RENEWABLE ENERGY INTEGRATION: VARIABILITY & UNCERTAINTY IMPACTS AND MITIGATION OPTIONS

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BALANCING IS A CRITICAL POWER SYSTEM RELIABILITY REQUIREMENT

Power systems must balance *aggregate* load with *aggregate* generation instantaneously and continuously

- This is not a new requirement – interconnected power system physics remains the same – but changes in generation, load, and storage resources impose new challenges and offer new opportunities
- Balancing must be done over a range of time frames from seconds to seasons
  - Some response was inherent (or should have been) when synchronous generators supplied all response
  - Advanced technologies are making it necessary and useful to more carefully define specific balancing requirements for each time frame
  - *Regulation is one balancing timeframe*
- Balancing can be done by controlling generation or load (flexibility) – Storage is both
  - Each technology has unique capabilities and limitations
  - *Storage is one balancing technology*

Functional specifications of balancing requirements enables all technologies to compete and facilitates the selection of the optimal balancing resource mix

SOURCES OF VARIABILITY AND UNCERTAINTY

Power systems have always dealt with variability and uncertainty

- Increased renewable generation increases variability and uncertainty
- Increased renewable generation may decrease the availability of traditional generation, historically used for balancing

Sources of Variability and Uncertainty

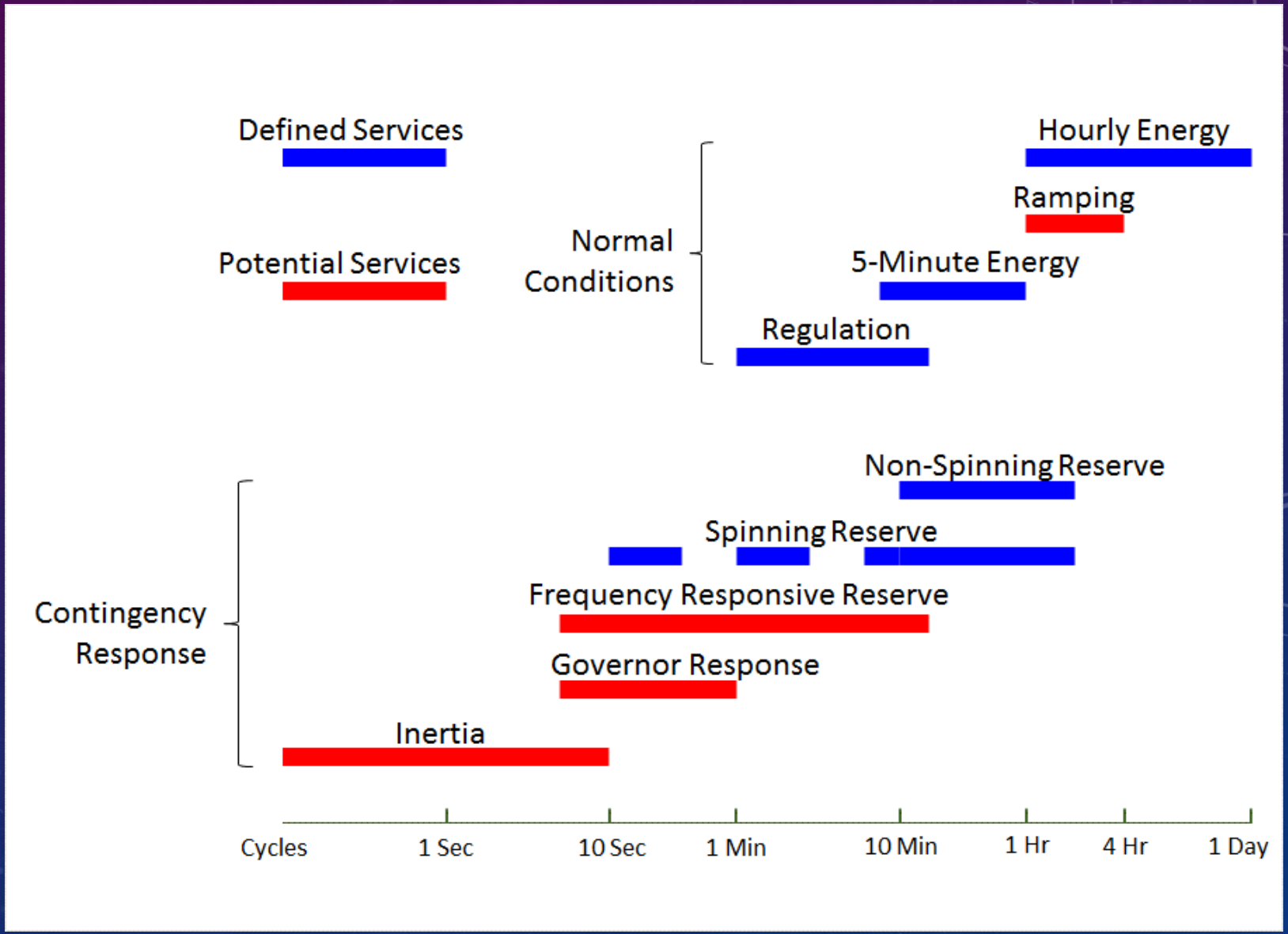
- Sudden failure of a large conventional generator (contingency)
- Natural variability of loads
  - Seasonal, weekly, and daily variability – Largely correlated
  - Minute-to-minute & second-to-second variability – Largely uncorrelated
- Daily and hourly energy transactions
- Wind and solar generation
  - Second-to-second variability greatly reduced through aggregation
  - Large, infrequent ramps are slower than conventional contingencies
  - Excess solar generation & evening ramp can be problematic at high penetrations

ANCILLARY SERVICES & 5-MINUTE ENERGY MARKETS: HOW POWER SYSTEMS OBTAIN AND PAY FOR FLEXIBILITY

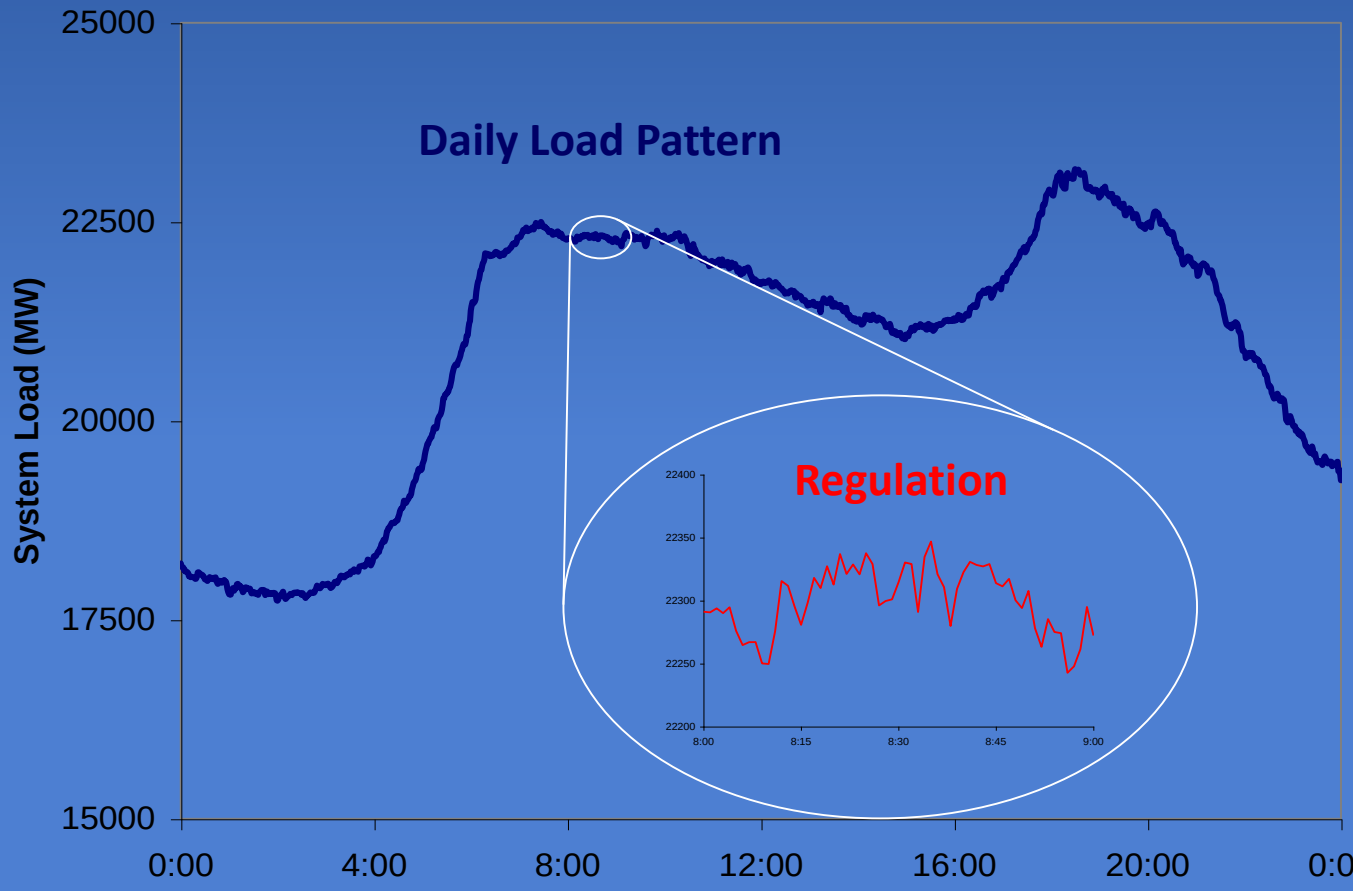
- Distinguished by Response Speed, Duration, and Frequency of Response
- Paid and unpaid services – possible changes here
- Alternative response suppliers/technologies – economic selection
  - Generation (old and new), demand response, storage
  - Vertically integrated utilities perform the same optimization but it is not as transparent

- Energy markets: day-ahead hourly, hour-ahead, 5-minute
- Ancillary services:
  - Dedicated reserves for faster response than energy markets can provide
  - Resources often selected through hourly markets
    - Real-time resource availability often depends on energy market and other conditions
  - Prices typically based largely on energy market opportunity costs (cooptimized selection) – problematic for storage and demand response

EXISTING & POTENTIAL NEW SERVICES



Regulation Is The Most Expensive Ancillary Service Utilities Consume



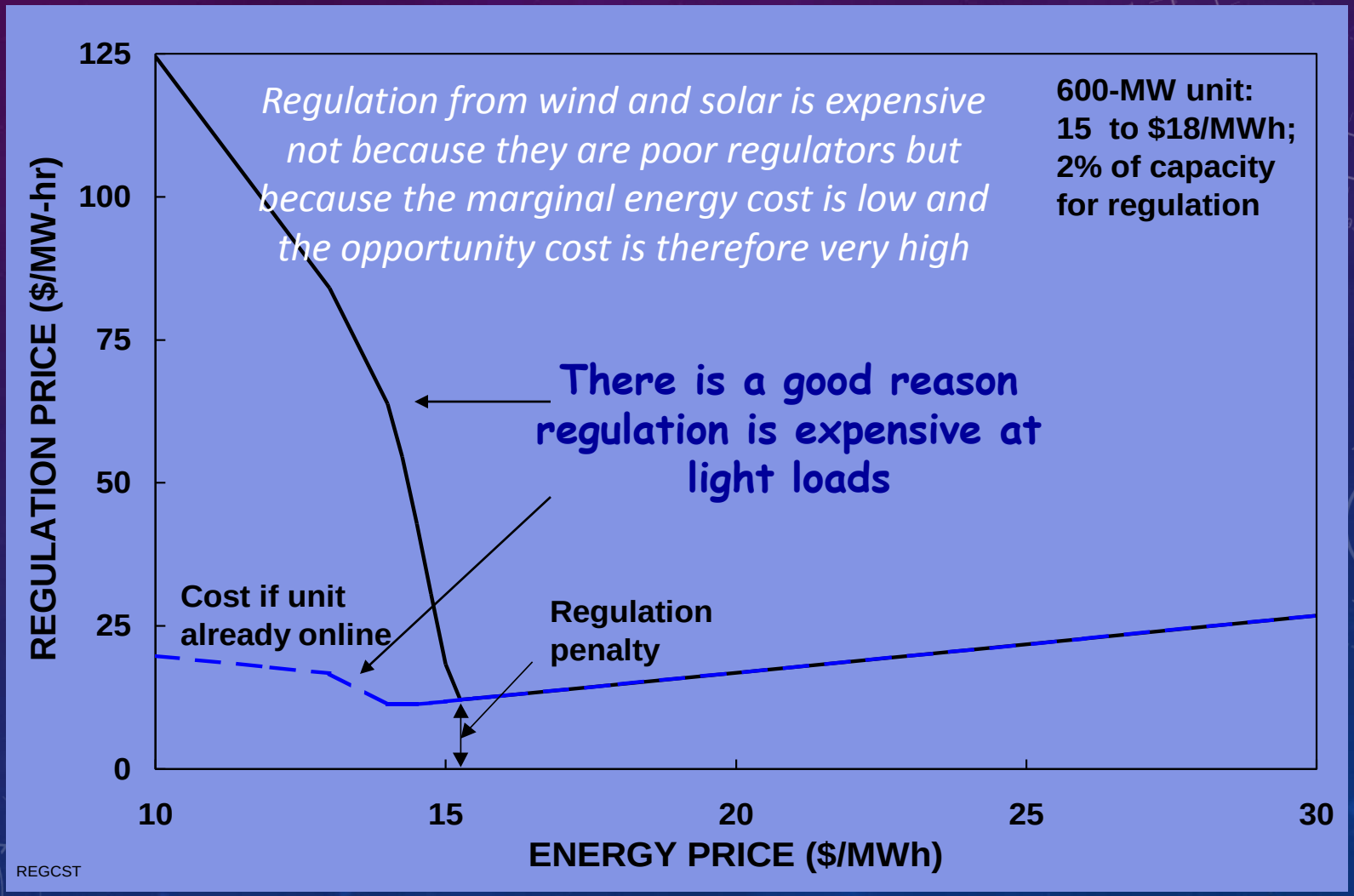
Aggregate load follows a predictable daily pattern

Regulation requirements are more random

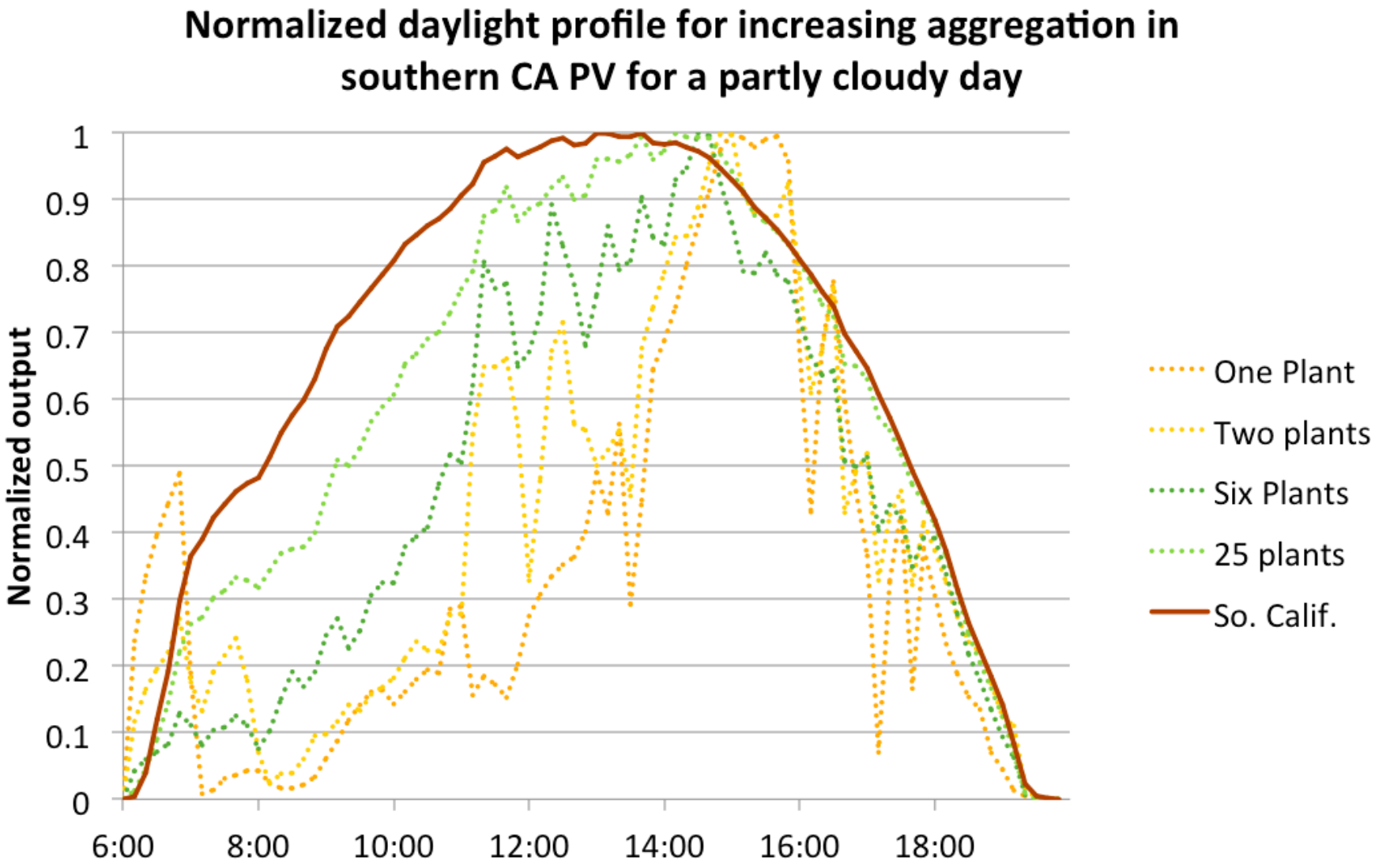
Regulation is <u>not</u> peak reduction, interruptible load, emergency response, curtailment, time-of-use, etc.

Regulation is the minute-to-minute balancing of the power system. It is slower than power quality and flicker. It is faster than energy markets.

WITH COMPETITION, REGULATION PRICE DEPENDS ON SPOT ENERGY MARKET

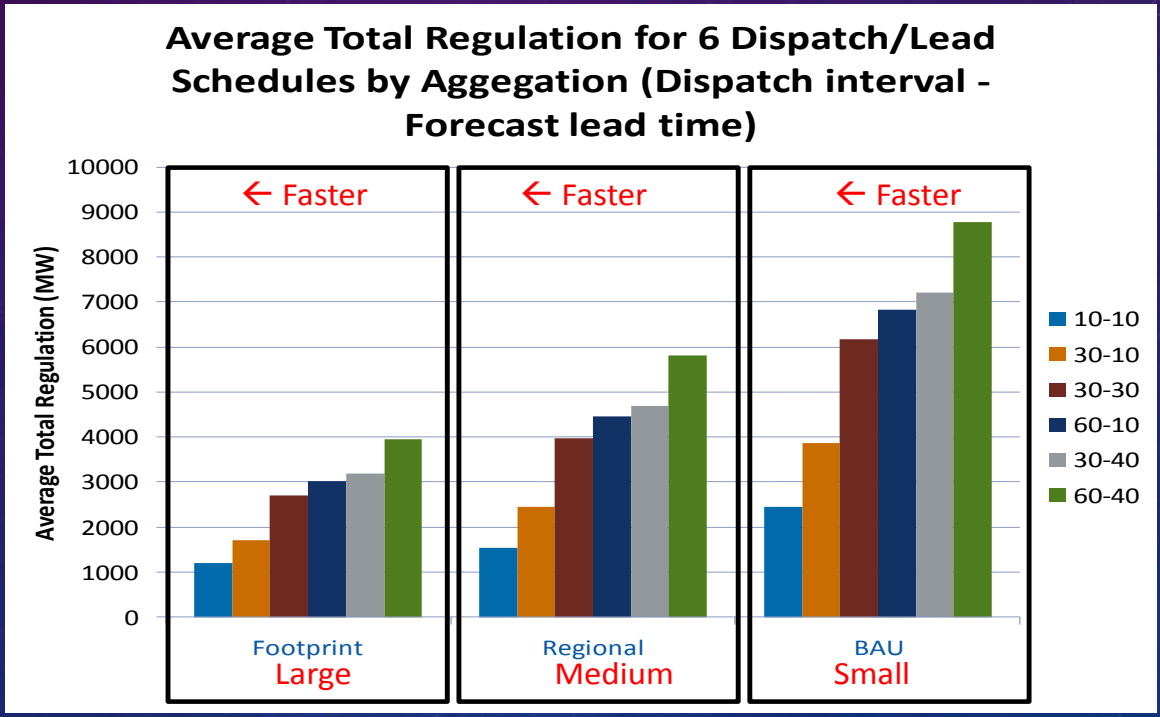


Aggregation Reduces Total System Variability



BALANCING AREA SIZE AND DISPATCH FREQUENCY IMPACT REGULATING RESERVES

Scheduling interval and lead times are policy choices we make, they do not require investing in new generation or transmission



Milligan, M.; B. Kirby, J. King, S. Beuning (2011), *The Impact of Alternative Dispatch Intervals on Operating Reserve Requirements for Variable Generation*. Presented at 10th International Workshop on Large-Scale Integration of Wind (and Solar) Power into Power Systems, Aarhus, Denmark, October.

VOLATILE ENERGY MARKET PRICES ELICIT DESIRED BALANCING RESPONSE

- Energy markets – energy arbitrage
  - Day-ahead hourly, hour-ahead, 5-minute
    - *Fast response at very little cost to the power system*
  - 5-minute markets *beginning* to settle on actuals
  - 5 minute markets are thin

2013 avg Energy Prices ($/MWH)			
	Day-Ahead	5-Minute	
		Average	Within Hour Range
CAISO	$43.40	$41.07	*$34.05*
MISO	$37.35	$36.33	*$30.01*
NYISO	$31.13	$31.22	*$28.76*

ANCILLARY SERVICES PROVIDE DEDICATED RESPONSE THAT IS FASTER THAN ENERGY MARKET RESPONSE

- Existing Ancillary Services
  - Regulation (up, down, combined), Spin, Non-Spin, 30 minute
  - Faster, more frequent services pay more
  - *Duration* has lower value

	2013 avg AS Prices ($/MW-hr)			
	Reg (up+dn)	Spin	Non-Spin	30-min
CAISO	$7.81	$2.74	$0.19	
ERCOT	$13.46	$9.77		$3.47
MISO	$9.10	$3.25	$1.75	
NYISO	$10.11	$8.57	$4.22	$0.48
ISONE	$11.68	$3.00	$2.49	$2.29

FREQUENCY RESPONSIVE RESERVE CONCERNS

- WECC
  - Frequency response worsening and expected to continue
  - Formed the Reserve Issues Task Force
  - Started drafting a new Frequency Responsive Reserve requirement
- NERC
  - Frequency Response Initiative started in 2010
  - Identified frequency response withdrawal as a major concern
    - Inability to sustain & Outer loop control
  - Developed frequency metrics for the interconnection & for BAs
  - BAL-003-1 – Frequency Response and Frequency Bias Settings
  - Established the Integration of Variable Generation Task Force (IVGTF) and the Essential Reliability Services Task Force (ERSTF)
    - Enumerating specific balancing requirements
    - Identifying standards requirements
    - Collecting data to quantify concerns
- ERCOT
  - Establishing requirements and services

WHY ARE NEW SERVICES NEEDED?

- Power system physics remains the same
  - Balancing is required instantaneously & continuously
- New ancillary service supply technologies require clearer definitions and requirements
  - Some response was inherent (or should have been) when synchronous generators supplied all response
  - ❖ Need standards & resources
- Changed net load patterns require additional response resources
  - ❖ No new standards required, just resources

IS THIS WIND & SOLAR'S FAULT?

Yes, No, & Sort of

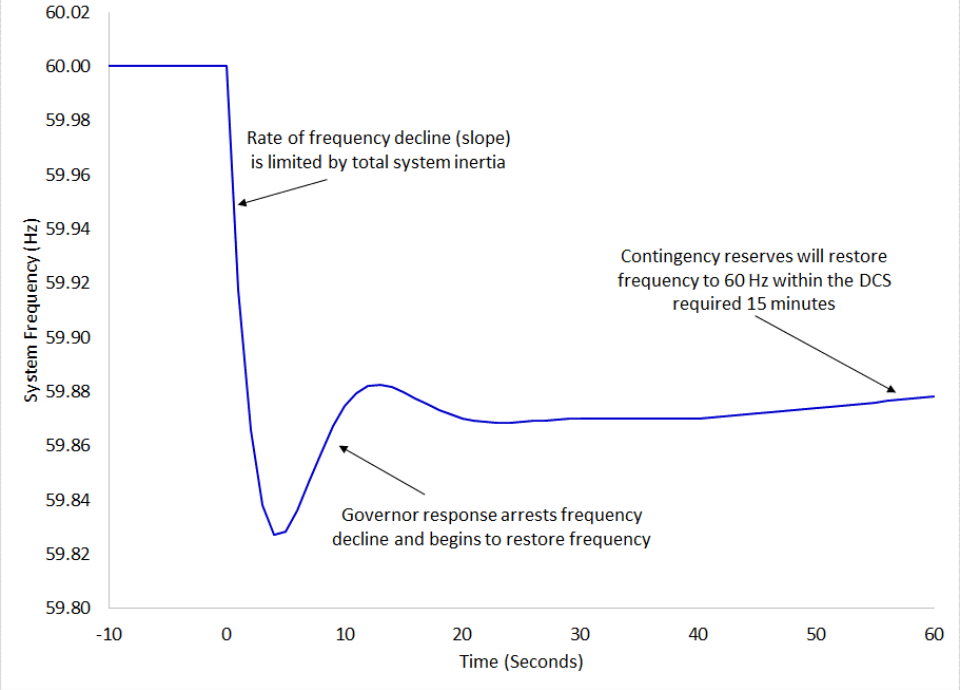
- No: All interconnections were having frequency response concerns long before wind and solar
  - Eastern interconnection frequency response was/is the worst and it has relatively little wind or solar
- Yes: wind & solar can …
  - Increase ramping requirements
  - Displace synchronous inertia and governor response (but…)
- Sort of: Demand response, energy storage, wind, & solar can control their fast response
  - Can offer specific services
  - Require better definitions of requirements/value

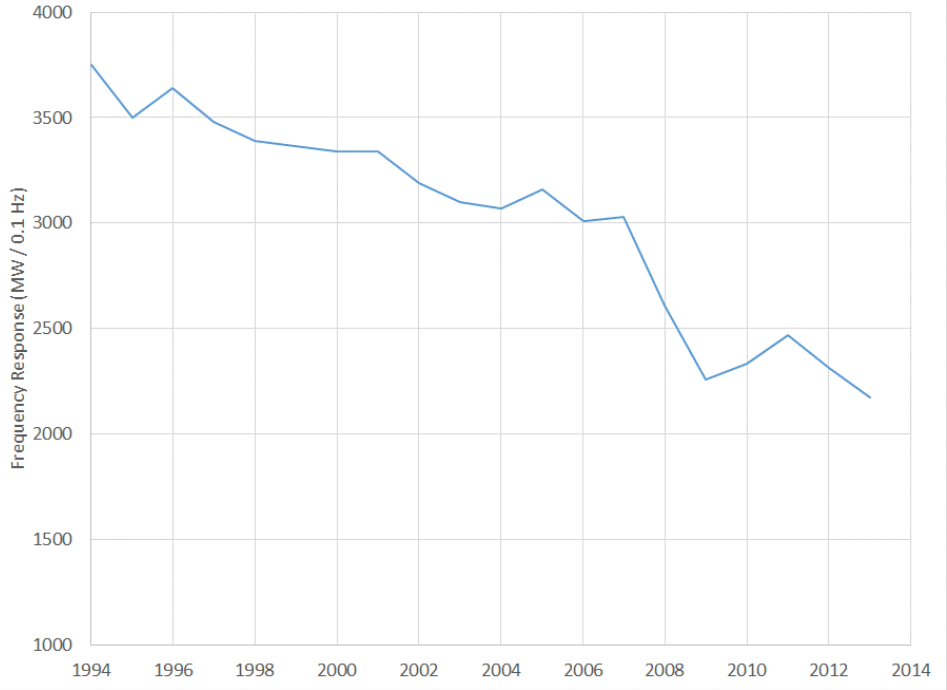
FREQUENCY RESPONSIVE RESERVE – GOVERNOR RESPONSE & INERTIA: *SYNCHRONOUS GENERATION GAVE A BUNDLED RESPONSE*

- Inertia is inherent with synchronous generators and motor loads
- Governors were assumed to be a best practice
- Specifying 10 minute spinning reserve and 15 minute balancing should have been all you needed
  - Standards did not specify fast balancing requirements or mandate fast capability

GOOD IDEA – BUT THERE WERE PROBLEMS…

- Frequency response declining in all interconnections
- NERC Governor Response Survey:
  - 30% of EI generators provided expected governor response
  - 38% had no response, 19% had opposite response





ERCOT LEADING IN ANCILLARY SERVICE EVOLUTION

- ERCOT is the smallest interconnection and has significant non-synchronous wind generation so physical frequency concerns are more immediate
  - Eastern Interconnection & WECC are not seeing an immediate problem so are collecting data and studying but not taking immediate action
  - *(Quebec is also a relatively small interconnection but is vertically integrated)*
- Established a technology-neutral, functionally-based reliability requirement
  - Avoid the first stage of UFLS for specified two-unit generation contingency
- Specifying services to support the reliability criteria
- Technology-neutral service specifications but aware of technology limitations
  - Governor response *capability* is a technology-specific unpaid condition of interconnection
- Continued reliance on markets to obtain the lowest cost optimal resource mix

Current Ancillary Services in ERCOT

- **Responsive Reserve Service (2800 MW all year round),**
  - Deploys during generation trip events and energy scarcity
  - Provided by Generation Resources, 10-minute service
  - Includes Load Resources with Under-Frequency Relays (UFR), 0.5 second trip.
- **Regulation Reserve Service (400-600 MW)**
  - To control system ACE (i.e. frequency for ERCOT), balance net load variability
  - Load Frequency Control (LFC) sends Reg-Up or Reg-Down signal every 4s
- **Non-Spinning Reserve Service (1100-1500 MW)**
  - Used to compensate for net load forecast errors, to recover Regulation Up and Responsive Reserves, to replace capacity lost during a large Generator trip;
  - 30-minute service

- All online Resources (with headroom) are required to provide governor or governor-like response. This is not an AS.

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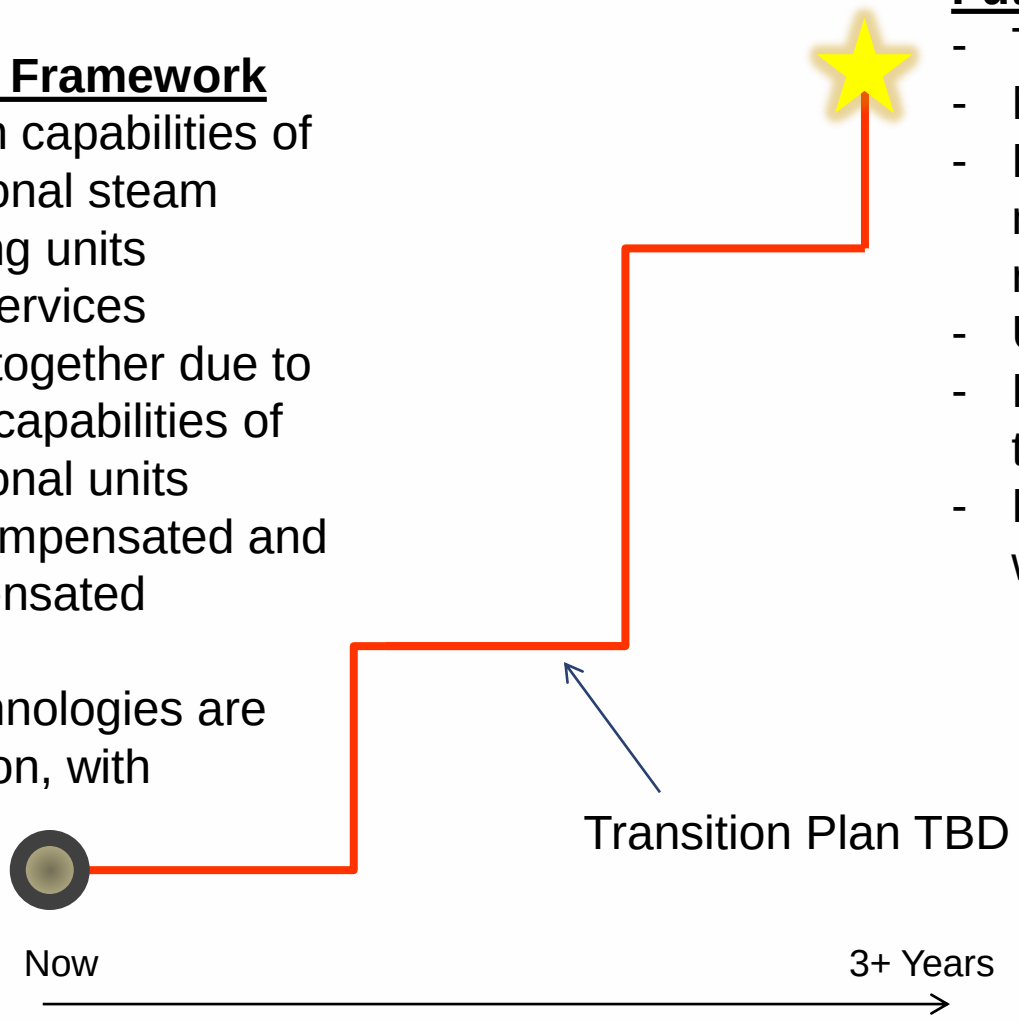
Why is a change in the AS framework being proposed?

- Current AS Framework has performed well but has issues:
  - Based on inherent characteristics of steam generators;
  - Distinct operational requirements (fast frequency response/primary frequency response/contingency reserve) are bundled as a single Responsive Reserve Service;
  - Hence, inefficient and at times inadequate procurement of RRS amounts;
  - Decline in synchronous inertia during high wind low load conditions leads to higher RoCoF than in the past, calling for unbundling of the RRS and more dynamic procurement.
  - Awkward to fit capabilities of other technologies (e.g. CCGTs with duct firing, load resources, storage) that could provide AS efficiently.
- Changes in market design and control systems (e.g. 5 minute dispatch, HRUC) have reduced the need for other services
- New regulatory requirements (NERC BAL-003-1)

Why Ancillary Services Re-think?

Current AS Framework

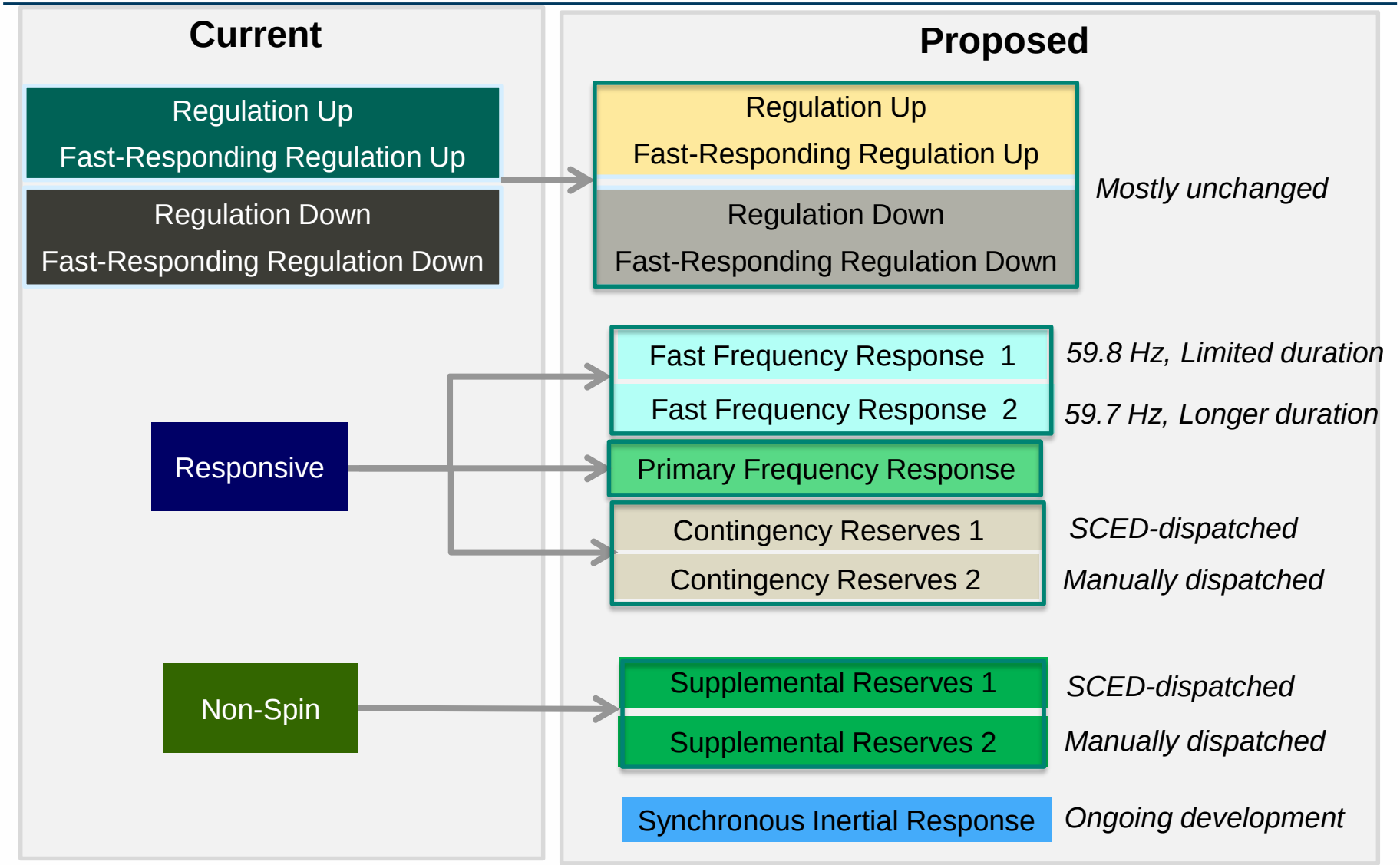
- Based on capabilities of conventional steam generating units
- Unique services bundled together due to inherent capabilities of conventional units
- Mix of compensated and uncompensated services
- New technologies are cobbled on, with difficulty



Future AS Framework

- Technology neutral
- Market-based
- Based on fundamental needs of the system, not resource characteristics
- Unbundled services
- Flexible for new technologies
- Pay for performance, where practical

Proposed Transition to Future Ancillary Services



Fast Frequency Response Service

- The objective FFRS and PFRS is to ensure that for instantaneous loss of two largest units (2750 MW) frequency is arrested above UFLS threshold of 59.30 Hz.
- FFRS should provide fast (within 0.5 s) automatic response at specified frequency threshold to arrest frequency decay following generation trip event; - *(this is a DR service, generation can not move that fast – BJK)*
- Supplements the inherent inertial response from synchronous machines;
- Provides sufficient time for Primary Frequency Response to deploy;
- FFR should sustain until ERCOT issues recall instruction;
- After recall, restore its capability to respond as soon as possible, to be ready for the next event.
- Presently, no separate FFR Service, however up to 1400 MW of Responsive Reserve Service can be provided by Load Resources, which satisfy some of the FFR characteristics.

FFR1 and FFR2

Two groups were introduced for FFR service (due to technology limitations):

- FFR1 (e.g. energy storage, industrial scale refrigeration loads):
  - automatic response within 30 cycles
  - at 59.8 Hz,
  - **sustained for minimum 10 minutes,**
  - **recovery time 15 minutes.**
- FFR2 (e.g. industrial loads):
  - automatic response within 30 cycles
  - at 59.7 Hz,
  - **sustained until ERCOT's recall,**
  - **recovery time 180 minutes (e.g. industrial loads).**

Primary Frequency Response Service

- Primary Frequency Response (PFR) is **immediate proportional** increase or decrease in real power output provided by a Resource in response to system frequency deviations. *(This is generation governor response – "immediate" is several seconds, but no intentional delay – BJK)*

- Minimum Frequency Response Obligation (NERC BAL-003) for ERCOT is 413 MW/0.1Hz, determined based on instantaneous loss of two largest units.

- Currently in ERCOT, governor response is provided by all online generators with headroom, including generation capacity reserved for RRS and Regulation.

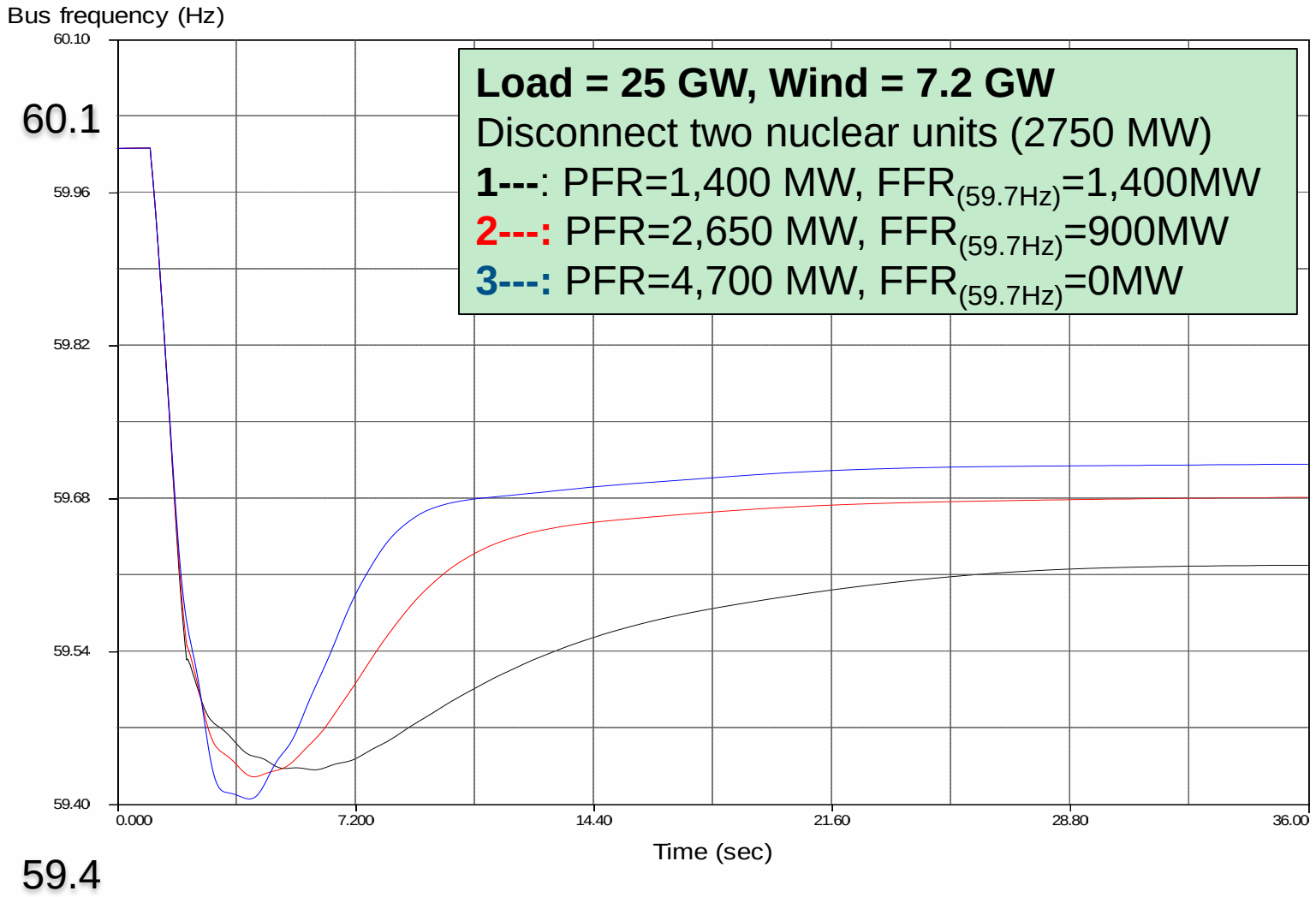
- In the future resources providing PFRS must reserve capacity and have tighter dead-band settings than other resources.

- Maximum MW capacity that Resource may bid for PFRS will be determined based on its average performance for the past events.

FFR and PFR interdependency

- FFR and PFR are highly interdependent and the required quantity of each service varies based on the system conditions.
- ERCOT is developing methodology for the regular assessment of the needed amounts of FFR and PFR and **equivalency ratio *("R")*** between PFR and FFR.
  - *FFR would be paid "R" times the PFR payment per MW-hr since 1 MW of FFR provides equivalent performance as "R" MW of PFR*
    - *"R" can vary based on system conditions*
  - *PFR can be priced because it is generation based and has a calculable opportunity cost*
  - *FFR is difficult to price directly since the DR opportunity cost is specific to each load technology, may depend on the deployment length, and the FFR capital cost often dominates*
  - *BJK*
- Required amounts for Contingency Reserve Service (CRS) will also depend on FFR/PFR capacity requirement at different system conditions.

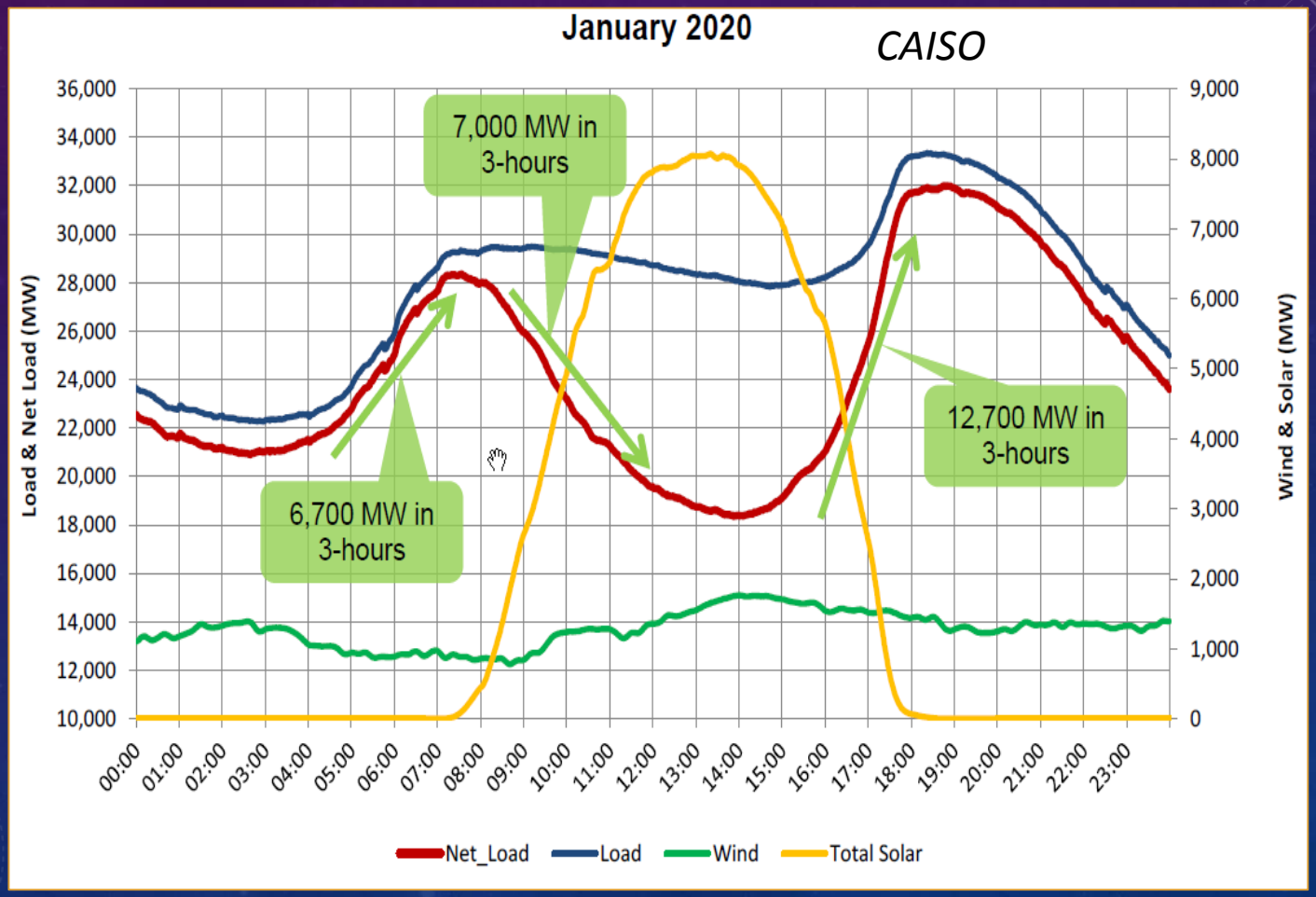
PFR/FFR at High Wind, Low Load (HWLL)



1 MW FFR ≈ 2.35 MW PFR

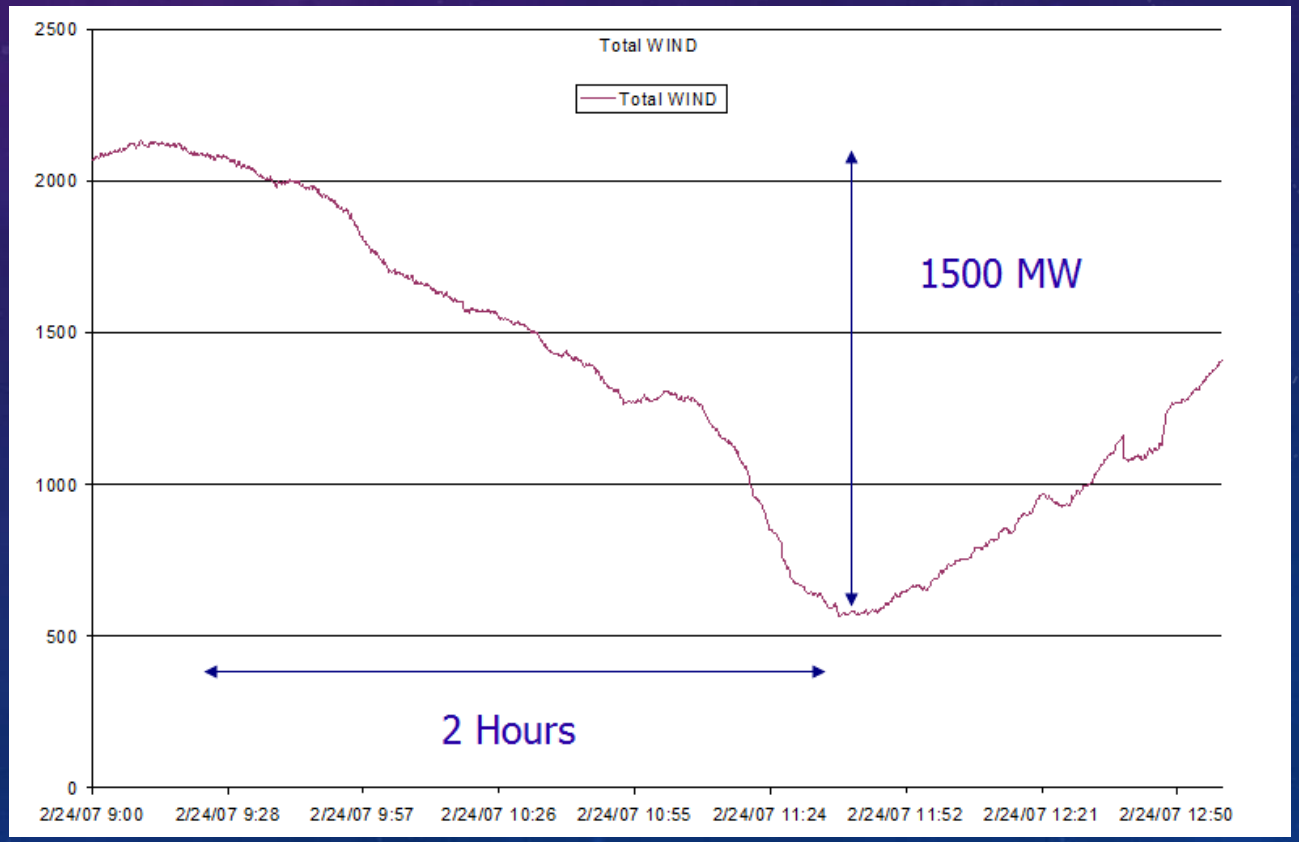
RAMPING REQUIREMENTS

- Standards are adequate (CPS1&2 & DCS & BAAL) but resources may not be sufficient



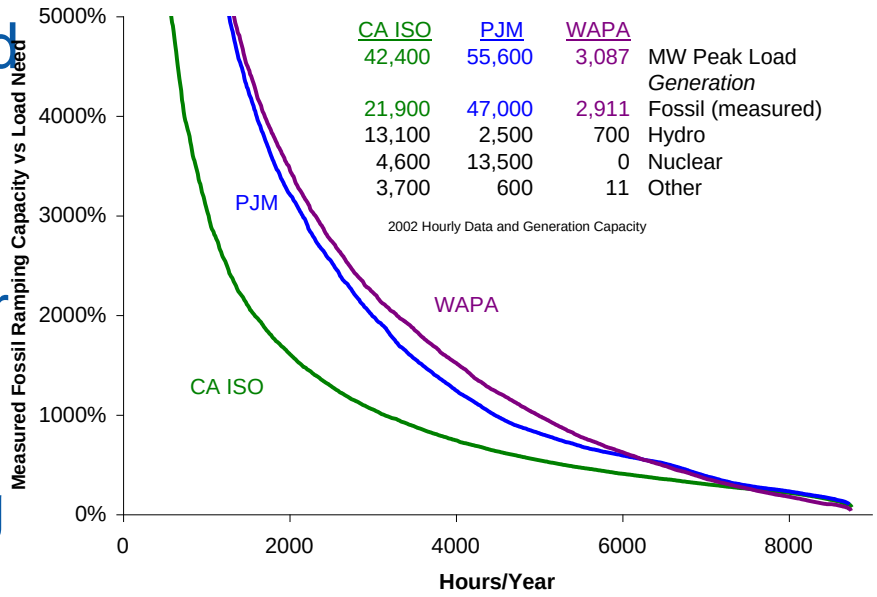
WIND RAMPS ARE DIFFERENT THAN SOLAR

- Infrequent, like contingencies
- Possible short-term forecast
- Longer and slower than contingencies
  - Non-spin may be adequate but ramp may be too slow to use contingency reserves



Better use of existing flexibility

- Tap into maneuverable generation that may be "behind the wall"[1]
- Provide a mechanism (market, contract, other) that benefits system operator and generator
- Fast energy markets help provide needed flexibility[2] and can often supply load following flexibility at no cost[3]



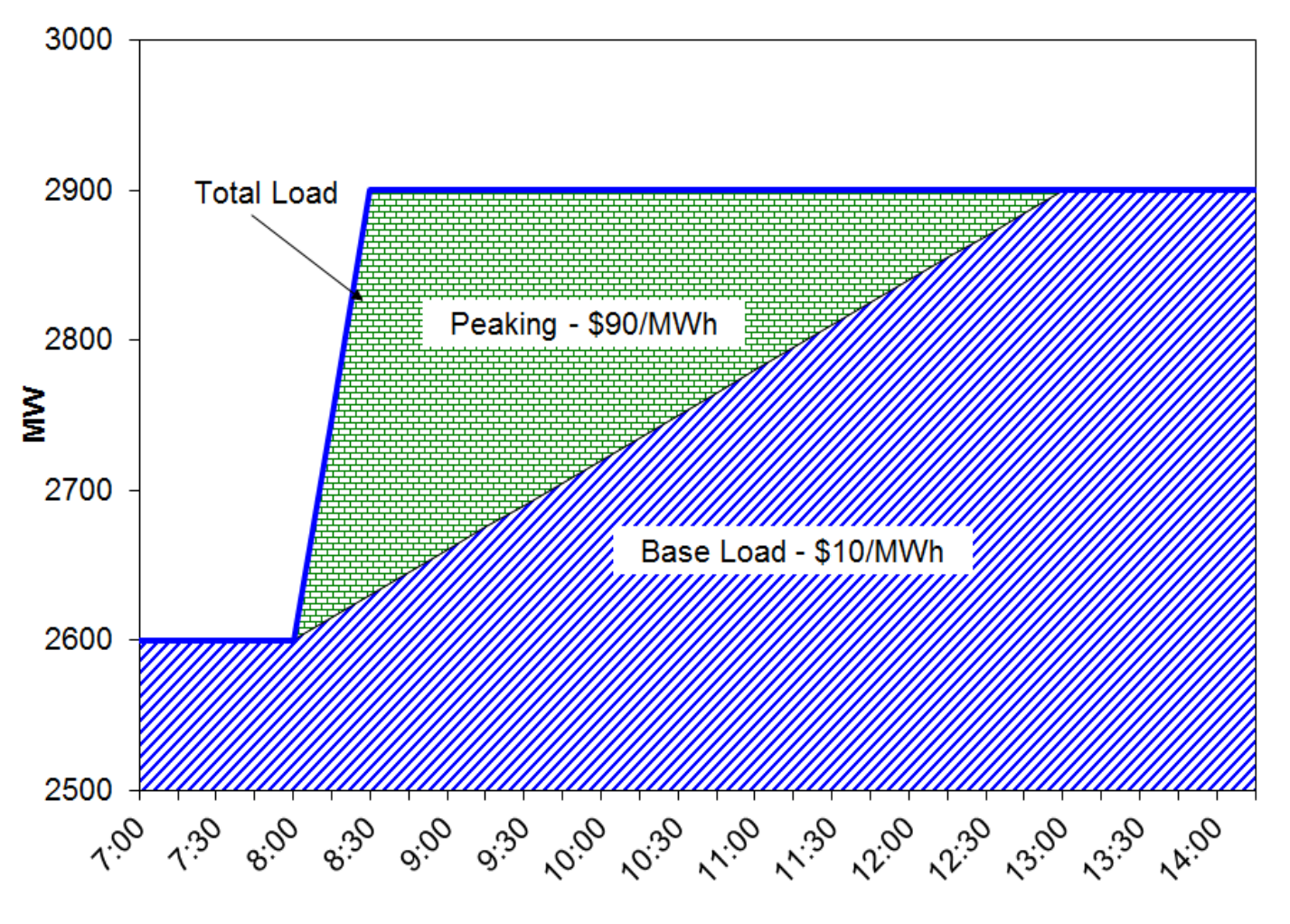
- Very high wind and solar penetration may challenge ramping
  - Increases ramps
  - Displaces conventional ramping generation

[1]Kirby & Milligan, 2005 Methodology for Examining Control Area Ramping Capabilities with Implications for Wind http://www.nrel.gov/docs/fy05osti/38153.pdf

[2]Kirby & Milligan, 2008 Facilitating Wind Development: The Importance of Electric Industry Structure. http://www.nrel.gov/docs/fy08osti/43251.pdf

[3]Milligan & Kirby 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration . http://www.nrel.gov/docs/fy07osti/41809.pdf

INADEQUATE RAMPING CAPACITY DISTORTS ENERGY MARKETS



CAISO & MISO ARE CONSIDERING RAMPING PRODUCTS

- Day-ahead & real-time cooptimized market product based on opportunity cost
- Forecasted net-load ramp & a reserve for 90-95% confidence forecast error
- System-wide service but could be locational
- ~90% of the ramping need is due to load and interchange changes so MISO cost socialized

CONCERNS FOR DEMAND RESPONSE AND STORAGE

- Ancillary Service markets are based on energy market opportunity costs
  - Storage and DR have little (or difficult to quantify) opportunity costs
  - Markets clear hourly, bidding your capital cost reduces your profit
  - AS prices do not reflect energy market commitment, dispatch, and efficiency benefits
- Viable storage and DR technologies collapse AS and energy arbitrage market prices if deployed in quantity
  - Both storage and society lose

POSSIBLE MARKET STRUCTURE SOLUTIONS

- Force storage to guess the hourly market clearing price
  - Barely underbid the current generation marginal cost
  - Difficult and may not be legal
- Limit market share OR price "equivalent" services based on the equivalent generation price, including opportunity cost
  - ERCOT currently limits DR to no more than half of the 2800 MW Responsive Reserve. Generation always sets the market clearing price. DR and generation are paid the same per MW-hr
  - Effective but limits market share and both society and storage/DR suffer
  - ERCOT is proposing to price all fast response based on generation opportunity costs
    - FFR from DR, which is "R" times as effective as PFR from generation, would be priced at "R" times the PFR price per MW-hr

POSSIBLE MARKET STRUCTURE SOLUTIONS (CONTINUED)

- Treat storage and DR as regulated assets – similar to transmission
  - PUC determines if storage or DR is the lowest cost solution
    - Compares capital + operating cost vs generation marginal cost over the project's life for one or more services
  - Turn dispatch over to the system operator
- Long-term system operator contracts
  - Very similar to treating storage and DR as a regulated asset
- Self provision by Load Serving Entity
  - Difficult for LSE to make a long-term commitment with changing AS requirements

CONCLUSIONS

- Power systems require flexibility and the needs are rising
  - Needs are being quantified
- AS and fast energy markets work well (for generators) and are being refined
  - Co-optimization of energy and ancillary services based on marginal production opportunity costs
- DR and storage with fast and accurate response are ideal for power system balancing, as is flexible generation
- With technology options there are alternatives for all balancing needs
  - Resource selection is an economic choice/optimization

CONCLUSIONS (CONCLUDED)

- Storage and DR, with low opportunity costs but important capital costs, are unfairly disadvantaged with the current ancillary service and 5-minute energy market structure
  - Both society and the resources lose
- Forcing DR and storage to conform to current market rules is impractical and inefficient
- Four market structure solutions appear to be practical
  - All three require an analysis to determine if DR or storage is the lowest cost solution

❖ Equivalent services can be prices based on the cost (including opportunity cost) of an equivalently effective amount of generation response

❖ LSEs could determine that self-supply with was cheaper than purchasing AS requirements from the ISO

❖ ISO could determine that DR or storage is cheaper than market procurement of AS

❖ Regulators could determine that DR or storage is better for rate payers than market provision of AS from generation and could authorize rate-based investment in DR or storage that is then dispatched by the system operator