Scaling Up Wind Farms: System Costs and Benefits

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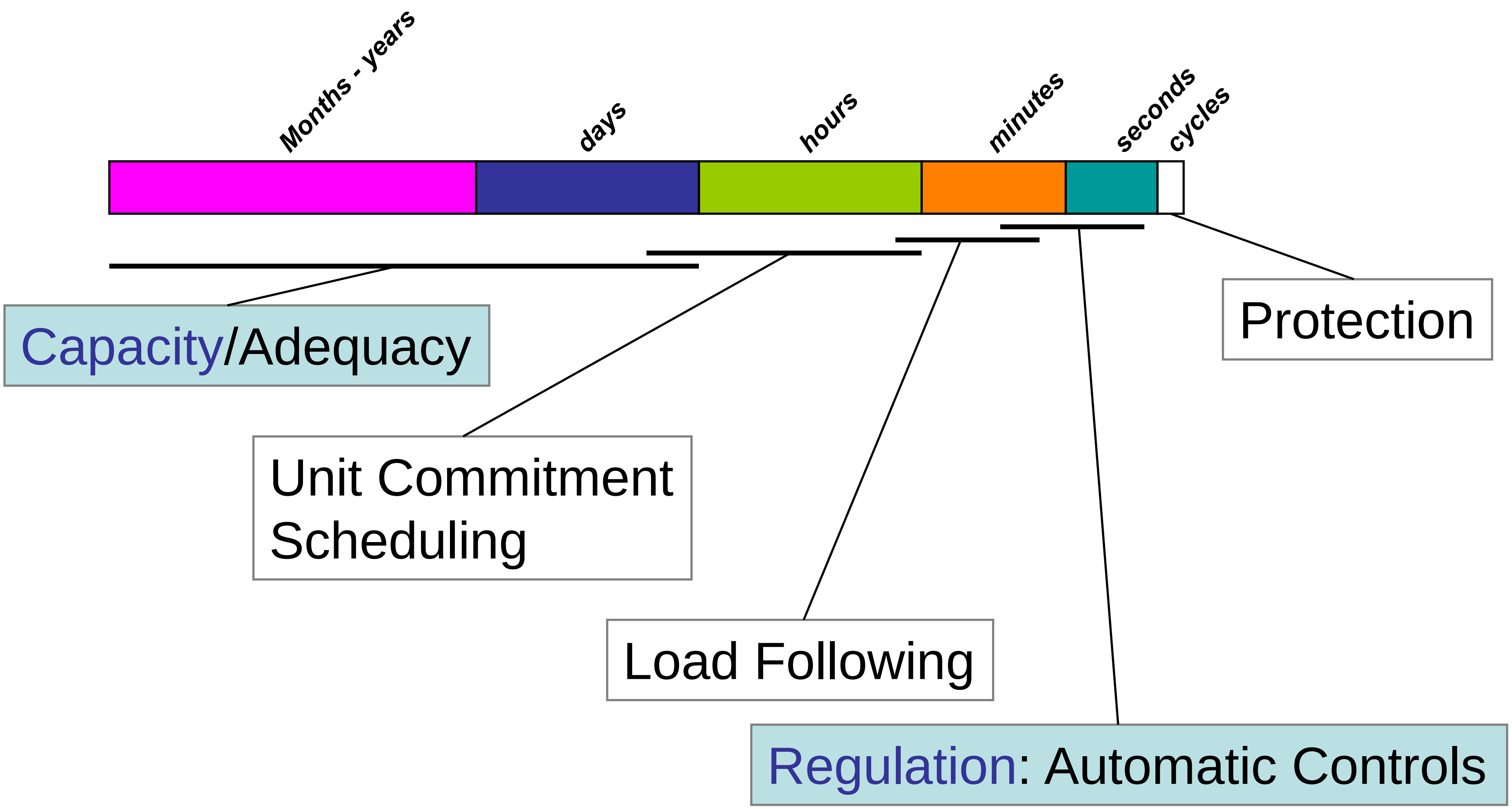
Power System Operation Timescales



Wind: Generation or Negative Load?

Obviously generation. But…

- Except for the minus sign, it does not lie outside the range of other loads: tea kettles, hair driers, industrial electric furnaces.
- Many loads have poor statistical properties.

Analyzing it as negative load always works.

- If R(L) is the proper complex algorithm for finding how much “R” is needed to serve L,
- Then R(L – W) is right for load with wind, and
- R(L–W) – R(L) is wind’s contribution to R.

Minnesota Studies

Two widely-cited studies were conducted in 2004 and 2006.
2004: Study reliability and cost impacts of nearly 900 MW of wind by 2010.
2006: Study reliability and cost impacts for wind to supply 15%, 20%, and 25% of load by 2020.

General findings point out the benefit

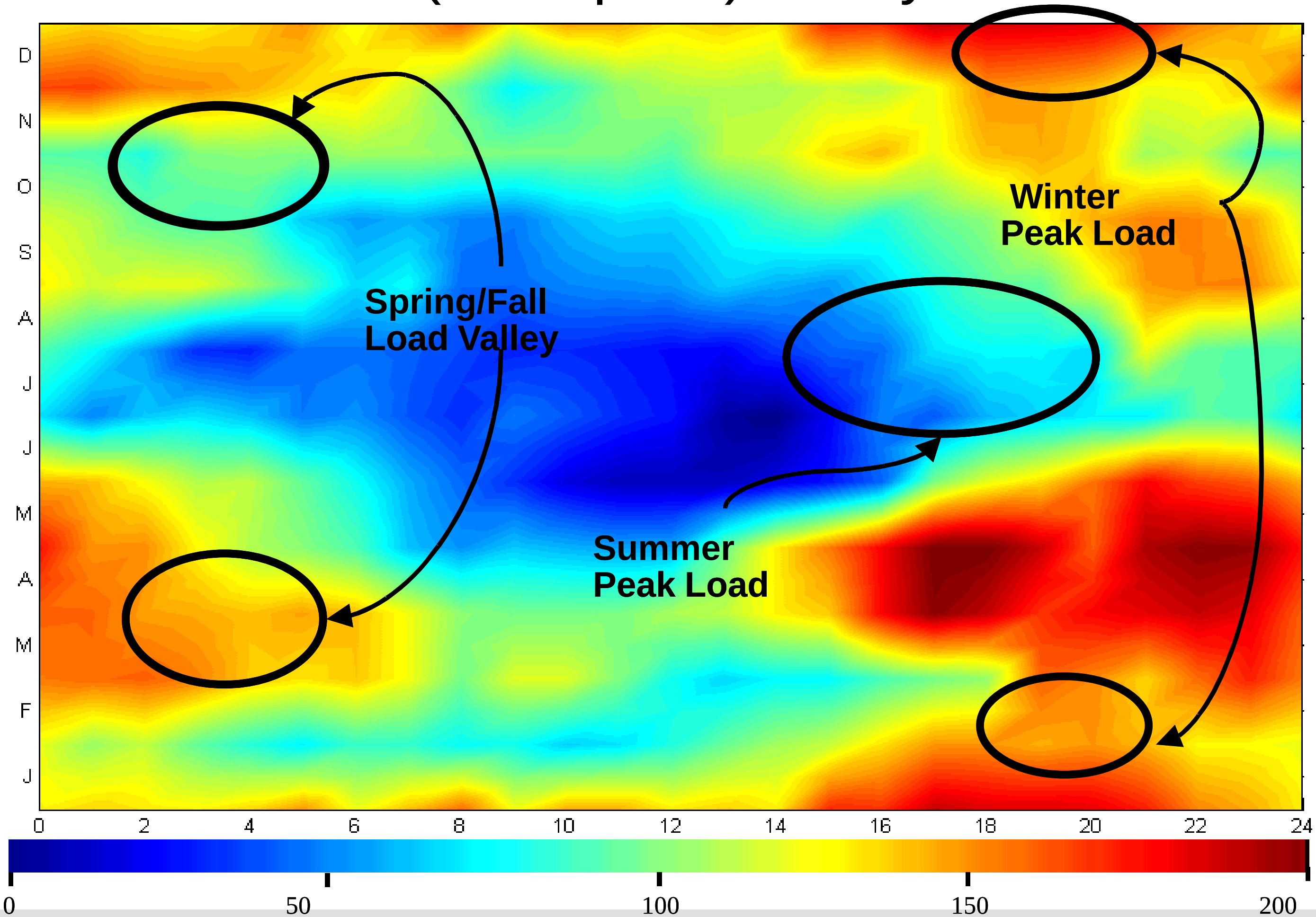
- Geographic diversity of wind
- Accurate wind forecasts
- Markets

Costs

- Unit Commitment/Scheduling
- Regulation

Our Data

Data from Taiban Mesa, Courtesy of PNM, Abraham Ellis.
This is a 200 MW (nameplate) facility in New Mexico



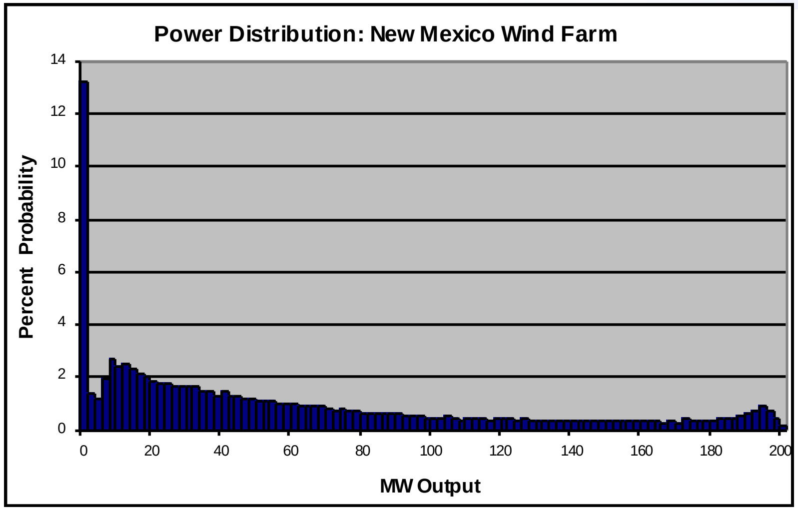
Wind Has Capacity Value

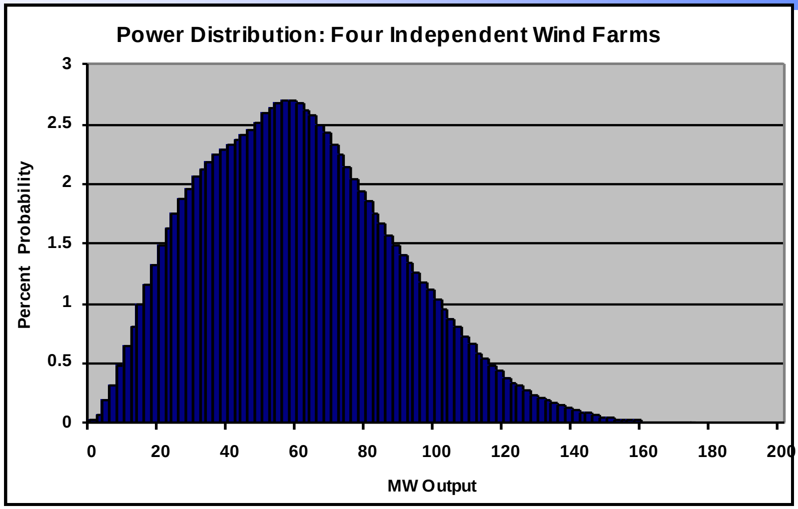
- Required capacity, C(L), prevents load shedding.
- C(L) = C such that Prob(L>C) = 1/29,200
  - ISO-NE probability standard. 1 event in 10 years, event = 3 hours. Others give similar results.

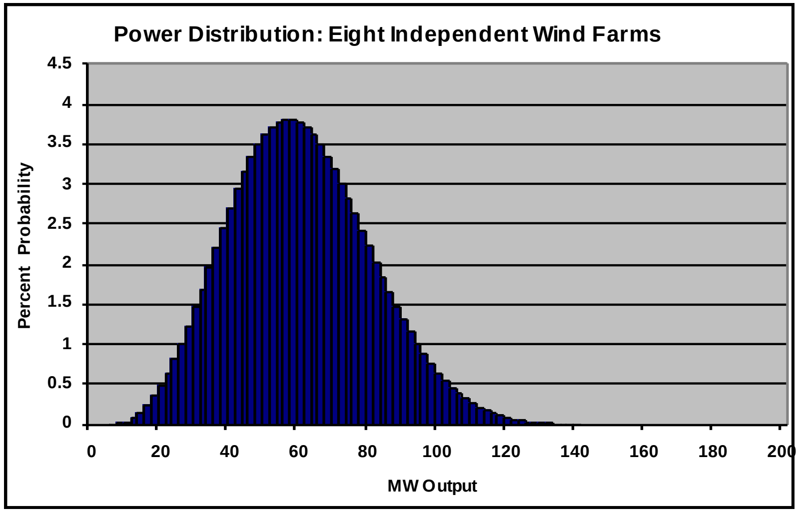
Cap. Value of wind = C(L) – C(L – W)

- First 3 analyses: load & wind uncorrelated.
  - Normal load and Normal wind distributions.
  - Normal load and NM wind distributions.
  - ISO-NE load and NM wind distributions.
- All give similar results.

Net Output of Independent Wind Farms





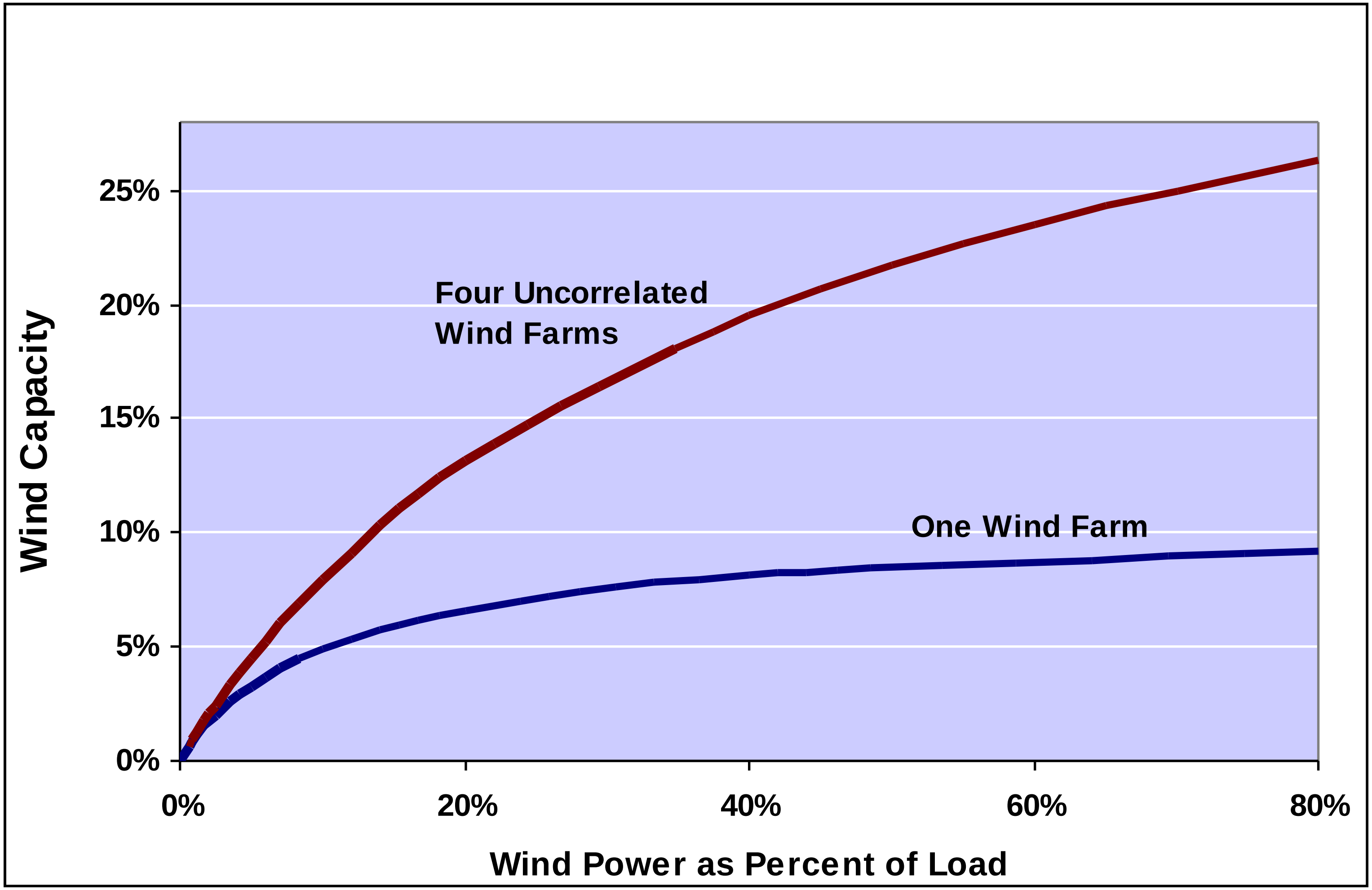


The output of numerous uncorrelated plants approaches a normal distribution.

Wind Capacity Value

Wind as % of Load	Average Wind Power	Average (L – W)	Wind's Capacity Value	Incremental Cap. Value % of Power
Normal Load & Normal Wind: SD same as 4 Uncorrelated Wind Farms				
10%	**200**	1800	**135**	52%
20%*	**400**	1600	**159**	12%
Normal Load & NM Wind: Single Farm				
10%	**200**	1800	**83**	25%
20%	**400**	1600	**108**	13%
Normal Load & NM Wind: 4 Uncorrelated Wind Farms				
10%	**200**	1800	**149**	64%
20%	**400**	1600	**237**	44%
ISO-NE Load & NM Wind: Single Wind Farm				
10%	**200**	1800	**98**	32%
20%	**400**	1600	**132**	17%
ISO-NE Load & NM Wind: 4 Uncorrelated Wind Farms				
10%	**200**	1800	**160**	70%
20%	**400**	1600	**263**	52%

Wind Capacity Value



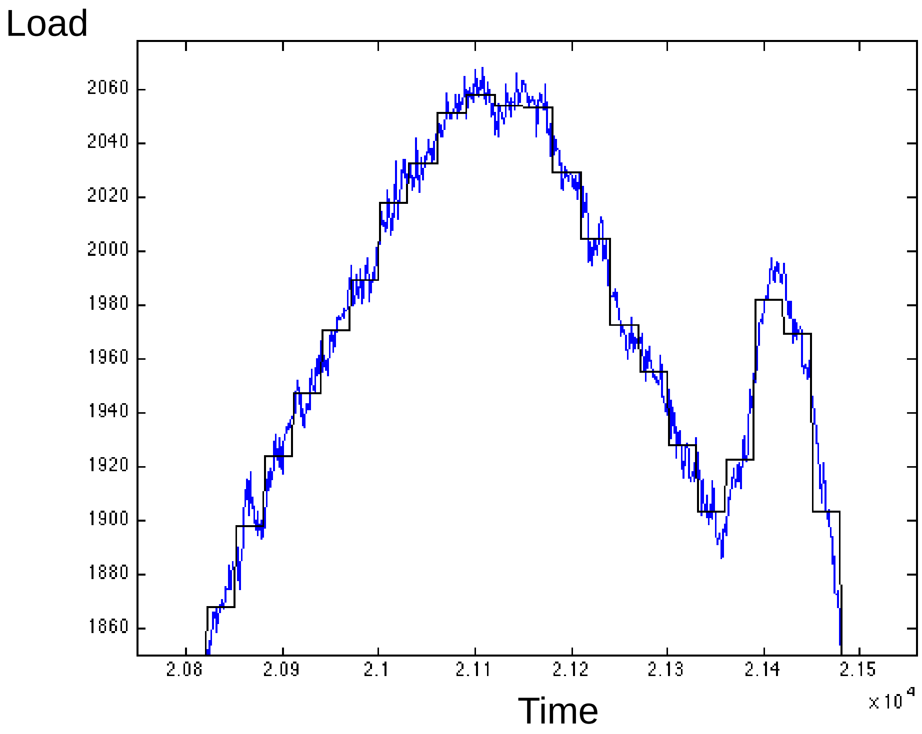
Wind Capacity: Policy Implications

- Wind need not be correlated with peak load to have capacity value.

Statistical independence is enough

- If wind is self-correlated, wind is not independent of load because it is correlated with the "–W" part of Load = L–W.
- Diversity of location is valuable
- Transmission is valuable
- Larger administrative areas are valuable
- NM Wind's anti-correlation with load cuts its capacity value almost in half.

Regulation: Reserves for Fast Timescale



Fast variations in load are matched by automatic generation control.

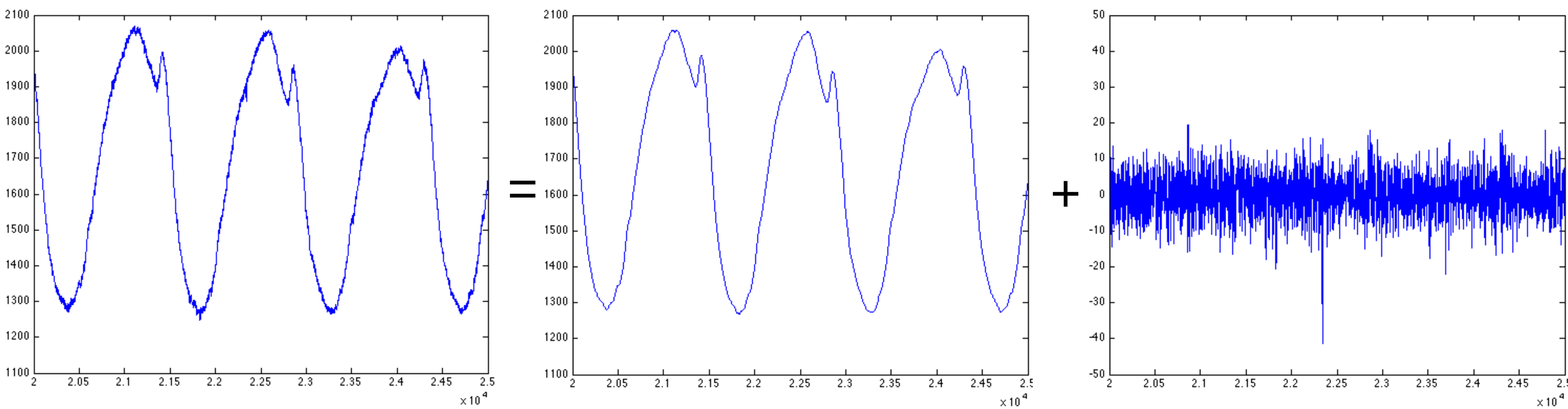
How much generation should be reserved for this purpose?

Literature: 3σ *method*

A commonly cited procedure in the literature suggests a statistical evaluation of historical load data:

• separate the load into slowly and quickly varying components.

• The regulation reserve required is 3 times the standard deviation of the points in the quickly-varying component.



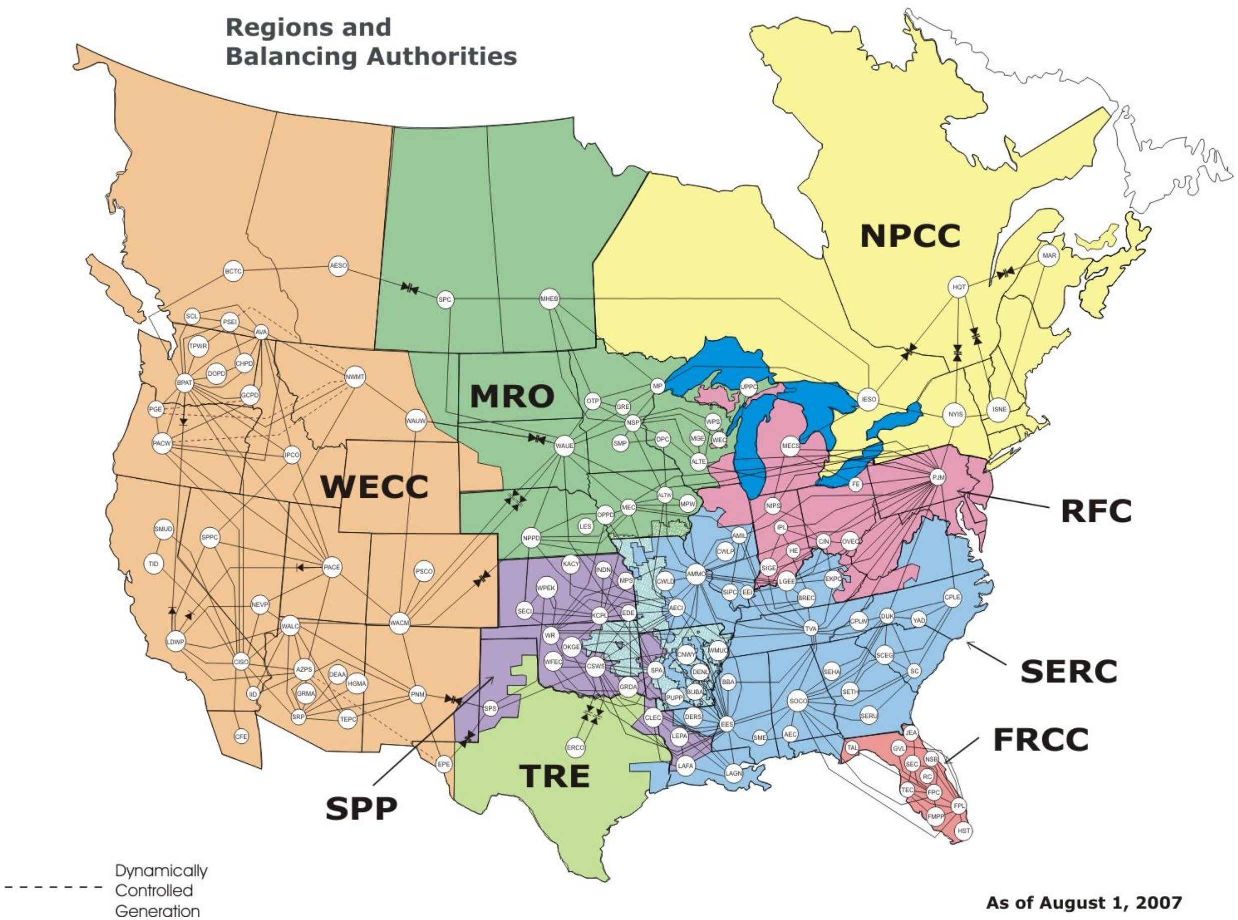
Slow

Fast

There appears to be little justification for this approach.

Practice: Match CPS2 requirement

Background: Balancing Authorities



Practice: Match CPS2 requirement

Background: Area Control Error (ACE), L10, and CPS

- ACE is a local measure for power balance within a balancing authority.

- **L10 violation** occurs when the ACE exceeds a balancing authority specific L10 bound during a 10 minute interval. An L10 violation is not penalized.

- **CPS2 violation** occurs when the number of L10 violations during a month exceeds 10% of the 10 minute intervals during that month. This is penalized.

Regulation: Match CPS2 requirement

We calculate the regulation reserve required to match the CPS2 Requirement.

Applying a statistical representation for historical data, we derive the regulation required to meet the CPS requirement, allowing for **one expected violation every five years:**

$$R_C = 1.69\sigma_{LF} - L_{10}$$

R_C Regulation Capacity

σ_{LF} StdDev(Load - Load Following Generation)

L_{10} L10 limit

Regulation: Wind Power Requirement

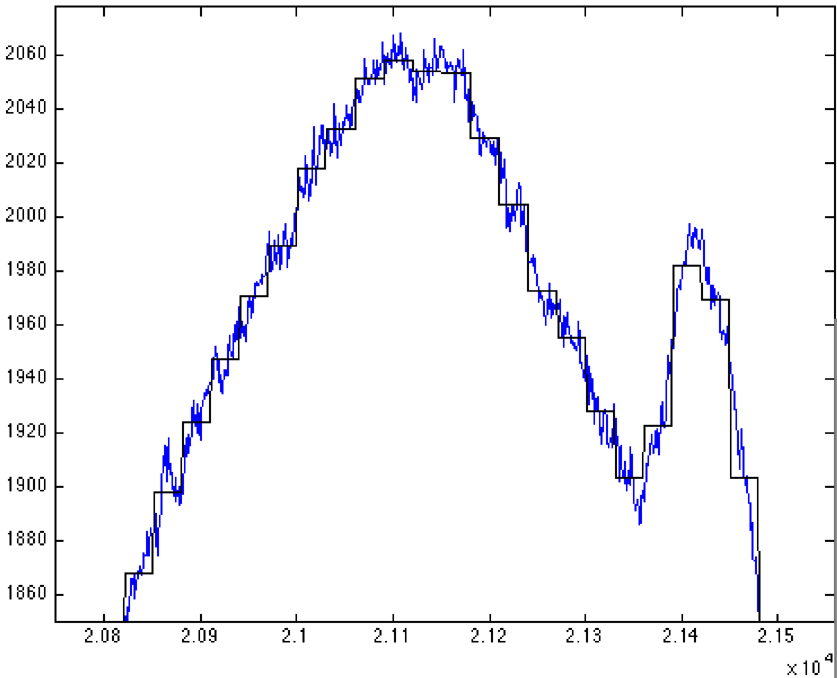
To analyze the effect of additional wind power on the regulation capacity, we assume:

- Wind generation does not supply its own regulation
- On a fast timescale, wind power is uncorrelated with load.
- Wind power is analyzed as negative load

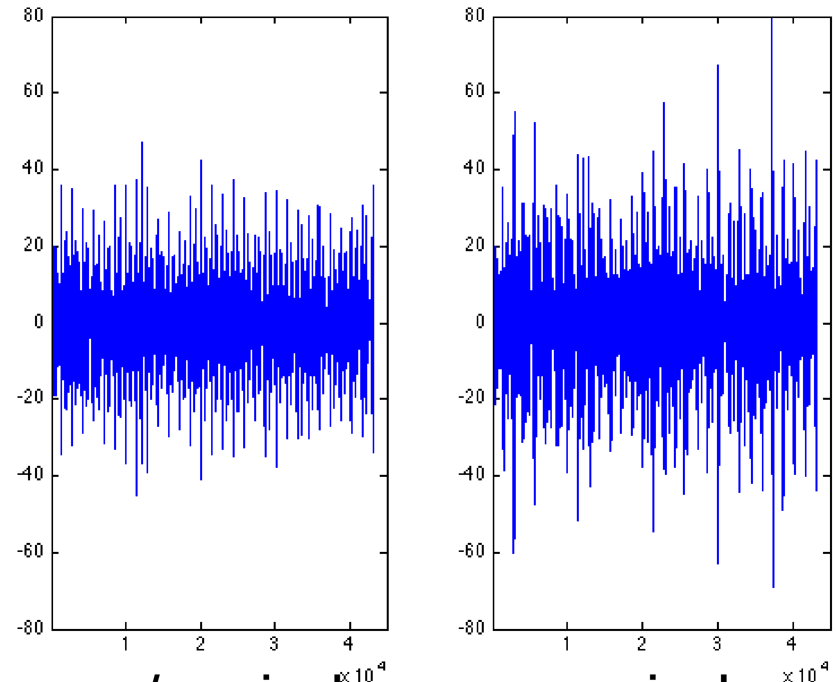
Then, the change in needed regulation capacity is

$$\Delta R_C = R_{Cwind} - R_C$$

Data



Construction: 30 minute load-following dispatch matches load and wind 30-minute average.



w/o wind

wind

Load deviations are wider when wind power is included.

Additional Regulation

Using the data available to us, for this example the additional regulation required is calculated to be

$$\Delta R_C = 3.21 \text{ MW}$$

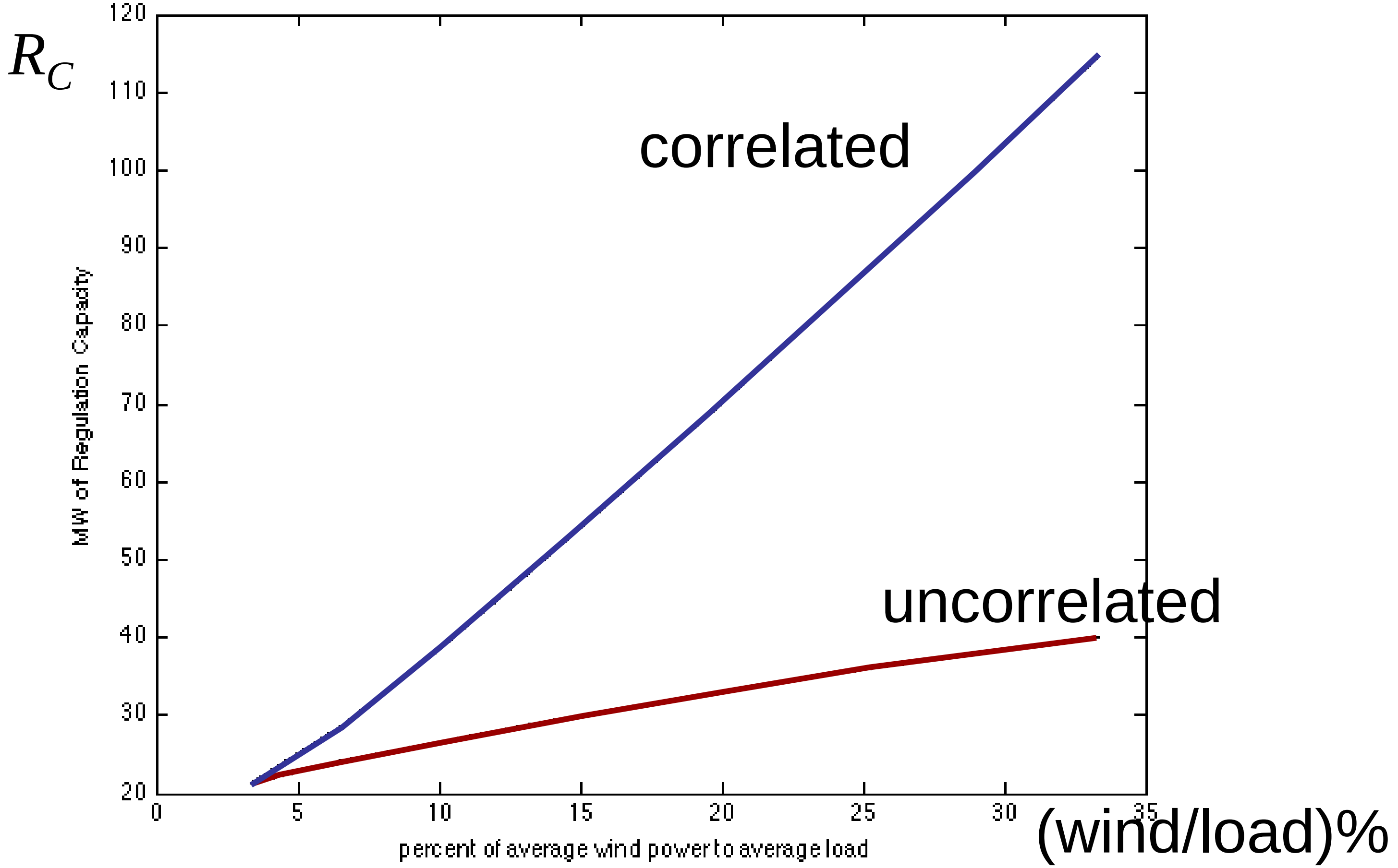
For comparison, the additional amount required, as calculated using the 3σ method, is more conservatively estimated to be

$$\Delta R_C = 4.20 \text{ MW}$$

Comments: Our method is well defined in terms of a reliability criterion.

Regulation: Wind Power Expansion

The amount of regulation required with additional wind power depends on the correlation between wind farms.



Regulation: Discussion

- Analysis of wind power best treats it as a negative load.
- New wind generation should be sited to be uncorrelated with existing wind generation, if possible.
- Increasing the size of balancing authorities will reduce the regulation reserve required. Alternatively, separating wind power in the reliability criteria could reduce its effect on regulation.