# Energy Storage Applications in a Vertically Integrated Utility

PRESENTED BY

Ray Byrne, Ph.D.



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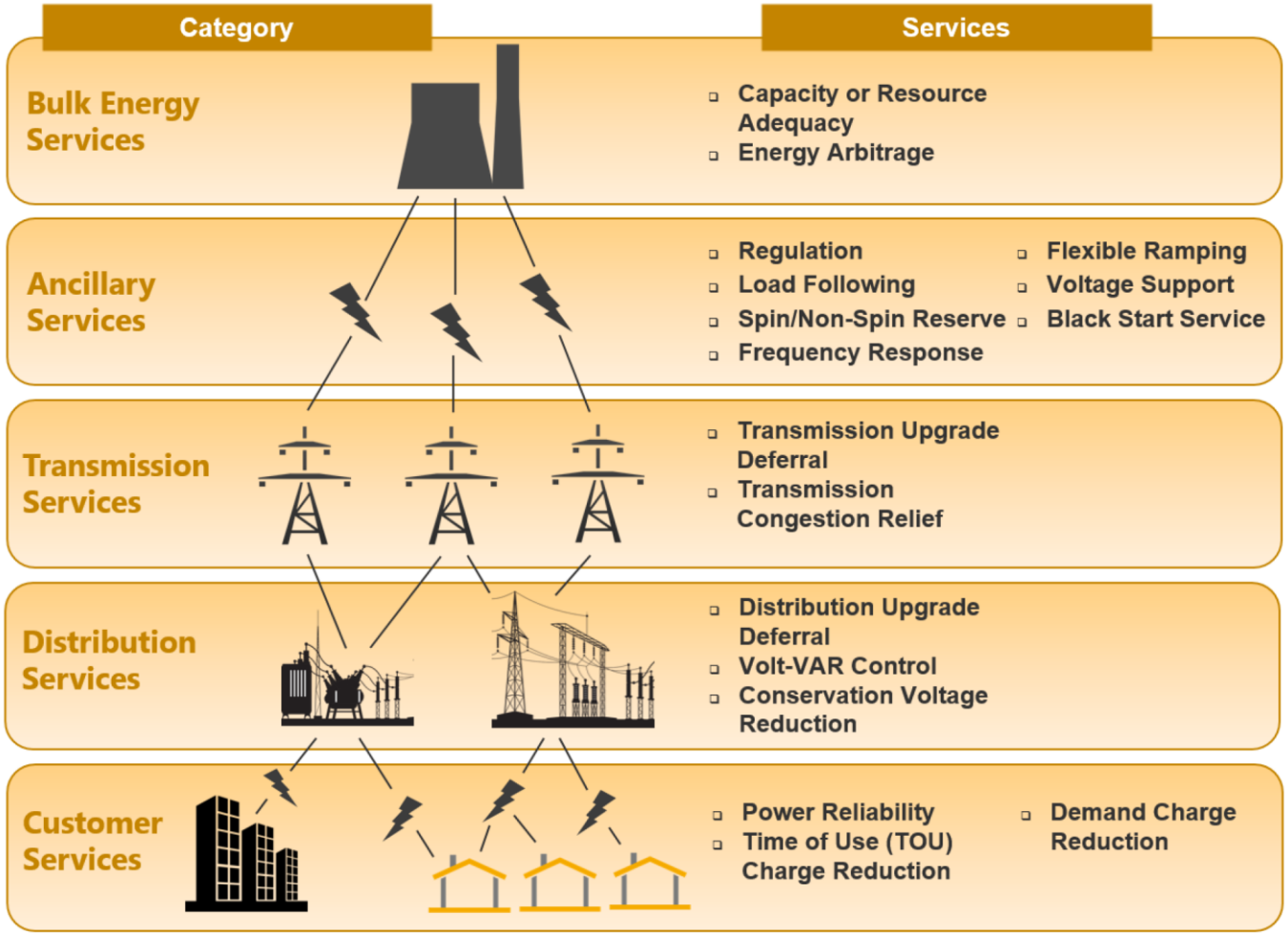
# Energy storage application time scale

- "Energy" applications – longer times scale, hours to days, large amounts of energy
- "Power" applications – shorter time scale, milliseconds to minutes, real-time control of the electric grid

| Energy Applications | Power Applications |
|---|---|
| Arbitrage | Frequency regulation |
| Renewable energy time shift | Voltage support |
| Demand charge reduction | Small signal stability |
| Time-of-use charge reduction | Frequency droop |
| T&D upgrade deferral | Synthetic inertia |
| Grid resiliency | Renewable capacity firming |

# Energy Storage Applications by Grid Service Category




Patrick J. Balducci, M. Jan E. Alam, Trevor D. Hardy and Di Wu, “Assigning value to energy storage systems at multiple points in an electrical grid”, *Energy Environ. Sci*., 2018, 11, pp. 1926-1944.

A. Akhil, G. Huff, A. Currier, B. Kaun, D. Rastler, S. Chen, A. Cotter, D. Bradshaw and W. Gauntlett, *DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA*, Albuquerque, NM, 2015, pp. 29, 149–166

# Bulk Energy Services: Energy Arbitrage

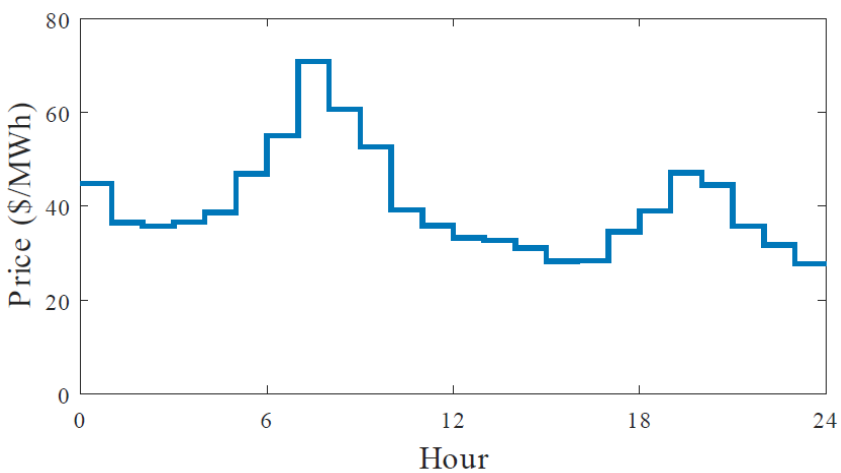
## Buy low, sell high

$\eta_c$ = conversion efficiency

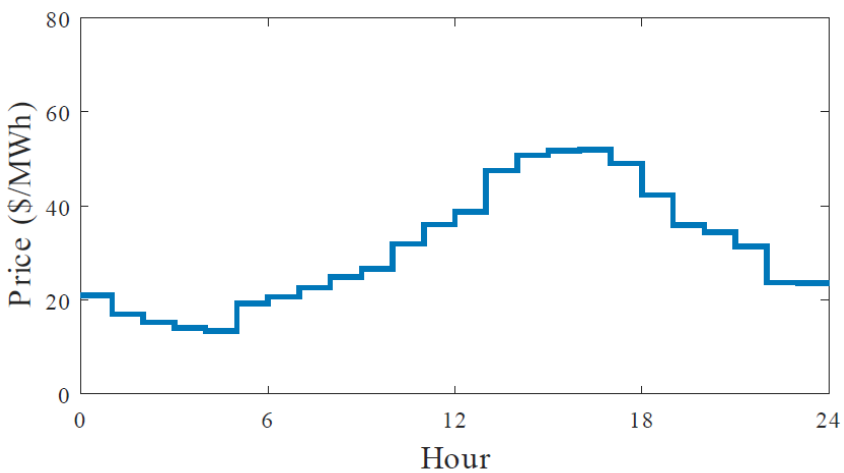
$LMP_H$ = average high LMP, $LMP_L$ = average low LMP

$q$ = charge quantity

$$\text{arbitrage opportunity} = q\eta_c LMP_H - qLMP_L$$




(a) Day ahead LMP for ISO-NE node 4476 (LD.STERLING13.8), March 23, 2017.




(b) Day ahead LMP for ISO-NE node 4476 (LD.STERLING13.8), July 14, 2016.

# Bulk Energy Services: Energy Arbitrage

Market area – market prices

Vertically integrated utility – efficiency savings

Different variants

- Charge with inexpensive renewable energy
- Arbitrage day ahead and real-time markets
- Day ahead market only

Rarely the highest potential revenue stream

85% efficiency => 117.6% price difference

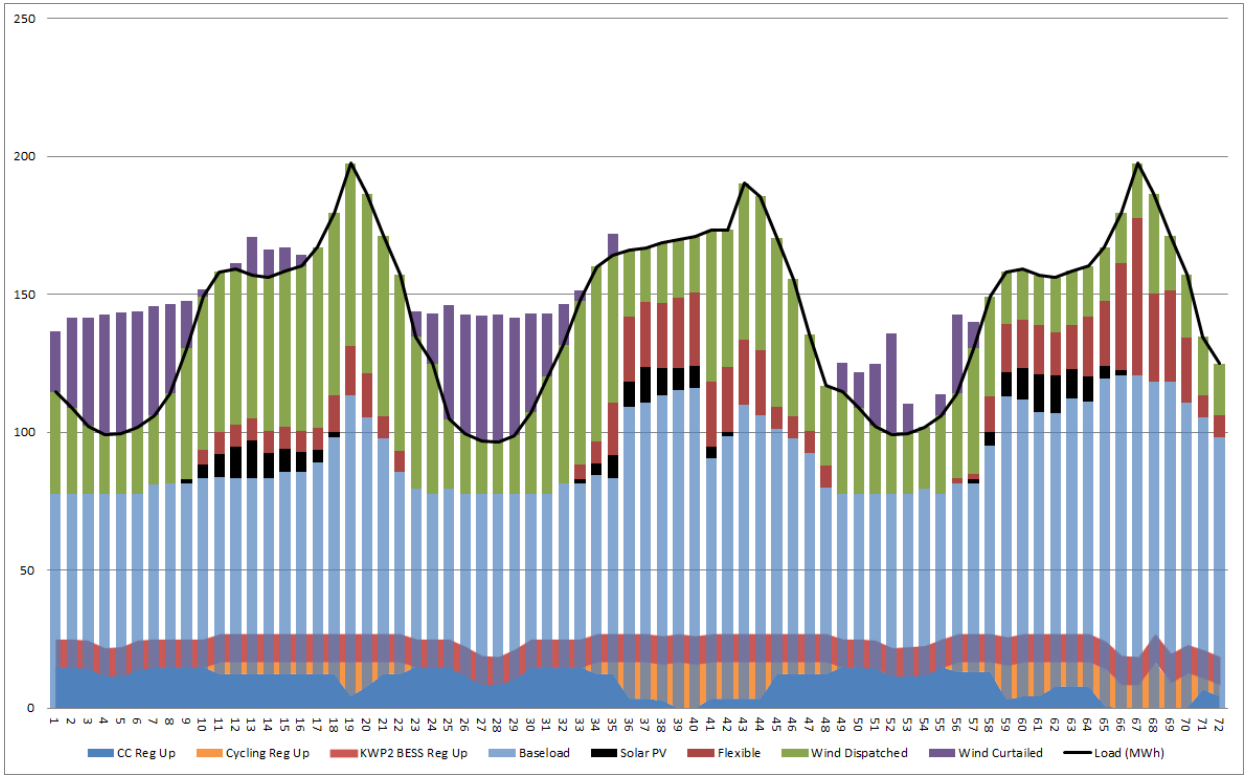
65% efficiency => 153.8% price difference

# Bulk Energy Services: Energy Arbitrage

Vertically integrated utility dispatch generation stack (unit commitment and economic dispatch)

Cost savings from:

- More efficient operation of generation fleet
- Less curtailment
- Reduced operating reserves (e.g., must run units)



# Bulk Energy Services: Energy Arbitrage

**Question:** How do you value arbitrage in a vertically integrated utility?

**Answer:** production cost modeling

Fairly involved modeling effort, requires:

- Accurate grid model (if you want to consider congestion)
- Generator models (e.g., heat rate, fuel costs, start-up costs, min run time, max run time, maintenance schedule, etc.)
- Renewable generation models (e.g., historical variability data, forecasted future variability)
- Load models (e.g., detailed load models by region/location, forecasted load growth)
- Power purchase agreement models
- External interface models (e.g., scheduled imports, etc.)
- Equipment retirements
- Insight into scenario development
- Expensive, complicated software tools (e.g., PLEXOS, PROMOD, GE-MAPS, GridView, etc.)

# Bulk Energy Services: Capacity or Resource Adequacy

**Question:** what is capacity or resource adequacy?

**Answer:** in simple terms, is there enough generation to meet load under all reasonable conditions (including bad weather, unexpected outages/contingencies, and renewable variability), along with some margin

Who is responsible for ensuring adequate capacity?[1]

**FERC?**

- Resource planning and procurement is state-jurisdictional
- Some states have opted to participate in organized wholesale electricity markets with FERC-jurisdictional capacity markets

**NERC? WECC?**

- NERC and WECC develop operating standards aimed at ensuring operational reliability
- NERC and WECC publish information on resource adequacy planning but do not have mandatory planning standards

**Utilities, state commissions and local governing bodies!**

- Utilities and their regulators are ultimately responsible for ensuring resource adequacy in their jurisdictions

[1]Arne Olson, Zach Ming, "Resource Adequacy Today and in the Future in California and the Pacific Northwest", Western Electric Coordinating Council Joint Standing Committee Meeting, June 26, 2019

# Bulk Energy Services: Capacity or Resource Adequacy

**California Example** – three distinct requirements (https://www.cpuc.ca.gov/RA/)

| Requirement | Determination |
|---|---|
| System RA | Each LSEs CEC-adjusted forecast plus a 15% planning reserve margin |
| Local RA | Annual CAISO study using a 1-in-10 weather year and an N-1-1 contingency |
| Flexible RA | Annual CAISO study that currently looks at the largest three-hour ramp for each month needed to run the system reliably |

**System resource adequacy** - LSE must demonstrate procurement of 90% of System RA obligation for the five summer months of the coming compliance year (annual report due 10/31). LSE must demonstrate procurement of 100% of their monthly System RA obligation (filed 45 days prior to compliance month)

**Local resource adequacy** - For its three-year forward obligation, each LSE must demonstrate procurement of 100% of Local RA obligation for each month of compliance years one and two and 50% of Local RA obligation for year three (annual report due 10/31). From July to December, LSE must demonstrate procurement of their revised (due to load migration) Local RA obligation (filed 45 days prior to compliance month).

**Flexible resource adequacy** - LSE must demonstrate procurement of 90% of Flexible RA obligation for each month of coming compliance year (annual report due 10/31). LSE must demonstrate procurement of 100% of their monthly Flexible RA obligation (filed 45 days prior to compliance month).

# Bulk Energy Services: Capacity or Resource Adequacy

Best practices[1], two-step process:

1. Perform a reliability study to determine the quantity of resources needed to meet a defined reliability target
   - Uses "Loss-of-Load Probability" modeling techniques
   - Reliability target is typically defined as "1-outage day-in-10 years" though there is no industry standard

2. Translate the required quantity of resources into a Planning Reserve Margin (PRM) heuristic for easy application to multiple processes
   - PRM defined as % of typical year (1-in-2) peak load
   - PRM of 12-20% is typical across the industry
   - Thermal generators rated at firm capacity level
   - Dispatch-limited resources (hydro, wind, solar, DR, storage) require more advanced techniques

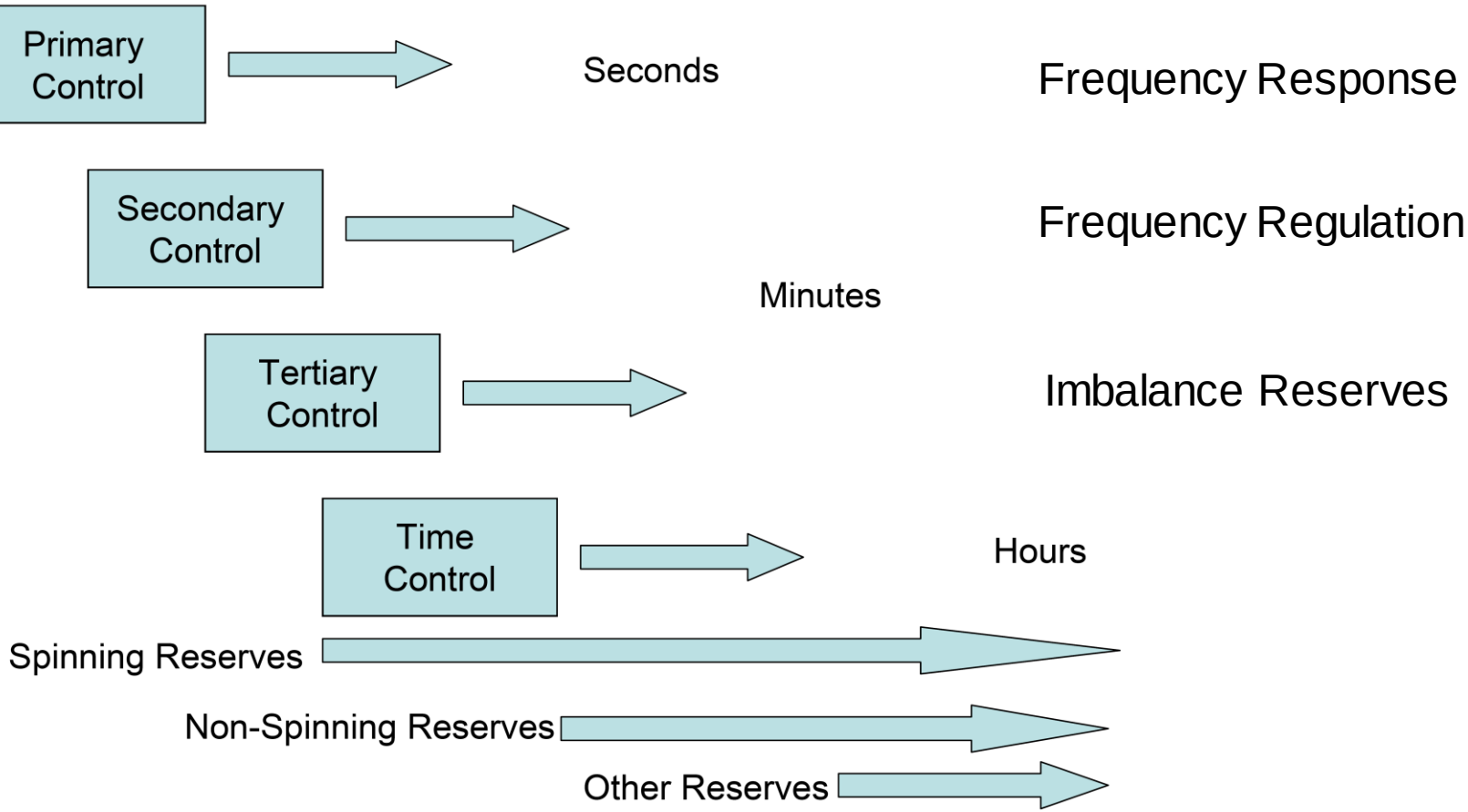
What is the value of storage for capacity or resource adequacy?

- The cost savings achieved relative to other scenarios that meet the resource adequacy requirements that do not contain energy storage.
- The cost of the marginal resource required to meet capacity or resource adequacy

[1]Arne Olson, Zach Ming, "Resource Adequacy Today and in the Future in California and the Pacific Northwest", Western Electric Coordinating Council Joint Standing Committee Meeting, June 26, 2019

# Ancillary Services

Ancillary services are required to maintain grid reliability



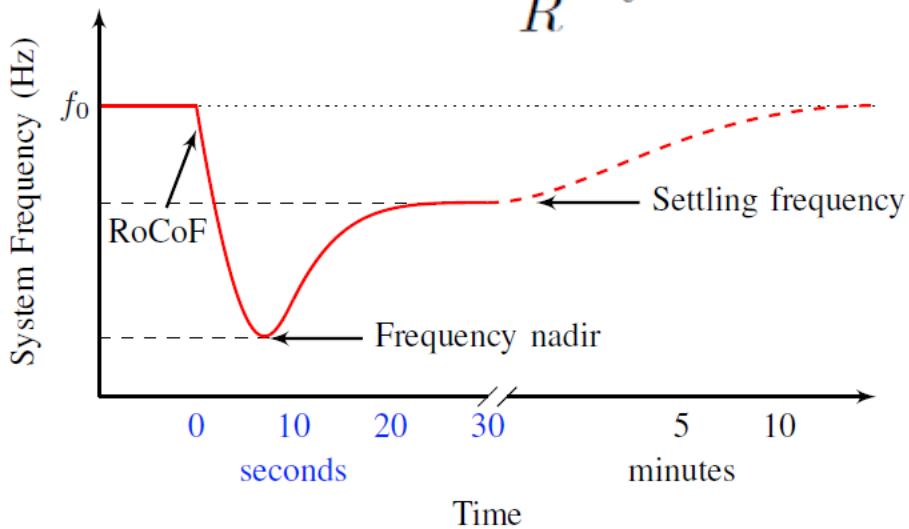

Balancing and Frequency Control, A Technical Document Prepared by the NERC Resources Subcommittee, North American Electric reliability Corporation, Princeton, NJ, January 26, 2011

# Ancillary Services: Frequency Response or Frequency Droop

Frequency droop: generator speed control proportional to the speed (frequency) error

Energy storage can provide frequency droop via a control law

$$\Delta P = -\frac{1}{R}\Delta f$$



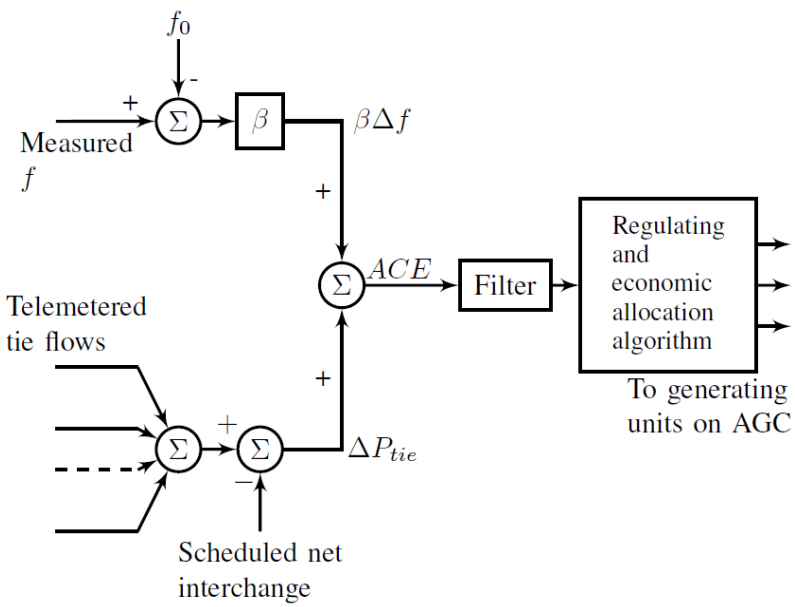

February 15, 2018 – FERC Order 842, all new generation must be capable of providing primary frequency response as a condition of interconnection.

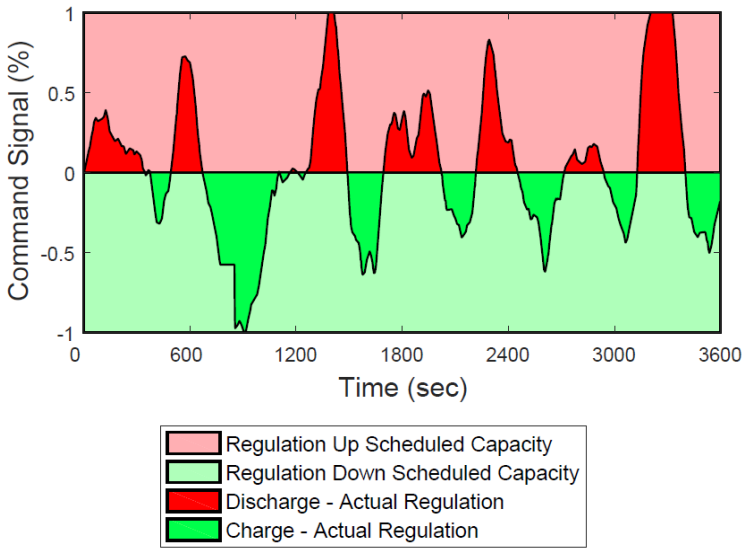
No compensation, but this is currently a point of contention

# Ancillary Services: Frequency Regulation

Second by second adjustment in output power to maintain grid frequency

Follow automatic generation control (AGC) signal




Representative regulation command signal (RegD from PJM)

# Ancillary Services: Frequency Regulation

What is the value of storage for frequency regulation?

- The cost savings achieved relative to other scenarios that meet the frequency regulation requirements that do not contain energy storage.
- The cost of the marginal resource required to meet frequency regulation requirements

Step one is calculating the required amount of frequency regulation

- Increasing renewable variability will increase the amount of reserve products that must be procured, including frequency regulation
- At some point, the location of renewable variability will become important which will require more accurate models

# Ancillary Services: Imbalance Reserves (spin/non-spin)

| | Operating Reserves | | Planned Reserves | |
|---|---|---|---|---|
| On-Line | **Regulating Reserve (a)** | **Other On-Line Reserve (d)** | Operations Planning / Unit Commitment (f) | System Planning / Resource Installation (g) |
| On-Line | **Spinning Reserve (b)** | | | |
| Off-Line | **Non-Spinning Reserve (c) such as Interruptible Load Fast-Start Generation** | **Other Off-Line Reserve (e) such as Curtailable Load Off-Line Units** | | |
| | **<= 10 min** | **10-60 min** | hours to days | weeks to years |

Balancing and Frequency Control, A Technical Document Prepared by the NERC Resources Subcommittee, North American Electric reliability Corporation, Princeton, NJ, January 26, 2011

# Ancillary Services

NERC reliability requirements drive ancillary service requirements

**Control Performance Standard 1 (CPS1)** In simple terms, CPS1 assigns each Balancing Authority a share of the responsibility for control of steady-state Interconnection frequency. The amount of responsibility is directly related to Balancing Authority Frequency Bias.

**Control Performance Standard 2 (CPS2)** CPS2 is a "safety valve" standard that was put in place when CPS was developed. There was concern that if CPS1 was the only regulating standard, a Balancing Authority could grossly over or under generate (as long as it was opposite the frequency error) and get very good CPS1 score. This would negatively impact its neighbors with excessive flows.

The amount of ancillary services required for a balancing authority is derived from the NERC reliability requirements

Balancing and Frequency Control, A Technical Document Prepared by the NERC Resources Subcommittee, North American Electric reliability Corporation, Princeton, NJ, January 26, 2011

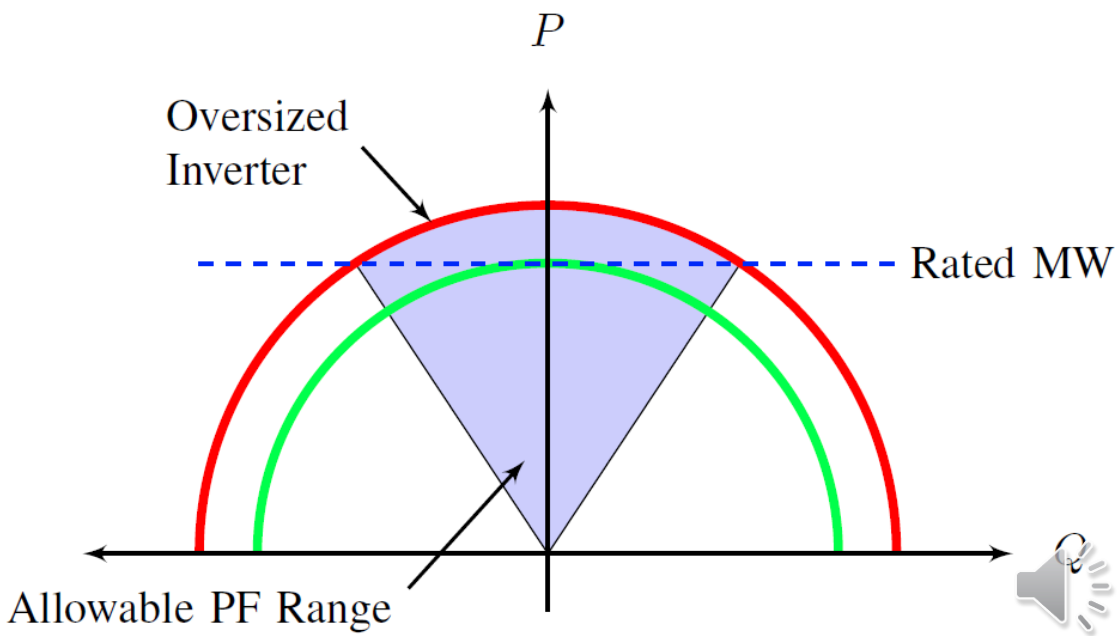
# Ancillary Services: Voltage Support

Inject real/reactive power to control voltage

Can support reactive power over a wide state-of-charge range, limited by inverter rating

NERC VAR-001-4.2 — Voltage and Reactive Control

Purpose: To ensure that voltage levels, reactive flows, and reactive resources are monitored, controlled, and maintained within limits in Real-time to protect equipment and the reliable operation of the Interconnection




Balancing and Frequency Control, A Technical Document Prepared by the NERC Resources Subcommittee, North American Electric reliability Corporation, Princeton, NJ, January 26, 2011

# Ancillary Services: Voltage Support

What is the value energy storage providing voltage support in a vertically integrated utility (transmission operator)?

- The cost savings achieved relative to other scenarios that meet the NERC requirements that do not contain energy storage.
- The cost of the marginal resource required to meet the NERC requirements

Static Synchronous Compensator

Series Compensation

Synchronous Condenser

Static Var Compensator

SOURCE: General Electric Flexible AC Transmission System (FACTS), https://www.gegridsolutions.com/facts.htm

# Ancillary Services: Black Start

Black Start: (PJM definition) A generating unit that has equipment enabling it to start without an outside electrical supply or a generating unit with a high operating factor (subject to Transmission Provider concurrence) with the demonstrated ability to automatically remain operating, at reduced levels, when disconnected from the grid (www.pjm.com)

NERC Requirements for Critical Black Start (EOP-005-2)

- Each generator owner/operator shall participate in the Reliability Coordinator's restoration drills, exercises, or simulations as requested by the Reliability Coordinator

- Each generator owner/operator with a Blackstart Resource shall have documented procedures for starting each Blackstart Resource and energizing a bus

- Each generator owner/operator with a Blackstart Resource shall notify its transmission owner/operator of any known changes to the capabilities of that Blackstart Resource affecting the ability to meet the transmission owner/operator's restoration plan within 24 hours following such change

Image: NOAA

# Ancillary Services: Black Start

What is the value energy storage providing black start in a vertically integrated utility (generation operator)?

- The cost savings achieved relative to other scenarios that meet the NERC requirements that do not contain energy storage.
- The cost of the marginal resource required to meet the NERC requirements

# Transmission (or Distribution) Services: Upgrade Deferral

Projected load growth requires a transmission or distribution upgrade

Energy storage can be deployed to defer the investment

$ES_0$ = energy storage cost
$T_0$ = deferred transmission investment
$r$ = interest rate
$K$ = number of deferral years

$$ES_0 \leq T_0 \left(1 - e^{-rK}\right)$$

# Transmission Services: Transmission Congestion Relief

There are three components to the locational marginal price (LMP):

- System energy price - cost to serve power on a system, ignoring transmission and congestion costs
- Congestion price - represent the price of congestion at binding constraints on the power system
- Loss price - the cost of marginal losses

Congestion keeps a node from receiving electricity from the lowest cost producer, thus increasing the cost

What is the value energy storage providing congestion relief in a vertically integrated utility (transmission operator)?

- Customer perspective – reduction in energy prices by reduction of congestion prices
- Utility perspective –reduces overall generation costs because the lowest cost assets can serve the load

# Distribution Services: Volt-Var control

The majority of voltage issues are in distribution networks

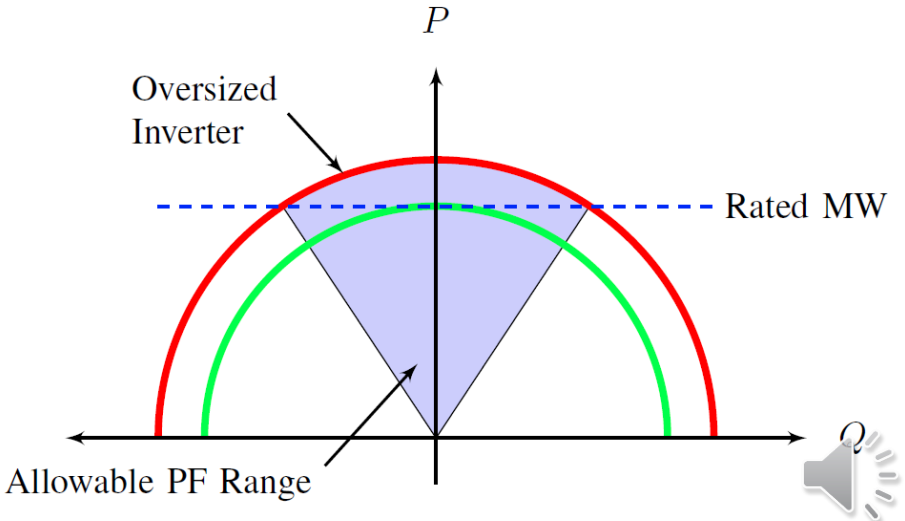
Reactive power does not "travel"

What is the value energy storage providing volt-var control in a vertically integrated utility?

- The cost savings achieved relative to other scenarios that meet the voltage requirements that do not contain energy storage.
- The cost of the marginal resource required to meet the voltage requirements

Competing resources:

- Capacitor banks
- Inverter-based generation (e.g., solar PV)
- Tap changing transformers



# Customer Services: Power System Reliability

Events like Hurricane Sandy and Hurricane Katrina have increased the interest in grid resiliency applications

Value of Lost Load (VOLL) – typically estimated based on

- Market prices
- Surveys

Data for public administration likely under-estimates the value

Value to a utility? What customers are willing to pay for increased reliability/resilience

Sterling Municipal Light Department
2 MW, 3.9 MWh system

# Customer Services: Time of Use Charge Reduction

Time of use charge reduction is the behind-the-meter equivalent of energy arbitrage

For a vertically integrated utility that is procuring energy from another source, there is the opportunity to engage in time-of-use charge reduction

Like energy arbitrage, this is often not a large benefit

**Weekday**

| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Apr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| May | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| Jun | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| Jul | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| Aug | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| Sep | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| Oct | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| Nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |

**Weekend**

| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Jun | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Jul | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
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| Oct | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Customer Services: Demand Charge Reduction

Behind-the-meter application

Demand charge typically based on the maximum rate of consumption ($/kW) over the billing period

Narrow spikes can significantly increase the cost of electricity

For a vertically integrated utility procuring energy from another resource that includes demand charges, this can result in a significant benefit

Some independent system operators employ demand charge like structures. A good example is the capacity market obligation in ISO NE

**Weekday**

| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Apr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 | 0 | 0 |
| Jun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 | 0 | 0 |
| Jul | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 | 0 | 0 |
| Aug | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 | 0 | 0 |
| Sep | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 | 0 | 0 |
| Oct | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 | 0 | 0 |
| Nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |

**Weekend**

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jul | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aug | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sep | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oct | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nov | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dec | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Summary and Conclusions

Valuing energy storage in a vertically integrated utility is much more complicated than market areas and behind the meter applications where you have price signals

- Requires production cost modeling for applications like arbitrage which is data intensive and uses expensive and complex software tools
- Requires dynamic modeling software tools for applications like frequency regulation and frequency response which are complex software tools
- Requires comparative analysis for many other applications which requires assigning cost data to various grid functions – there are often not apple-to-apple comparisons (different alternative solutions provide a different basket of functions)
- The regulatory environment can be complex. Guidelines and best practices are still evolving, as well as the regulatory environment. This creates uncertainty for future valuations.
- Finally, battery energy storage technologies are in their infancy. Capabilities are still improving and prices are still falling as market penetrations increase. This adds further uncertainty, but the trend is favorable for energy storage

For more information, please visit the DOE Energy Storage program website:

www.sandia.gov/ess