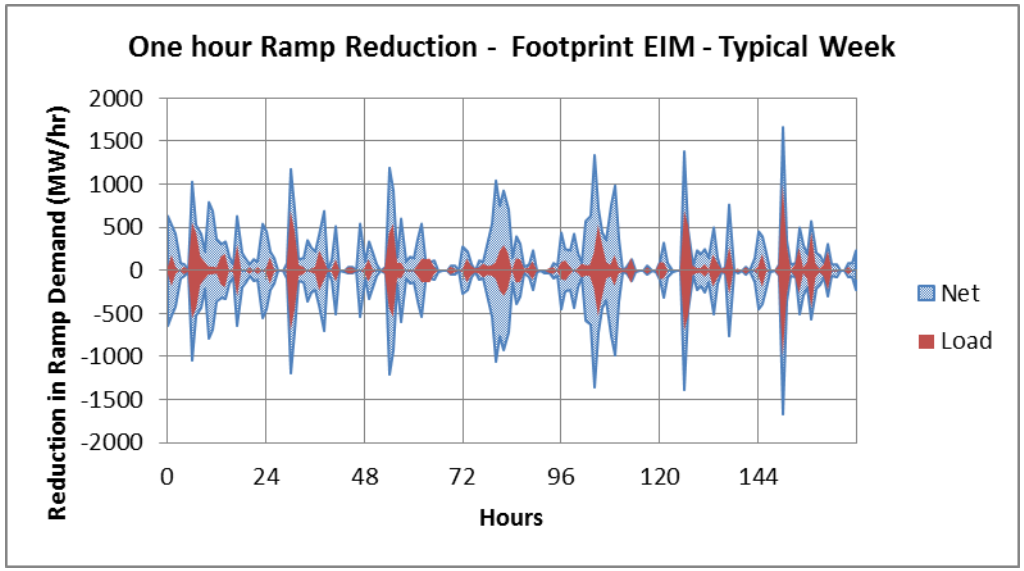
	Reduction over BAU			
	Footprint		Regional	
	MW	% Reduct.	MW	% Reduct.
Total Reg	570	36%	419	26%
Spin	481	45%	271	25%
Non-spin	963	45%	542	25%
Total	2014	42%	1233	26%



Ramp Demand Reduction – Footprint EIM

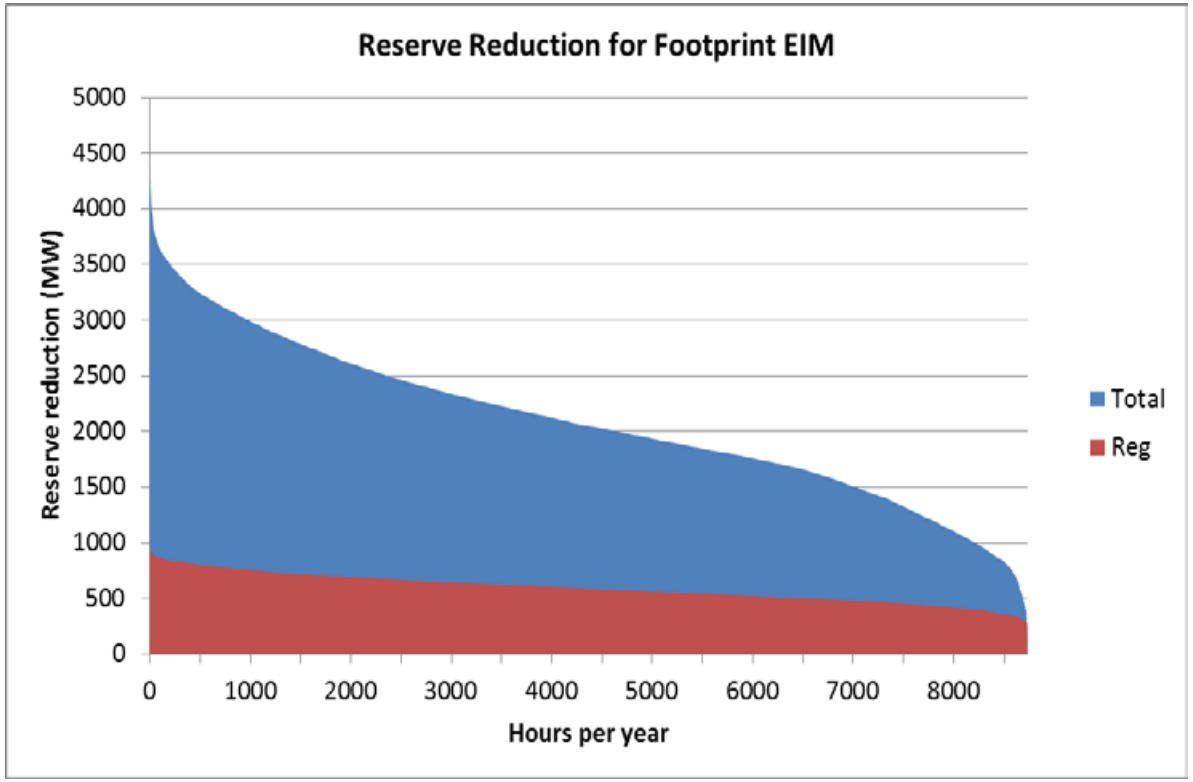
- Based on hourly ramps;
- Shows ramp reduction from EIM over BAU;
- Duration plot shows hours per year for reduction level;
- Reduction in net ramp is greater than 1000 MW for 251 hours per year and averages about 260 MW.





Reserve Reduction Duration – Footprint EIM

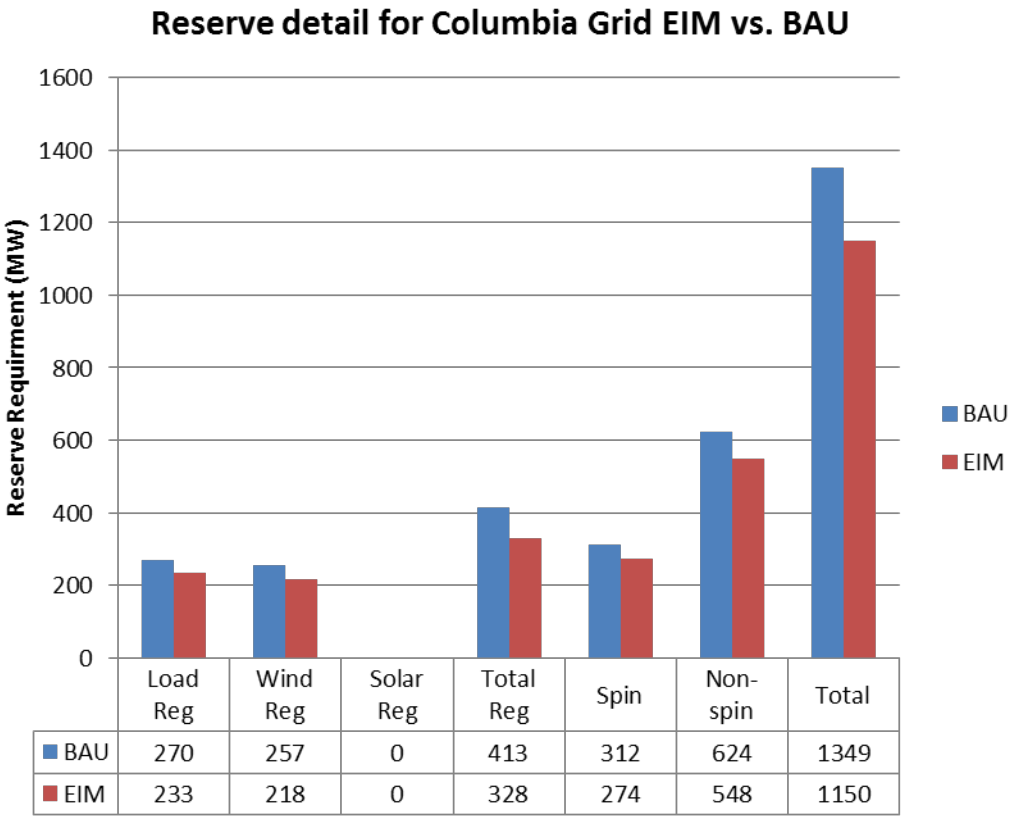
- Average reductions:
  - 590-MW Regulation;
  - 2092-MW Total Reserves.



Regional EIM – Columbia Grid (CG)

- Average reserves for a CG EIM;
- BPA dominates the wind so saving less than other regions;
- 8070 MW Wind.

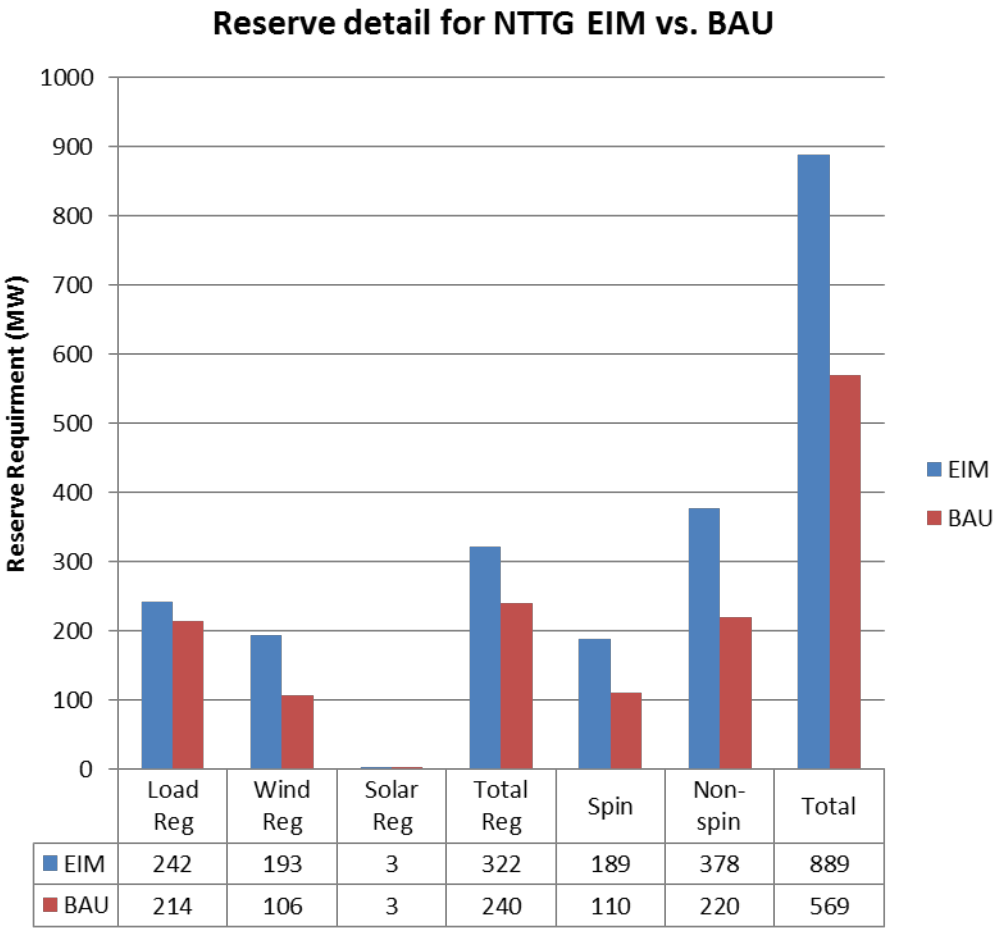
	Reserve Reduction	
	MW	% Reduc.
Load Reg	37	14%
Wind Reg	39	15%
Solar Reg	0	0%
Total Reg	85	21%
Spin	38	12%
Non-spin	76	12%
Total	199	15%



Regional EIM – NTTG

- Average reserves;
- Very small solar;
- Wind dominates savings;
- ~4200 MW wind and 20 MW solar.

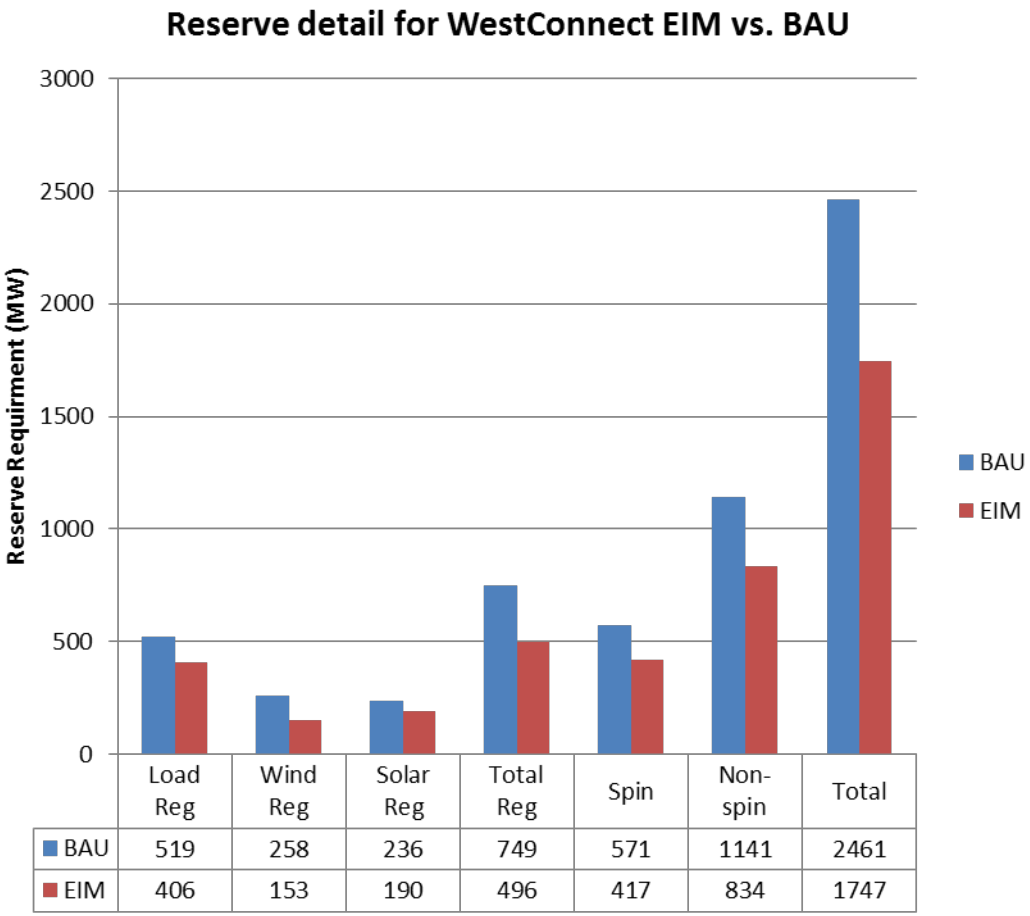
	Reserve Reduction	
	MW	% Reduc.
Load Reg	28	12%
Wind Reg	87	45%
Solar Reg	0	0%
Total Reg	82	25%
Spin	79	42%
Non-spin	158	42%
Total	319	36%



Regional EIM – WestConnect (WC)

- Average reserves;
- Substantial saving from wind and solar;
- ~5700 MW Wind and 4550 MW solar.

	Reserve Reduction	
	MW	% Reduc.
Load Reg	113	22%
Wind Reg	105	41%
Solar Reg	46	20%
Total Reg	253	34%
Spin	154	27%
Non-spin	307	27%
Total	714	29%



Conclusions

- Method for calculating additional reserve requirements due to wind and solar production;
- EIM results in substantial reduction in reserves requirements and ramping demand;
- Reduced participation reduces benefits for all but reduces the benefits to non-participants the most;
- Full participation leads to maximum benefit across the Western Interconnection, up to 42% of total reserve requirement;
- Regional EIM implementations have smaller but substantial benefits.