# LDES POTENTIAL NEW REVENUE STREAMS

**PATRICK BALDUCCI, BO CHENG**
Argonne National Laboratory

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# PRESENTATION OVERVIEW

Many LDES services are technically feasible but not yet clearly compensated. This presentation introduces a taxonomy for evaluating how different services progress from concept to compensation.

**Agenda:**

- Motivating challenge for LDES: Many valuable LDES services are not yet reflected in existing market structures
- Taxonomy: “Concept to Compensation” - A structured way to assess the maturity of compensation pathways for LDES services
- Review of selected LDES services: Discussion of current status, key barriers, and potential revenue opportunities
- Feedback and discussion: Gather input on the framework and areas for refinement

# CONCEPT-TO-COMPENSATION TAXONOMY

**Conceptualization**

Identification of energy system services or use cases, and demonstration of system capabilities

**Quantification**

Quantify the provided service in MW, MWh, hours, etc.

**Economic Valuation**

Estimate the economic value of the services in monetary units

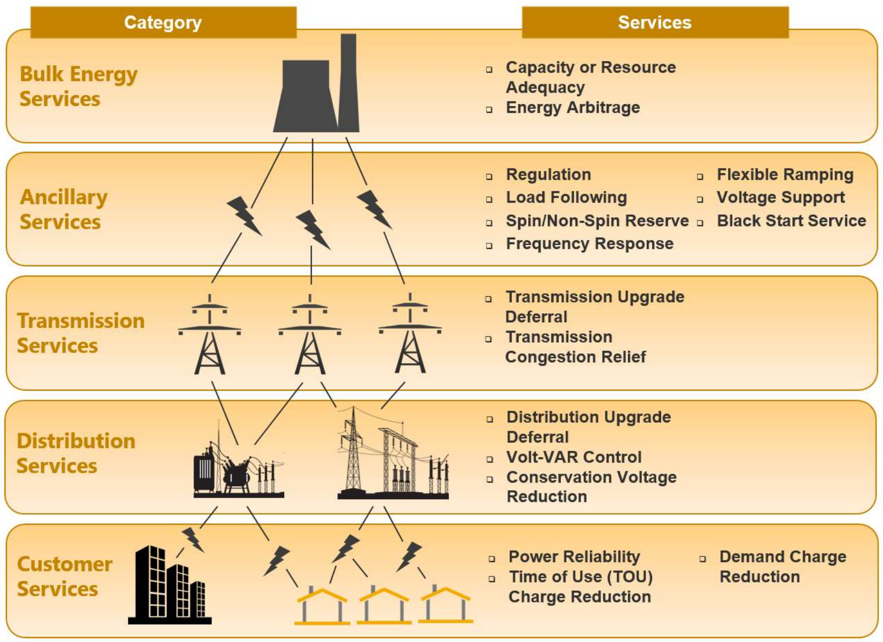
**Policy / Standardization**

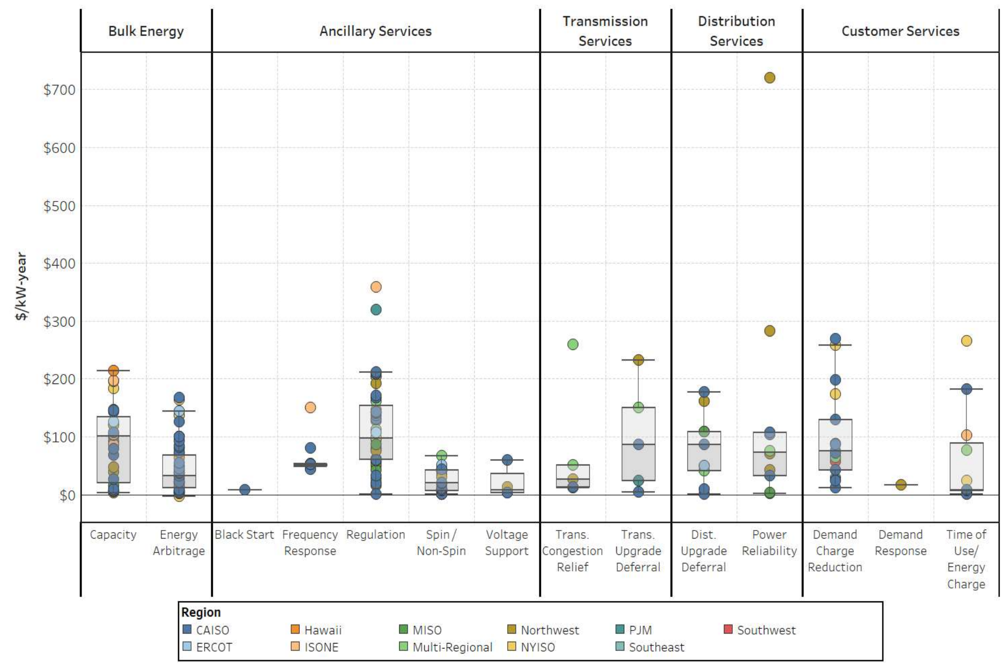
Establish formal rules and valuations mechanisms (e.g., through FERC orders or accreditation frameworks)

**Compensation**

Facilitate monetization of the service by implementing incentive mechanisms or update to modeling in IRP process

# META-ANALYSIS RESULTS




Source: Balducci, Patrick, Mongird, Kendall, and Weimar, Mark. Understanding the Value of Energy Storage for Power System Reliability and Resilience Applications. Germany: N. p., 2021. Web. https://doi.org/10.1007/s40518-021-00183-7.

# CASE EXAMPLE: FREQUENCY REGULATION

## An illustration of the progression from concept to compensation

| | |
|---|---|
| ***Concept*** | Recognition that multiple technologies can provide frequency regulation, which may differ in the quality of service |
| ***Quantification*** | Methodologies and models were developed to assess the relative value of frequency regulation across technologies, showing that both capacity (MW) and ramp rate are important |
| ***Economic Valuation*** | Pilots and studies estimated the monetary value of regulation and informed payment design; compensation based on movement, MW, and accuracy |
| ***Policy Status*** | FERC Order 755 introduced performance-based compensation for fast-responding resources |
| ***Compensation*** | Frequency regulation is compensated in current markets based on capacity, duration, movement, and performance (accuracy and response time) |

# MAPPING LDES SERVICES ACROSS COMPENSATION STAGES

| Category | LDES Service | Conceptualization | Quantification | Economic Valuation | Policy / Standardization | Compensation |
|---|---|---|---|---|---|---|
| Bulk Energy | Capacity | +++ | ++ | ++ | ++ | ++ |
| | Energy Arbitrage | +++ | ++ | ++ | ++ | ++ |
| Ancillary Services | Frequency Regulation | +++ | +++ | +++ | +++ | +++ |
| | Spin / Non-Spin Reserve | +++ | ++ | ++ | ++ | ++ |
| | Flexible Rampling | +++ | +++ | +++ | +++ | +++ |
| | Black Start | +++ | ++ | ++ | ++ | ++ |
| | Voltage Support | +++ | ++ | + | + | + |
| Stability Services | Critical Inertia | +++ | + | + | + | + |
| | Transient Stability | +++ | + | + | + | + |
| | Small Signal Stability | +++ | + | + | + | + |
| | Resilience / Reliability | +++ | + | + | + | + |
| | Frequency Response | +++ | ++ | ++ | + | + |
| Transmission | Transmission Deferral | +++ | +++ | +++ | + | + |
| | Transmission Congestion Relief | +++ | +++ | +++ | + | + |
| Distribution | Distribution Deferral | +++ | +++ | +++ | + | + |
| | Volt-VAR/CVR | +++ | + | + | + | + |
| Customer Energy Management | Power Reliability | +++ | +++ | ++ | ++ | ++ |
| | Time-of-Use Energy Charge Reduction | +++ | +++ | +++ | ++ | ++ |
| | Demand Charge Reduction | +++ | +++ | +++ | ++ | ++ |
| | Grid Flexibility | +++ | + | + | + | + |

**KEY: +++ mature at this stage; ++ activity exists but potential for improvement; + early-stage activity at this stage**

# KEY TAKEAWAYS FROM THE ASSESSMENT

- Energy arbitrage and capacity are compensated today, but existing market mechanisms do not fully align with LDES operational characteristics, leaving room for improved valuation and compensation
- Some ancillary services are already compensated, but coverage remains incomplete across the full range of services that LDES can provide
- Stability services remain at an early stage, with quantification still developing and limited pathways toward valuation and compensation
- Transmission-related services are increasingly recognized and valued, but policy frameworks and compensation mechanisms remain underdeveloped
- Behind-the-meter applications can already deliver value to end users, but compensation for services provided to the broader grid is still limited

# DISCUSSION AND FEEDBACK

- Is the proposed taxonomy an appropriate framework for assessing how LDES services progress from technical capability to compensation?
- Do the key takeaways from the assessment align with your intuition and experience, or are there areas that should be revised?
- Are there important LDES services, use cases, or distinctions that are missing from the current framework?
- Which services appear most promising for near-term progress toward improved valuation or compensation?
- Where do you see the largest gaps between recognized system value and current compensation mechanisms?

# BULK ENERGY

| Category | LDES Service | Conceptualization | Quantification | Economic Valuation | Policy / Standardization | Compensation |
|---|---|---|---|---|---|---|
| **Bulk Energy** | Capacity | +++ | ++ | ++ | ++ | ++ |
| | Energy Arbitrage | +++ | ++ | ++ | ++ | ++ |

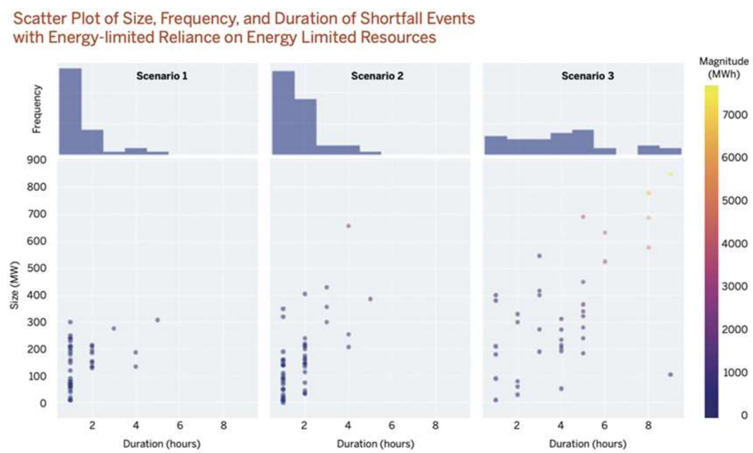
# CAPACITY

- Concept: LDES enhances resource adequacy by providing multi-hour to multi-day backup, replacing or deferring firm generation capacity.[1]
- Quantification: ELCC and other methods for capacity accreditation that differentiates across technologies; measures how much reliable capacity in MW a resource can provide to the power system relative to baseline LOLE.[2] *Is ELCC an appropriate metric?*
- Economic Valuation: Revenue-based capacity valuation, net CONE valuation, capacity auction results, etc.; a dollar value of the capacity is determined and multiplied by its accreditation value. [3]
- Policy Status: Capacity accreditation methods do not differentiate storage resources with greater than 10 hours duration.[4]
- Compensation: Storage beyond 10 hours are undervalued based on current market practices, ongoing research to evaluate magnitude of this gap; updates to temporal resolution in modeling also ongoing.

1. (Sepulveda et al. 2018); (Albertus et al. 2020); (Sepulveda et al. 2021);
2. (Schlag et al. 2020)
3. (Balducci et al. 2020) and (Balducci et al. 2022)
4. (PJM 2025), (PJM 2024A), (PJM 2024B); (NYISO 2024A) and (NYISO 2024B); (ISO-NE 2024); (CAISO 2024); (MISO 2024) and (MISO 2025); (SPP 2024); (ERCOT 2025); (CPUC 2024); (PJM 2024C)

# NEW RESOURCE ADEQUACY METRICS WOULD MORE CLOSELY CAPTURE ROLE LDES CAN PLAY IN SUPPORTING RELIABILITY

## Three Scenarios with the Same LOLE but Varied Reliability Needs

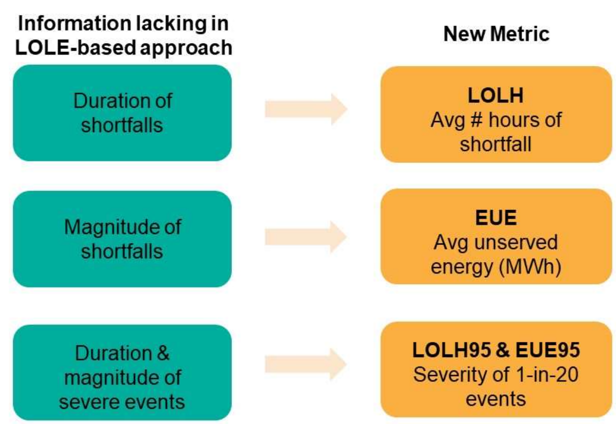



Redefining Resource Adequacy for Modern Power Systems (ESIG, 2021)

Balducci, P. and P. Levi (2024). *Improved Reliability and Resilience Valuation: Approaches and Metrics.* LDES National Consortium Annual Workshop. Commerce, CA.

| Event Characteristic | Metric Affected | California Aug 2020 | Texas Feb 2021 | Difference |
|---|---|---|---|---|
| Number of Events | LOLEv | 2 events | 1 event | -50% |
| Number of Days | LOLE | 2 days | 3 days | +50% |
| Number of Hours | LOLH | 6 hours | 71 hours | +1,083% |
| Unserved Energy | EUE | 2,700 MWh | 990,000 MWh | +36,567% |
| Max Shortfall | - | 1,072 MW | 20,000+ MW | +1,766% |

*Beyond 1-day-in-10-years: : Measuring Resource Adequacy for a Grid in Transition*. November 29, 2021 by Derek Stenclik - Telos Energy. https://www.esig.energy/beyond-1-day-in-10-years-measuring-resource-adequacy-for-a-grid-in-transition/




Key Lesson: Resource Adequacy Metrics and Market Rules are in Need of Revision

# ENERGY ARBITRAGE

- Concept: LDES enables the grid to shift energy over days, weeks, or even seasons.[1]
- Quantification: Estimates, over a given time horizon (days, weeks, seasons), the amount of energy in MWh that LDES can shift under system cost minimization objectives.[1]
- Challenges to economic valuation:
  - In the energy market, participants engaging in energy arbitrage typically rely on short-term price signals, such as intraday price fluctuations [2]
  - Modeling need to extended temporal resolution in LDES systems[3]
- Policy Status: FERC Orders 841 allows for storage participation in the energy market.[3]
- Compensation: Short term price spreads does not align with LDES operational characteristics or even grid needs and they ignore threats caused by extended energy deficit periods; updates to temporal resolution in modeling also ongoing.

1. (Albertus et al. 2020); (Andresen et al. 2014); (Denholm et al. 2021); (Dowling et al. 2020);
2. (Bhatnagar et al. 2022)
3. (Bistline et al. 2020); (Bistline 2021); (Gonzato et al. 2021); (Jafari et al. 2020)
4. (FERC 2018)

# ANCILLARY SERVICES

| Category | LDES Service | Conceptualization | Quantification | Economic Valuation | Policy / Standardization | Compensation |
|---|---|---|---|---|---|---|
| **Ancillary Services** | Frequency Regulation | +++ | +++ | +++ | +++ | +++ |
| | Spin / Non-Spin Reserve | +++ | ++ | ++ | ++ | ++ |
| | Flexible Rampling | +++ | +++ | +++ | +++ | +++ |
| | Black Start | +++ | ++ | ++ | ++ | ++ |
| | Voltage Support | +++ | ++ | + | + | + |

# FREQUENCY REGULATION

- Concept: Notrees Wind Farm - Energy storage equipment can supply Fast-Responding-Regulation-Service to the grid.[1]
- Quantification: Annual capacity commitment for frequency support in MW + energy and performance based measures (ramp rate – MW/min, duration, accuracy).[2]
- Economic Valuation: FERC Order 755 allows for two-part payment: Capacity + performance pay; performance based on duration, movement, accuracy and response time.[2, 4]
- Policy Status: FERC Order 755 introduced performance-based compensation for fast-responding frequency regulation services.[3]
- Compensation: PJM Reg D specifies performance pay metrics as stated above.[4]

1. (Wehner et al. 2015)
2. (Balducci et al. 2022)
3. (FERC 2011)
4. (PJM 2025)

# SPIN/NON-SPIN RESERVE

- Concept: Standby capacity from generating units already synchronized to the grid that can ramp up within 10 minutes (spin). Off-line capacity (or demand reduction) that can be synchronized and ramped up within 10 minutes (non-spin).
- Quantification: Online/offline capacity (MW) available that can increase output immediately after contingency; spinning reserve quantities co-optimized with energy services in PMAT model.[2]
- Economic Valuation: Ancillary service prices from ISO/RTOs; capacity payment for MW procured during commitment period + performance payment for deployed energy per MWh.[1]
- Policy Status: Minimum requirements under reliability standards.
- Compensation: Via ancillary service markets but not differentiated across technologies or performances.

1. (Balducci et al. 2022)

# FLEXIBLE RAMPING

- Concept: Introduces power system operational flexibility and the need for Flexible-Ramping-Product to address load variability and uncertainty.[1]
- Quantification: Outcome-based metrics that use a demand curve reflecting willingness to pay, and capacity-based metrics that procure a specified amount of ramping capability (MW). These metrics are defined by ramp magnitude (MW) and ramp frequency (time)..[1, 3]
- Economic Valuation: Capacity price for ramping capacity available for a given amount of time ($/MW for five minute intervals); energy deployed is compensated in $/MWh, market clearing prices are the opportunity costs to meet ramp capability requirements. [3, 4]
- Policy Status: FERC Approves New Flexible Ramping Product for CAISO.[2]
- Compensation: Flexible ramping product in CAISO[3], MISO[4], and SPP[4]

1. (Wang and Hodge 2016) (Huber et al. 2014)
2. (Devita and Archuleta 2016)
3. (CAISO 2024) (CAISO 2023)
4. (C. Wang et al. 2016) (Parker 2015)

# BLACK START

- Concept: Inverter based potential for black start, may improve resilience from distributed generation.[1]
- Quantification: Capacity (MW) available at least 90% of a predetermined time interval for black start services. [2]
- Economic Valuation: Cost-of-service valuation for Goldendale PSH; cost-of-service comprised of fixed costs (net CONE), variable costs (fuel, etc.), cost of training, fuel storage, and site-specific incentives.[2]
- Policy Status: Minimum requirements under reliability standards.
- Compensation: PJM, MISO, CAISO, NYISO use cost-of-service approach as defined above. [2] ISO-NE and ConEd territory of NYISO receive compensation based on a flat rate and claimed capacity. ERCOT pay an hourly standby fee and relies on a competitive bidding process.

1. (Jain et al. 2020); https://docs.nrel.gov/docs/fy22osti/82258.pdf; https://docs.nrel.gov/docs/fy20osti/75327.pdf;
2. (Balducci et al. 2022)

# VOLTAGE SUPPORT

- Concept: Recognition that inverter-based resources may result in deviations in voltages during fault events and the role of storage as a potential solution is discussed.[1]
- Quantification: Voltage support capability is quantified by the reactive power (kVAR or MVAr) that a PSH unit can inject or absorb during voltage disturbances.[1, 2]
- Economic Valuation: No standalone markets for voltage support, value is approximated using existing reactive power tariffs in NYISO, ISO-NE, and PJM. Alternative valuation approaches estimate the reliability benefit from avoided voltage violations or reduced unserved energy. [2]
- Policy Status: Minimum requirements under reliability standards.
- Compensation: Reactive power requirements exists but no revenue mechanisms exist.[3]

1. (Lin et al. 2024); (Energy Systems Integration Group 2024); (Ahmed et al. 2023)
2. (Balducci et al. 2022)
3. (Cova Acosta 2025); (CAISO 2015)

# STABILITY SERVICES

| Category | LDES Service | Conceptualization | Quantification | Economic Valuation | Policy / Standardization | Compensation |
|---|---|---|---|---|---|---|
| **Stability Services** | Critical Inertia | +++ | + | + | + | + |
| | Transient Stability | +++ | + | + | + | + |
| | Small Signal Stability | +++ | + | + | + | + |
| | Resilience / Reliability | +++ | ++ | + | - | + |
| | Frequency Response | +++ | ++ | ++ | + | + |

# CRITICAL INERTIA

- Concept: Transition to inverter-based resources do not provide inertia, but energy storage resources such as pumped storage and compressed air, can also use synchronous generators or pumps that can add inertia to the system.[1]
- Quantification: Recent modeling estimates minimum inertia needs and shows that storage can deliver synthetic inertia; minimum system inertia measured in megawatt-seconds (MWs).[2]
- Economic valuation: Some ongoing research on the economic valuation of inertia; payments for minimum inertia requirements + operational incentives for additional inertia services that benefit the grid; spot markets, auctions, contracts are all considered for payments per MWs; fixed cost is MWs/year and variable cost is MWs/hour.[2, 3]
- Policy Status: ISOs have methods that determine minimum levels of system inertia, recent report from the EU assesses policy options for securing inertia.[4]
- Compensation: No market for inertia currently exists, research in ongoing to explore the cost and value of critical inertia services.

1. (Denholm et al. 2020)
2. (Yang et al. 2024); (Hasan et al. 2024); (Koritarov and Uria-Martinez 2026)
3. (Dann 2024); (Xu et al. 2016); (Zhou et al. 2023); and (Badesa et al. 2017)
4. (ERCOT 2018); (Engie 2025); and (Sneha et al. 2025)

# TRANSIENT STABILITY

- Concept: LDES supports the grid during transient stability events by modulating their power output according to the nature of disturbance.[1]
- Quantification: Measured in Critical Clearing Time (CCT) in seconds after faults on major tie-lines; LDES enhances transient stability when in turbine mode with higher CCT relative to baseline.[1]
- Economic Valuation: No standard service associated with small-signal and transient stability attributes.
- Policy Status: NERC reliability standards require evaluation and maintenance of transient stability following major disturbances, with additional requirements emerging for inverter-based resource ride-through and dynamic performance.[2]
- Compensation: No compensation mechanism for transient stability currently exists.

1. (Balducci et al. 2022)
2. (NERC TPL-001) (FERC Order No. 901).

# SMALL SIGNAL STABILITY

- Concept: PSH plants affect the small-signal stability of the overall system through their inertia. Increasing inverter-based resource penetration can reduce system damping and introduce oscillatory modes. Battery storage can improve small-signal stability by modulating active power to damp these oscillations.[1, 2]
- Quantification: Damping ratio from Prony analysis can be used to determine how PSH can improve damping.[1] Value can be quantified by improvements in system oscillation damping, including increased damping ratios and reduced inter-area oscillation magnitude through active power modulation by storage. [2]
- Economic Valuation: No standard service associated with small-signal and transient stability attributes.
- Policy Status: NERC guidelines and FERC requirements drive validated IBR modeling and small-signal stability assessments to evaluate control interactions and mitigate oscillatory risks. [3]
- Compensation: No compensation mechanism for small signal stability currently exists.

1. (Balducci et al. 2022)
2. (Neely et al. 2013)
3. (ETM Guideline 2023) (FERC Order No. 2023)

# RESILIENCE

- Concept: LDES enables the grid to maintain power during and after extreme weather disruptions, reducing likelihood for multi-hour to multi-day outages.[1]
- Challenge to quantification: Extensive research on how LDES can enhance grid resilience under a range of system types and uncertainties; resilience could be measured based on MWh of unserved energy and value of lost load and many other approaches; technologies may differ in performance under different scenarios. [1]
- Challenge to economic valuation: Economic benefits of LDES are difficult to precisely quantify and no standard method exists for valuation. [2]
  - Stated Preference, Value of Lost Load (VoLL), Loss of Load Expectation (LOLE), input-output analysis, computable general equilibrium analysis, and scenario analysis of economic impact of outages.
- Policy Status: The concept of "resilience" is recognized in policy but no standardized wholesale market product currently compensates for resilience.[3]
- Compensation: Monetization currently through grants, resilience-driven procurements, etc.[4]

1. (Albertus et al. 2020b); (Twitchell et al. 2023); (Ruhnau and Qvist 2022); (Dowling et al. 2020)
2. (Balducci et al. 2021a); (Macmillan et al. 2023); (Anderson et al. 2019)
3. https://www.energy.gov/eere/energy-reliability-and-resilience
4. https://www.energy.gov/gdo/grid-resilience-utility-and-industry-grants, https://www.commerce.wa.gov/epic/grid-resilience

# FREQUENCY RESPONSE

- Concept: Recognition that low-inertia grids needs fast acting resources for frequency response.[1]
- Quantification: Frequency response is measured in MW per 0.1 Hz change in system frequency (MW/0.1Hz); can be measured as annual capacity allocated for frequency response (kW-year).[2]
- Economic Valuation: CAISO contracts frequency response with third parties, public markets currently do not exist for this service; contract price is ~$2m for 50 MW/0.1 Hz or $44 / kW-year.[3]
- Policy Status: NERC BAL-003-1.1 – Requires sufficient Frequency Response from the Balancing Authority to maintain Interconnection Frequency within predefined bounds. FERC Order 819 – allow the sale of frequency response service at market-based rates.[4]
- Compensation: ERCOT has introduced fast frequency response (FFR) as a new ancillary service but it is compensated the same as other response reserve services.[5]

1. (Yan et al. 2025); (Task 2020)
2. (Lavi and Apt 2023); (Poolla et al. 2019); (Vatsal et al. 2025); (Duan et al. 2025); (Greenwood et al. 2017)
3. (Balducci et al. 2022)
4. (FERC 2015)
5. https://www.ercot.com/mktrules/pilots/frrs; (Cherry 2025)

# TRANSMISSION

| Category | LDES Service | Conceptualization | Quantification | Economic Valuation | Policy / Standardization | Compensation |
|---|---|---|---|---|---|---|
| **Transmission** | Transmission Deferral | +++ | +++ | +++ | + | + |
| | Transmission Congestion Relief | +++ | +++ | +++ | + | + |

# TRANSMISSION DEFERRAL

- Concept: Energy storage can reduce peak flows and defer transmission upgrades. [1]
- Quantification: Transmission deferral value from a risk-based optimal sizing model, which evaluates storage as a transmission alternative. It relates the size of the storage resource (MW and duration) to the corresponding transmission capacity (MW) deferred, measured over the time length of the deferral.[1, 2]
- Economic Valuation: Value is the difference between the cost of building the transmission line now versus building the line later; economic value can be calculated based on capital costs of upgraded lines, fixed charge rate, time length of deferral, time value of money parameters.[1, 2]
- Policy Status: FERC Order 1920 mandates consideration of deferring infrastructure, reducing congestion, mitigating extreme weather. LDES may gain more recognition in transmission planning.
- Compensation: No current market mechanism for compensation

1. (Balducci et al. 2022);
2. (Ralph et al. 2011); (Marnell et al. 2019); (Brown and Botterud 2020) and (Chu, Baik, and Benson 2016)

# TRANSMISSION CONGESTION RELIEF

- Concept: Energy storage can reduce transmission congestion by shifting energy flows and deferring transmission upgrades..[1]
- Quantification: Storage value is assessed through grid models that optimize energy market participation and congestion relief; benefits are measured by reduced congestion hours and required storage capacity (MW/MWh).[1,2]
- Economic Valuation: Value is estimated through avoided congestion costs, reduced system costs, and deferred transmission investments. [1]
- Policy Status: FERC Order 1920 mandates consideration of deferring infrastructure, reducing congestion, mitigating extreme weather. LDES may gain more recognition in transmission planning.
- Compensation: Financial Transmission Rights (FTRs) are financial tools that hedge against transmission congestion costs. They pay the holder the difference in locational marginal prices (LMPs) between two locations, multiplied by the awarded FTR capacity. [3]

1. (Balducci et al. 2022)
2. (Arteaga et al. 2021); (Khani et al. 2015); (Tarashandeh and Karimi 2021); (Del Rosso and Eckroad 2013); (Brown and Botterud 2020) and (Chu, Baik, and Benson 2016)
3. (PJM 2020) (Muñoz-Álvarez and Bitar 2017)

# DISTRIBUTION

| Category | LDES Service | Conceptualization | Quantification | Economic Valuation | Policy / Standardization | Compensation |
|---|---|---|---|---|---|---|
| **Distribution** | Distribution Deferral | +++ | +++ | +++ | + | + |
| | Volt-VAR/CVR | +++ | + | + | + | + |

# DISTRIBUTION DEFERRAL

- Concept: Capacity additions from modular storage on the margin may defer larger lump investment in transmission and distribution equipment for utilities.[1]
- Quantification: Deferral relates the size of the storage resource (MW and duration) to the corresponding distribution capacity (MW) deferred, measured over the time length of the deferral; quantification of deferral scenarios are based on inputs such as upgrade costs, demand projections, and uncertainties; storage sizing, power output, discharge duration, and reliability are estimated.[1]
- Economic Valuation: Economic valuation is based on the cost differences for distribution investment costs now versus later; estimation is based on capital and operational costs, length of deferral, and financial parameters.
- Policy Status: FERC Order 1920 mandates consideration of deferring infrastructure, reducing congestion, mitigating extreme weather. LDES may gain more recognition in transmission planning.
- Compensation: No current market mechanism for compensation

1. (Eyer 2009)

# VOLT-VAR/CVR

- Concept: LDES resources can provide Volt-VAR and CVR services because their inverters supply fast, precise reactive power to regulate voltage.[1]
- Quantification: The system’s power rating (MW/kVA) determines the maximum MVAR support available, while the energy capacity (MWh) primarily affects duration and does not limit voltage services.[2]
- Economic Valuation: Research on the economic value of LDES providing Volt-VAR and CVR services is relatively limited. Where quantified, valuation is typically based on customer damage functions or avoided energy and reliability costs. [3]
- Policy Status: Real-time procurement of reactive power through a formal market mechanism is not currently implemented. [4]
- Compensation: No current market mechanism for compensation.[4]

1. (Gholami et al. 2022) (Petinrin and Shaabanb 2016)
2. (Ingebrigtsen et al. 2026)
3. (Patrick Balducci et al. 2021b)
4. (Jay and Swarup 2021)

# CUSTOMER ENERGY MANAGEMENT

| Category | LDES Service | Conceptualization | Quantification | Economic Valuation | Policy / Standardization | Compensation |
|---|---|---|---|---|---|---|
| **Customer Energy Management** | Power Reliability | +++ | +++ | ++ | ++ | ++ |
| | Time-of-Use Energy Charge Reduction | +++ | +++ | +++ | ++ | ++ |
| | Demand Charge Reduction | +++ | +++ | +++ | ++ | ++ |
| | Grid Flexibility | +++ | + | + | - | - |

# POWER RELIABILITY

- Concept: Behind-the-meter ESS can improve customer reliability by providing backup power during grid outages, reducing outage impacts and unserved energy costs.[1]
- Quantification: Reliability contribution is measured by storage power (MW), energy capacity (MWh), and duration relative to critical load requirements.[2]
- Economic Valuation: Reliability value is typically estimated using customer damage functions and Value of Lost Load (VoLL), which quantify avoided outage costs. [3]
- Policy Status: No specific regulatory framework currently requires procurement of behind-the-meter LDES for reliability services.
- Compensation: No market mechanism directly compensates behind-the-meter storage for outage mitigation; customers capture value through avoided outage costs and resilience benefits.

1. (Rezaeimozafar et al. 2022)
2. (Angizeh et al. 2021)
3. (Patrick Balducci et al. 2021b)

# TIME-OF-USE (TOU) CHARGE REDUCTION

- Concept: Reducing customer charges for electric energy when the price is specific to the time (season, day of week, time-of-day) when the energy is purchased.[1]
- Quantification: The value is typically calculated as the amount of energy shifted (MWh) multiplied by the difference between high and low TOU tariffs.[2]
- Economic Valuation: Similarly, the economic benefit is the energy shifted (MWh) times the tariff difference between charge and discharge periods.[2]
- Policy Status: here is currently no policy or regulatory framework that explicitly governs the procurement of behind-the-meter LDES for TOU charge reduction.
- Compensation: No formal market mechanisms exist to compensate storage for TOU price reduction. Customers effectively benefit from bill reduction based on tariff structure.

1. (Rezaeimozafar et al. 2022)
2. (Babacan et al. 2017)

# DEMAND CHARGE REDUCTION

- Concept: Demand charge reduction refers to using an LDES system to reduce the maximum power drawn by a customer's electric load, thereby avoiding peak demand charges.[1]
- Quantification: The benefit is quantified as the reduction in peak energy demand (MW) achieved by the LDES system.[2]
- Economic Valuation: The economic value is calculated as the peak demand reduction multiplied by the applicable demand charges.[2]
- Policy Status: here is currently no policy or regulatory framework that explicitly governs the procurement of behind-the-meter LDES for demand charge reduction.
- Compensation: No formal market mechanisms exist to compensate storage for demand charge reduction. Customers effectively benefit from bill reduction based on tariff structure.

1. (Rezaeimozafar et al. 2022)
2. (Babacan et al. 2017)

# GRID FLEXIBILITY AND INTEGRATED PLANNING

- Concept: Grid flexibility refers to the coordinated operation of behind-the-meter storage and other resources to support both data center operations and broader grid management, enabling integrated planning and load shaping.[1]
- Quantification: The primary benefit is a reduction in peak demand, though the specific contribution of storage and the precise quantification of its impact have not been fully established.[2]
- Economic Valuation: The economic value of behind-the-meter storage for integrated data center and grid flexibility has not been clearly quantified in published research, as its role remains largely conceptual. Some preliminary studies discuss profit-sharing mechanisms for system-level coordination of data centers, but these do not specifically address compensation for storage.[3]
- Policy Status: There is currently no policy or regulatory framework that explicitly governs the procurement of behind-the-meter LDES for data center/grid flexibility services.
- Compensation: No formal market mechanisms exist to compensate storage for these services. Customers invest in systems based on their own estimates of potential value, such as avoided peak charges or operational efficiencies.

1. (Takci et al. 2025) (Guo et al. 2021)
2. (Knittel et al. 2025)
3. (S. Zhou et al. 2024)

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# CONTACT INFORMATION


**Patrick Balducci**

pbalducci@anl.gov

503-679-7316

**Bo Cheng**

bcheng@anl.gov

847-987-2454