

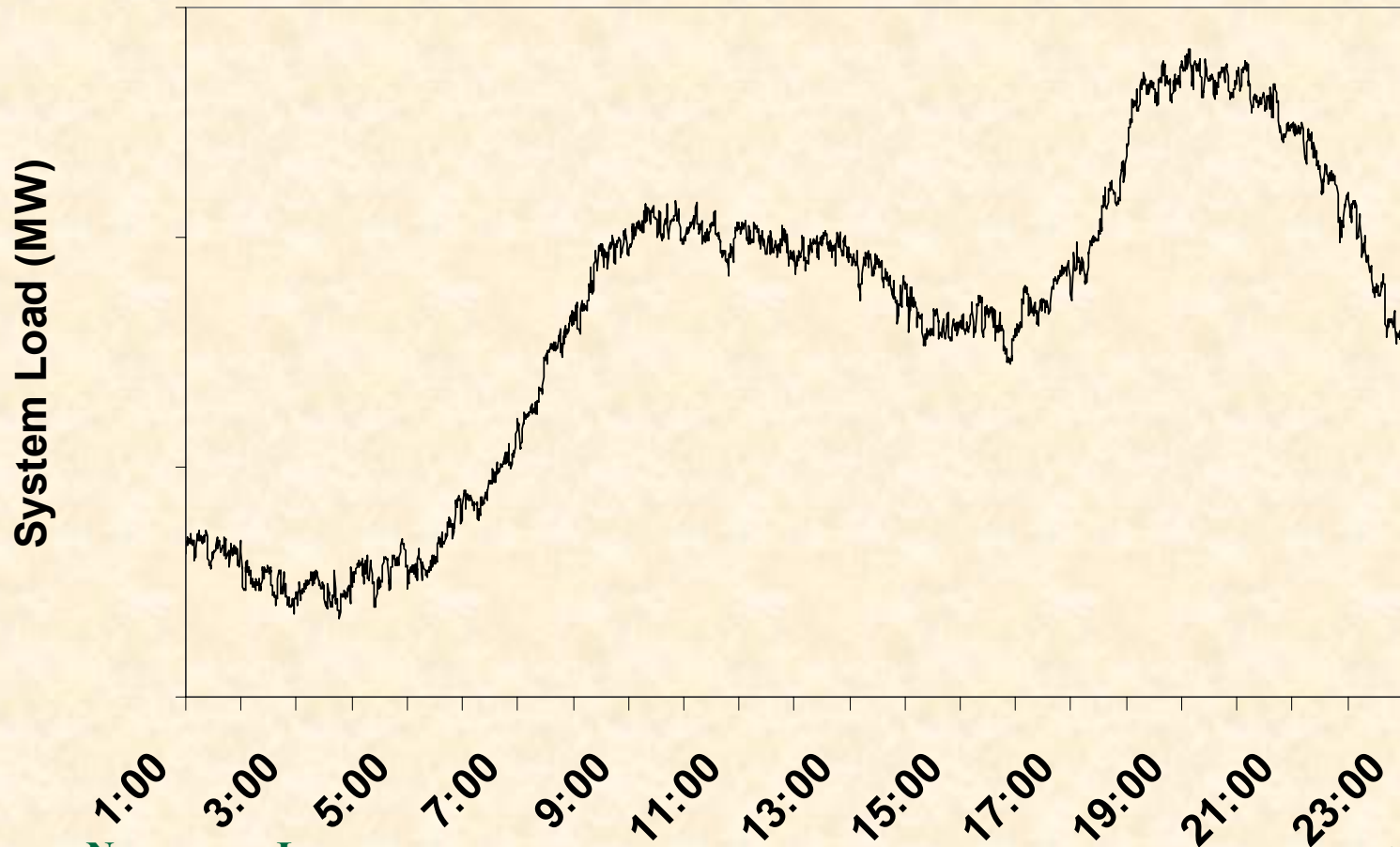
Regulation and Load Following Analysis for the California RPS Integration Study

Brendan Kirby

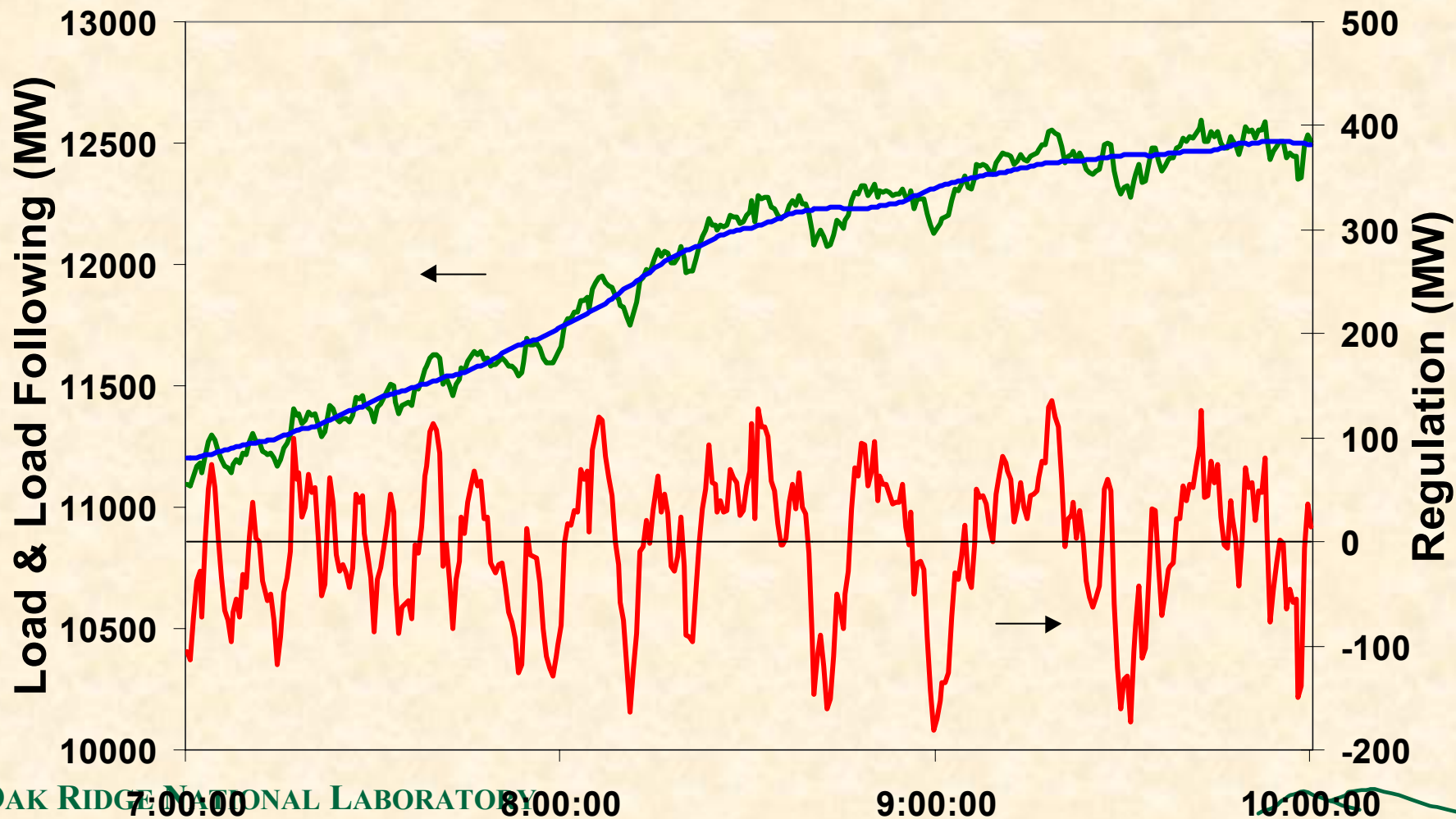
Oak Ridge National Laboratory

**kirbybj@ornl.gov - 865-576-1768 -
www.ornl.gov/psr**

Typical System Load Data



Regulation and Load Following Balance the System Under Normal Conditions



Regulation & Load Following

- Both address the time varying characteristic of balancing generation and load under normal operations
- The “system” only has to compensate for the aggregation
- The aggregation is composed of individual loads and generators with *diverse* characteristics

Regulation Matches Generation To Load, Minute-to-minute

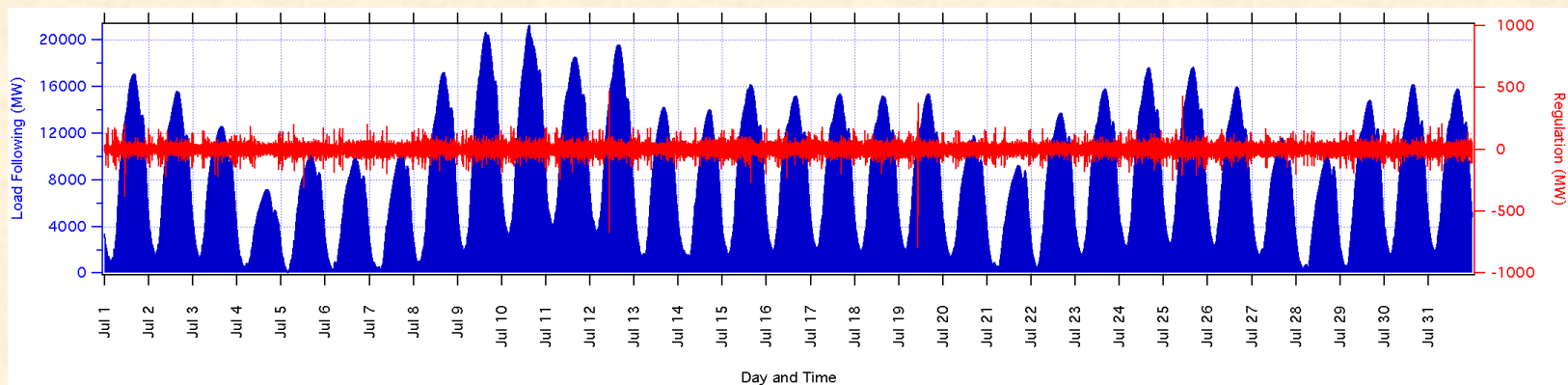
- **Regulating units**
 - Online
 - Not fully loaded
 - Not at minimum loading
 - With automatic generation control
 - With ability to move rapidly (MW/minute)
- **Costs**
 - Degraded heat rate
 - Lost energy sales opportunity
 - Forced to be on line
 - Procured through regulation market

Load Following Is Longer-term Analogue To Regulation

- **Use of generation to meet hour-to-hour and daily variations in load**
- **Occurs over 10 minutes to hours**
- **FERC did not require in Order 888 tariffs**
- **Provided by hourly and sub-hourly energy markets**

Regulation & Load Following Differ

	<i>REGULATION</i>	<i>LOAD FOLLOWING</i>
<i>Patterns</i>	<i>Random, uncorrelated</i>	<i>Largely correlated</i>
<i>Generator control</i>	<i>Requires AGC</i>	<i>Manual</i>
<i>Maximum swing (MW)</i>	<i>Small</i>	<i>10 – 20 times more</i>
<i>Ramp rate (MW/minute)</i>	<i>5 – 10 times more</i>	<i>Slow</i>
<i>Sign changes</i>	<i>20 – 50 times more</i>	<i>Few</i>



Control Area Performance Criteria

- **Concerned with impacts on frequency & unscheduled flows**
- **Statistical measures for control areas**
 - CPS1 limits annual average of 1 minute deviations
 - CPS2 limits 10 minute excursions
- **Assessment of individual loads & generators may have to be more deterministic**

CPS1

$$\text{AVG}_{\text{annual}} \{ \text{ACE}_i / (-10B) * \Delta F_i \} \leq \epsilon^2$$

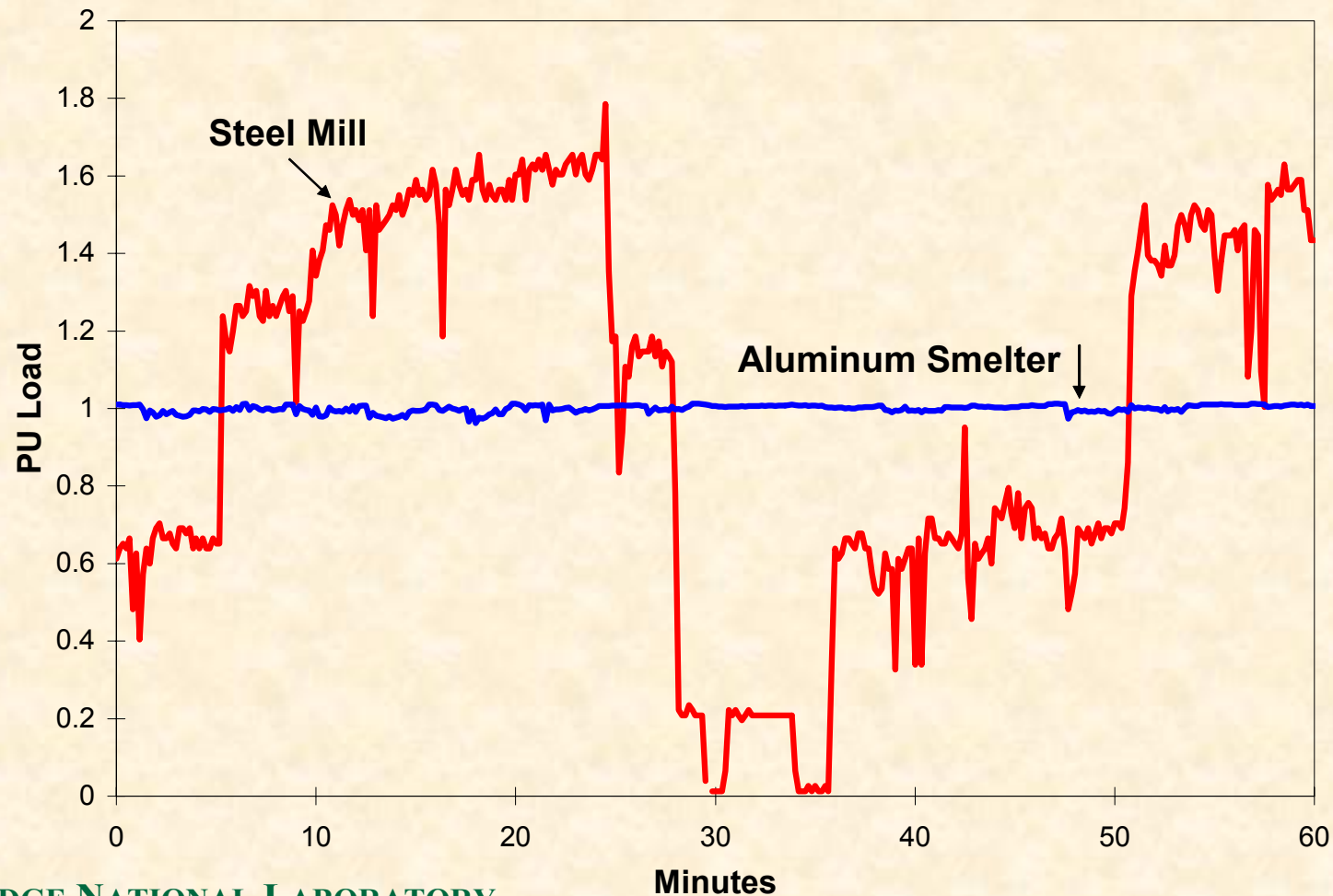
- ACE_i & ΔF_i are 1 minute averages
 - ϵ is the 1 minute average acceptable interconnection frequency error
- Limits average contribution to frequency error

CPS2

$$|\mathbf{ACE}_{10}| \leq \mathbf{L}_{10}$$

- \mathbf{ACE}_{10} is a 10 minute average
 - \mathbf{L}_{10} is based on acceptable interconnection frequency error
 - Compliance required $\geq 90\%$ of time
- Limits ACE excursions

Diversity in Regulation Demand



Aggregation Benefits Regulation

Individual load intrahour fluctuations are generally uncorrelated

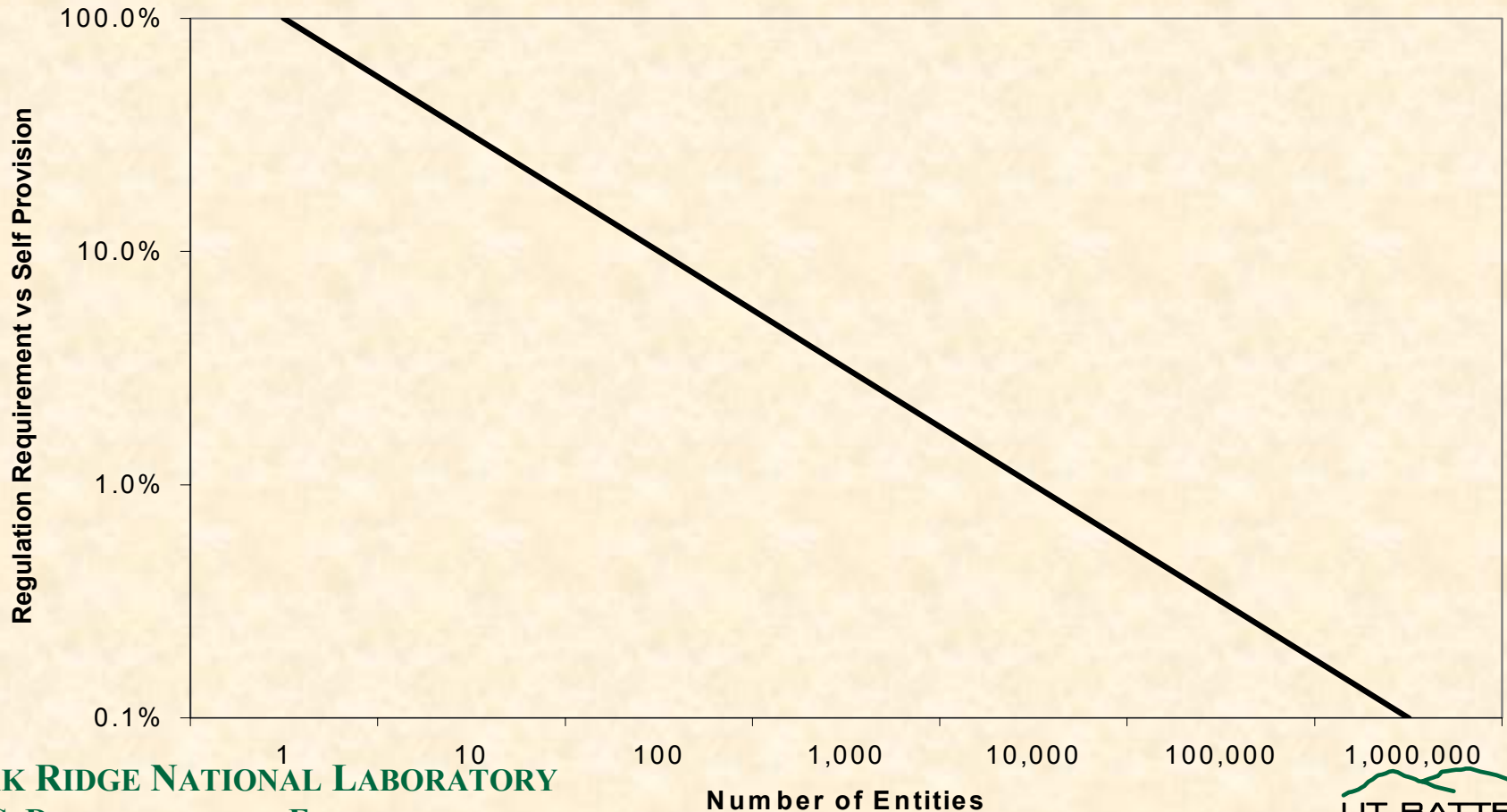
- Energy requirement

$$\mu_{SYSTEM} = \sum \mu_{INDIVIDUAL}$$

- Fluctuations

$$\sigma_{SYSTEM} = \sqrt{\sum \sigma_{INDIVIDUAL}^2}$$

Regulation Requirement per Transaction Drops With Aggregation of Similar Transactions



Allocation Method Should Meet Key Objectives

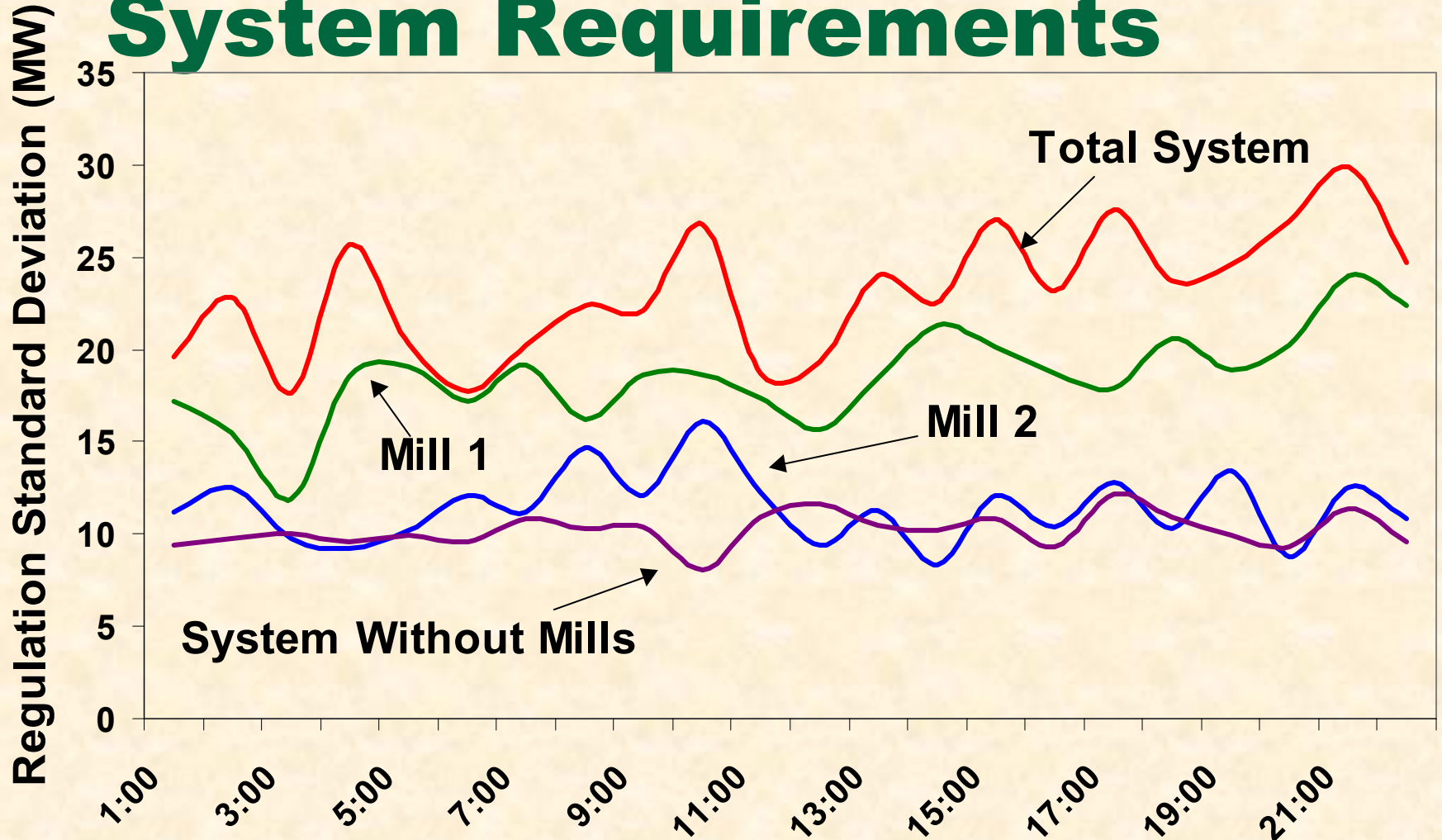
- **Recognize positive and negative correlations (pay loads that reduce total regulation)**
- **Independent of subaggregations**
- **Independent of order in which loads added to system**
- **We developed a Regulation Vector Allocation Method that meets these objectives**

Numerical Implementation Of Vector Allocation Method Straightforward

$$\sigma_{i_allocation} = \frac{\left(\sigma_{Total}^2 + \sigma_i^2 - \sigma_{Total-i}^2 \right)}{2 * \sigma_{Total}}$$

- Handles correlated and uncorrelated components
- Independent of sub-aggregation
- Independent of order
- Disaggregate as many (few) components as desired

Individual Loads Impact System Requirements



Some Individual Loads Impose Large Ancillary-Service Costs

	Percentage of Total		
	Energy	Regulation	Load-Following
Control Area "A"			
Nonindustrials	66%	7%	42%
Industrials	34%	93%	58%
Control Area "B"			
Nonindustrials	97%	56%	90%
Industrials	3%	44%	10%

Regulation Cost Results

- A negative value means there is a cost imposed on the system.
- A positive value means there is a benefit provided to the system.

Resource	Regulation Cost (\$/MWh or mills/kWh)	
	Procured	Total
Total Load	-0.20	-0.42
Medium Gas	0.04	0.08
Biomass	0.00	0.00
Geothermal	-0.05	-0.10
Solar	0.02	0.04
Wind (Altamont)	0.00	0.00
Wind (San Geronio)	-0.21	-0.46
Wind (Tehachapi)	-0.07	-0.17
Wind (Total)	-0.08	-0.17

Energy Imbalance

- **Results from mismatches between energy schedules & delivery**
- **Physical power system must be balanced in real time**
- **FERC SMD NOPR clears energy imbalance through the spot market**

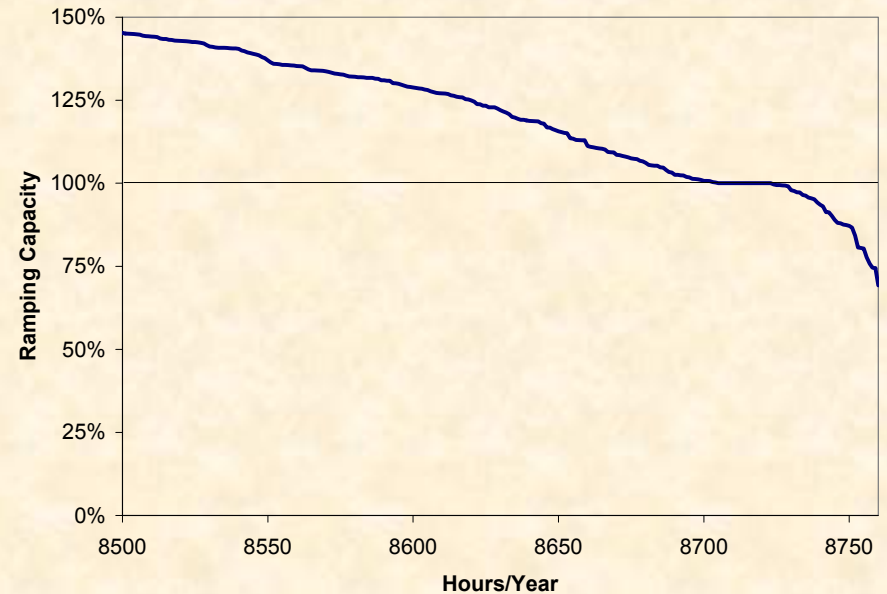
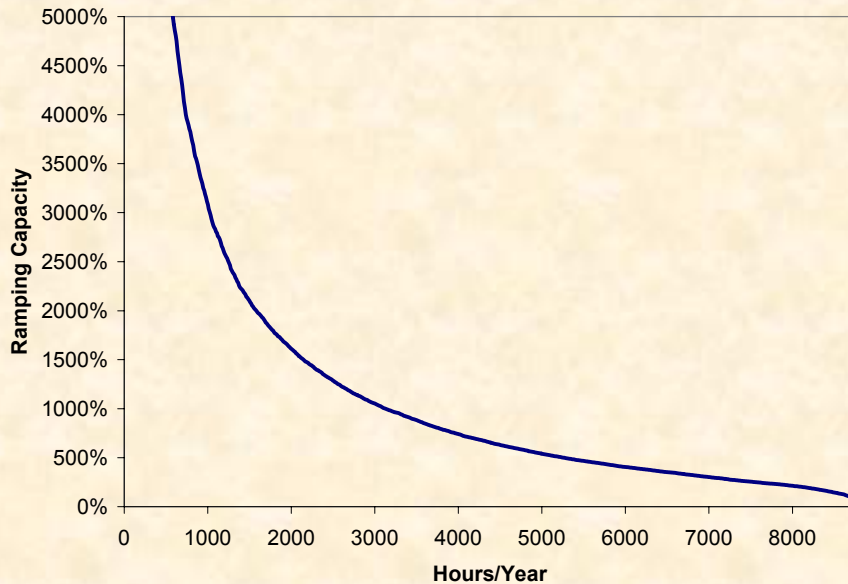
What About Load Following?

- **Restructured markets explicitly recognize regulation & energy, not load following**
 - **A volatile load (or generator) increases the control area need for regulation, CPS measures that need, the amount of regulation purchased increases, so does the cost**
 - **An energy consumer increases the control area need for energy, energy meters detect this, the fuel burned increases, and so does the cost**
 - **Ramping loads increase the need for load following, ACE detects the change, generators are dispatched, but where is the a cost?**

How Much Ramping Capacity Is Needed vs Available?

- **Available Data**
 - Hourly system load: 42352 MW max
 - Hourly generator output from emitting generators: 21851 MW max
 - 52% of max, 35% of average
 - no hydro, no nucs, no renewables, no imports
- **Analysis**
 - Determine each generator's capability
 - Min power, max power, max ramp rate
 - Determine hourly system ramping requirements
 - Determine hourly emitting generators hourly ramping contribution
 - Determine hourly emitting generators excess ramping capability

Very Preliminary Results Indicate Significant Excess Ramping Capacity Is An Inherent Characteristic Of The Current Generation Mix



Conclusions

- **Regulation & Load Following requirements can be quantified**
 - For the system
 - For individuals
- **Aggregation is critical for regulation**
- **Renewables regulation impacts are not dramatic**
- **Load following is not a specifically priced service**
 - This may be because there is inherently excess load following capacity