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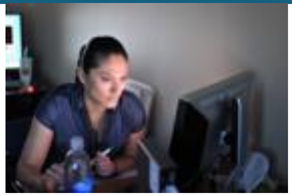
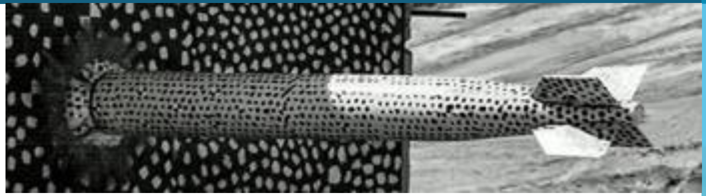
VALUATION OF ENERGY STORAGE: PROBLEMS, METHODOLOGIES AND SOFTWARE TOOLS





PRESENTED BY

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OUTLINE

- Energy storage applications
- Valuation analysis of energy storage
- Energy storage valuation problems:
  - Market problem
  - Generation problem
  - Transmission problem
  - Behind-the-meter problem
  - LDES problem
- Software tools

ENERGY STORAGE APPLICATIONS – POWER VS. ENERGY

- Power applications
  - Frequency regulation
  - Voltage support
  - Small signal stability
  - Renewable smoothing
- Energy applications
  - Energy arbitrage
  - Renewable energy time shift
  - Customer demand charge reduction
  - Transmission and distribution upgrade deferral

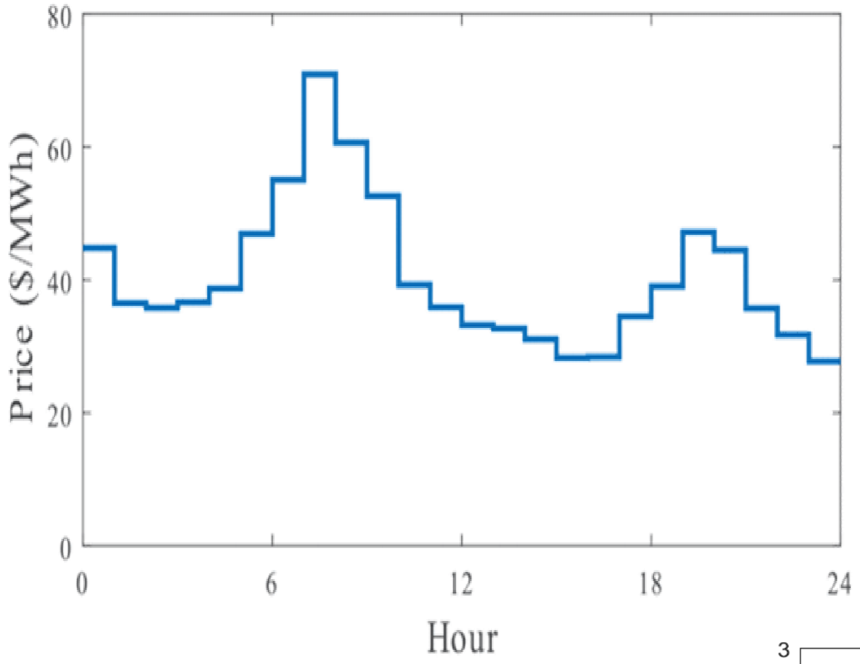
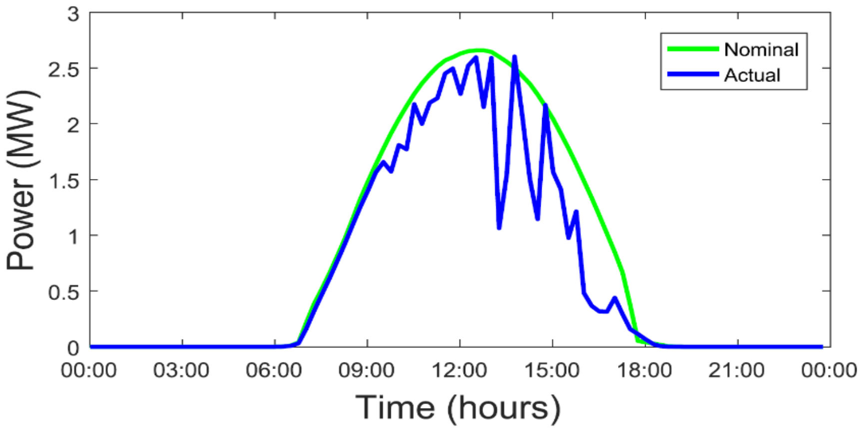


Image Credit - *Solar Power World*



ENERGY STORAGE APPLICATIONS – FTM VS. BTM

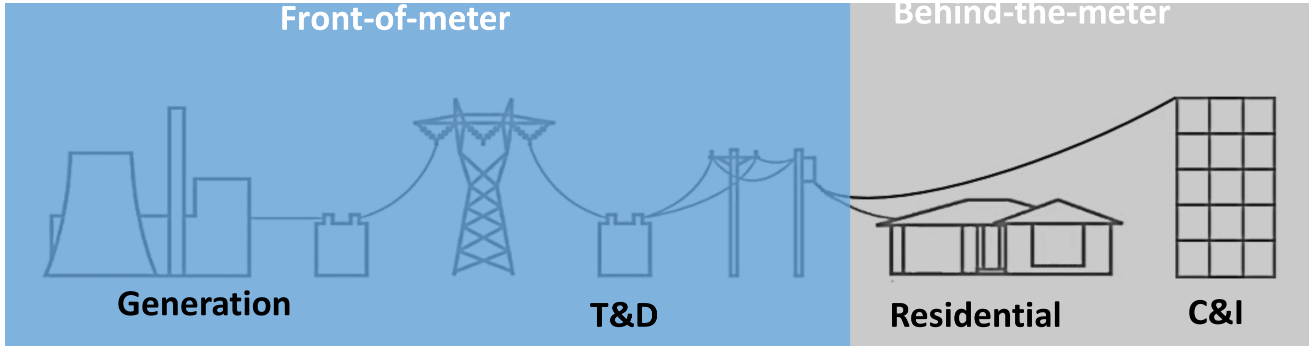


Image Credit: Navigant

- **Behind-the-meter** refers to the systems that are located at the customers' sites (homes, commercial and industrial facilities). BTM systems are usually owned by customers and intended for customers' use.

VALUATION ANALYSIS OF ENERGY STORAGE

- Identify revenue streams: what are the possible services that an ESS can provide?
- Select the right ES technology to provide those services.
- Evaluate the overall economic gain given the limits in performance of the selected storage technology.

ENERGY STORAGE VALUATION – MARKET PROBLEM

Given an energy storage device, an electricity market with a certain payment structure, and market data, how would the device maximize the revenue generated and provide value?

$$\max \sum_i \Big(\underbrace{\lambda_i (q_i^d - \eta_c q_i^r)}_{\text{arbitrage}} + \underbrace{q_i^{ru} (\lambda_i^{ru} + \delta_i^{ru} \lambda_i)}_{\text{regulation up}} + \underbrace{q_i^{rd} (\lambda_i^{rd} - \delta_i^{rd} \lambda_i)}_{\text{regulation down}} \Big) e^{-Ri}$$

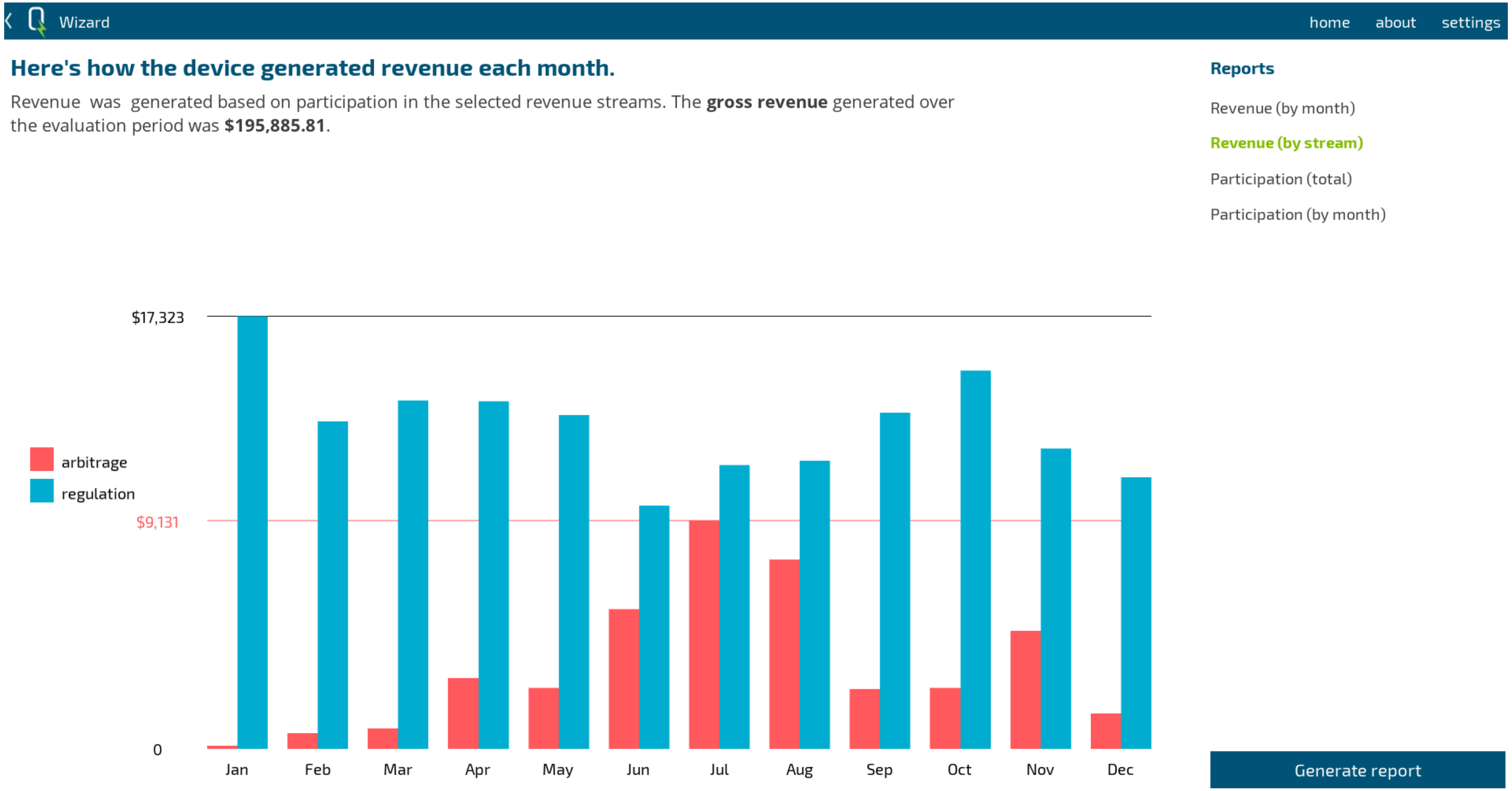
subject to:

$s_{i+1} = \eta_s s_i + \eta_c q_i^r - q_i^d + \eta_c \delta_i^{rd} q_i^{rd} - \delta_i^{ru} q_i^{ru}$	state of charge definition
$0 \le s_i \le \bar{S}$	state of charge limits
$q_i^d + q_i^r + q_i^{ru} + q_i^{rd} \le \bar{Q}$	power/energy charged limits

- Other constraints, such as requiring the final SoC to equal the initial SoC or reserving energy capacity for resiliency applications can be set.
- Varies based on market and available value streams

ENERGY STORAGE VALUATION – MARKET PROBLEM - EXAMPLE

The maximum revenue for arbitrage and frequency regulation of a 2MW/8MWh Li-ion BESS in MISO.



ENERGY STORAGE VALUATION – GENERATION PROBLEM

Given an energy storage device, a utility generation fleet, how would the device minimize operating cost of this generation fleet while meeting its load?

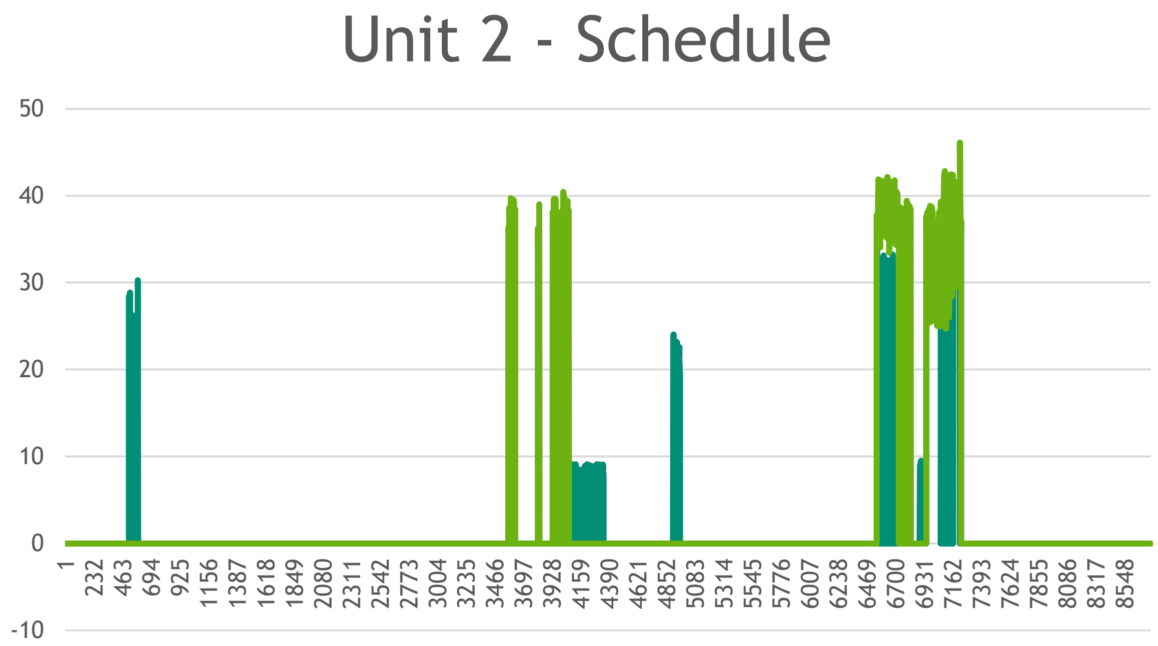
$$\min C = \sum_{i=1}^{24} \sum_{g=1}^{N} (f_g^i(P_g^i) cf_g + s_g^i cs_g + \alpha_g^i om_g)$$

- $f_g(P_g^i)$ is the fuel consumption of thermal unit g after time period i based on its power output P_g^i. cf_g is the fuel price for unit g
- s_g^i is a binary variable that indicates unit g starts at time i or not. cs_g is the start-up cost of unit g.
- α_g^i is a binary variable that indicates the status of unit g at time i. om_g is the variable O&M cost of unit g.

ENERGY STORAGE VALUATION – GENERATION PROBLEM - EXAMPLE

Case studies are conducted to evaluate the operating cost savings by using ESSs for a utility company in Alaska:

- 1 combined cycle, 4 gas units
- Minimum spinning reserve: 10MW if not islanded, 40MW if islanded.
- Natural gas price: 7.92/Mcf.
- Variable O&M cost and start-up cost for each unit are given in the following table.



	Fuel Cost ($)	O&M Cost ($)	Start-up Cost ($)	Annual Total ($)	Annual Saving ($)
Case 1 - No ESS	31,015,209	1,238,940	154,150	32,408,299	
Case 2 - 40MW/10MWh	30,700,007	1,218,237	59,810	31,978,055	430,244
Case 3 - 40MW/20MWh	30,681,801	1,227,761	24,845	31,934,407	473,891
Case 4 - 40MW/40MWh	30,723,217	1,178,834	15,445	31,917,496	490,802

ENERGY STORAGE VALUATION – TRANSMISSON PROBLEM

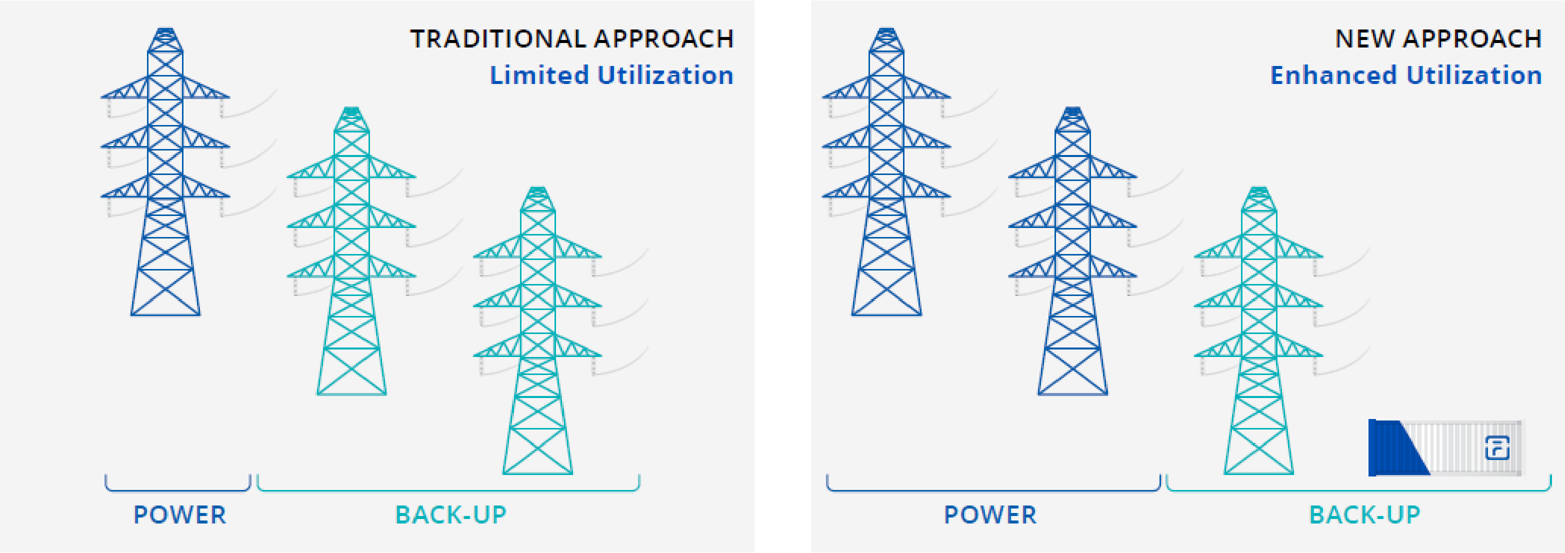
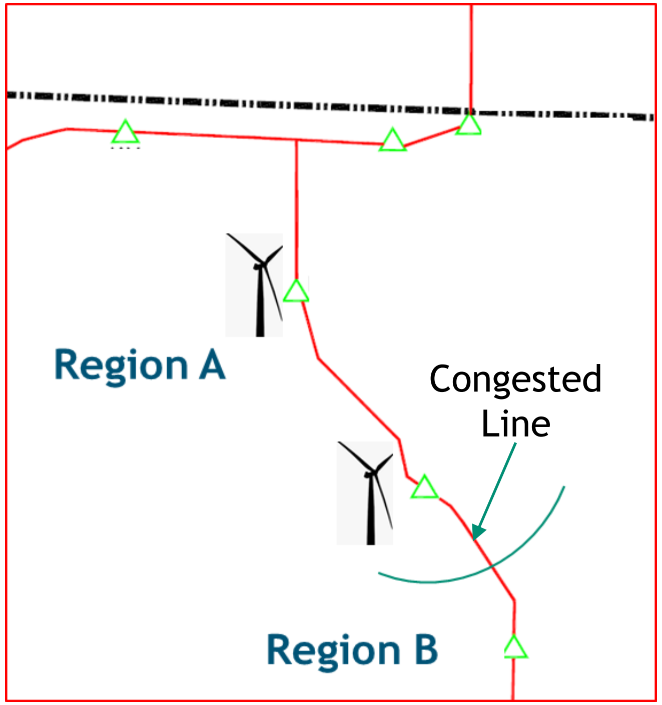
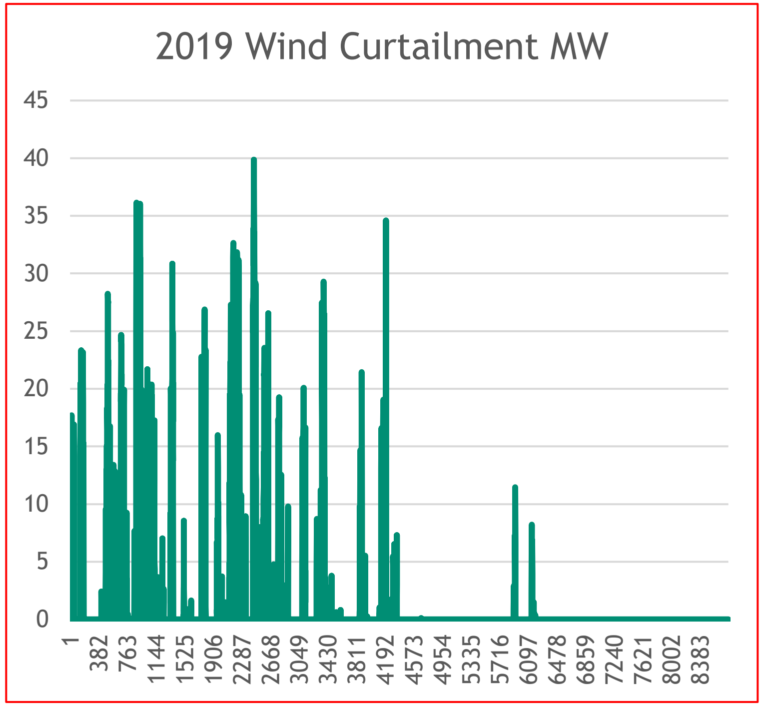


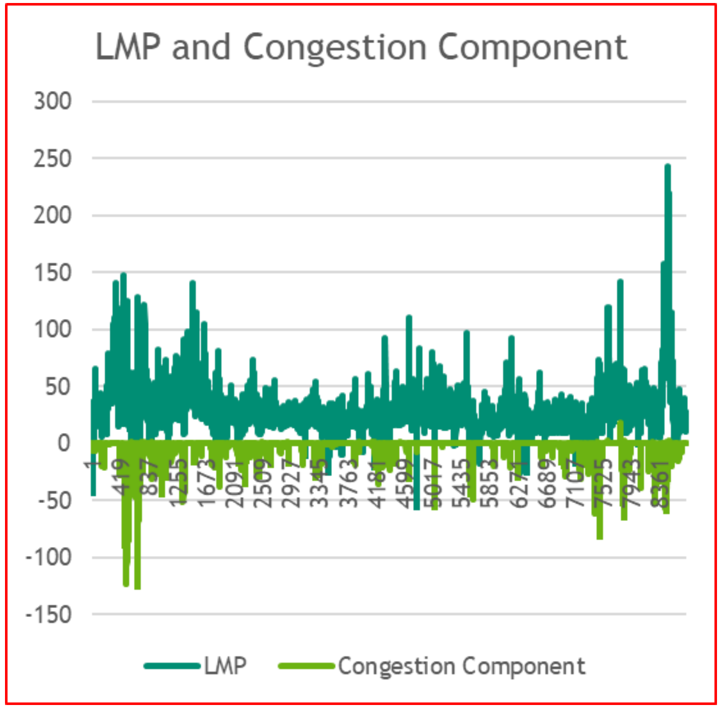
Image Credit: FLUENCE- Storage as Transmission White Paper

- Maximize the benefits from cost-base services together with market-based services:
  - Congestions relief: maximize opportunity for upstream generators to sell more energy at higher prices; minimize overall congestion cost
  - Market activities: energy arbitrage, ancillary services
- Evaluate the impact of virtual transmission in transmission planning: reduce the amount of transmission to meet N-1 security requirement.

ENERGY STORAGE VALUATION – TRANSMISSON PROBLEM - EXAMPLE



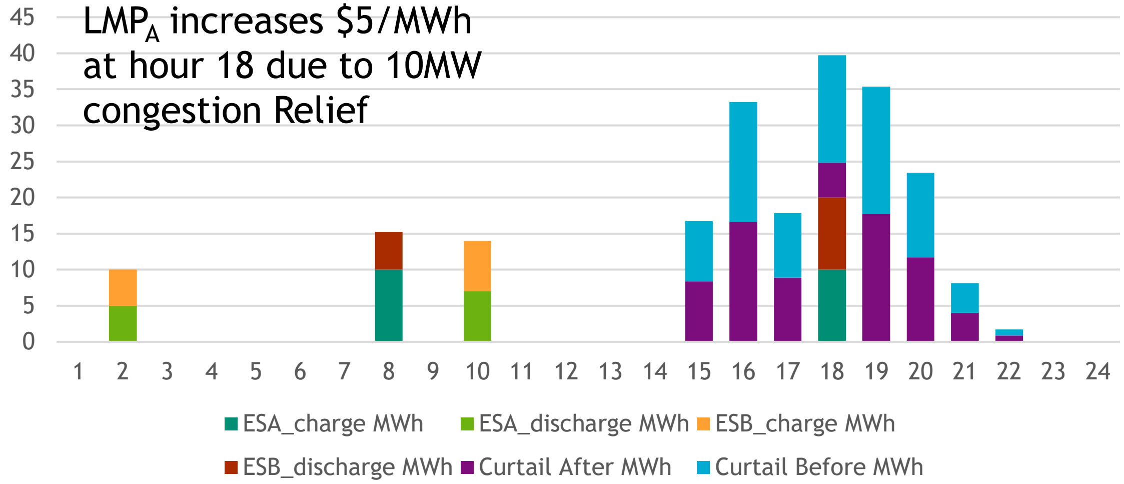




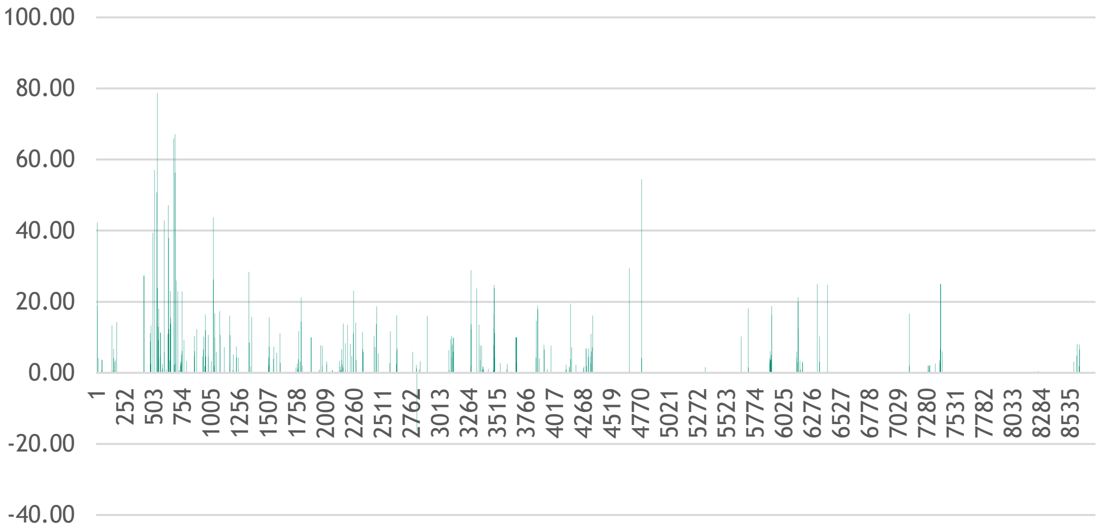
- Congestions make the marginal wind plant in region A curtail its output.
- Congestion component of LMP are negative indicating that if the congestions are relieved, more wind energy in region A can be sold to region B at higher LMPs
- In this case study:
  - Maximize the revenue for generators in region A by using storage as virtual transmission.
  - Compare with arbitrage benefit from wind curtailment.

ENERGY STORAGE VALUATION – TRANSMISSON PROBLEM - EXAMPLE

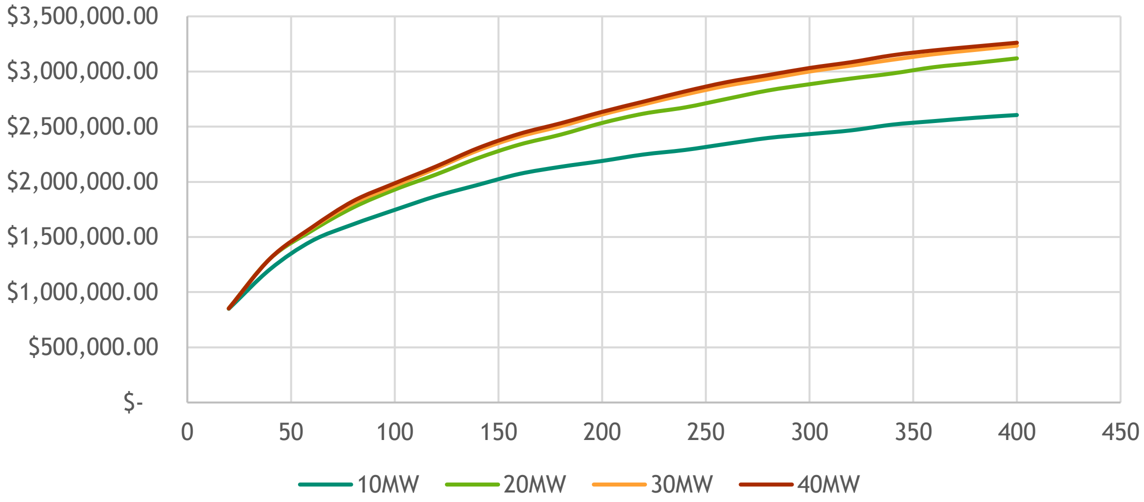
10MW/20Wh Case - Charge/discharge 24h Profile Example



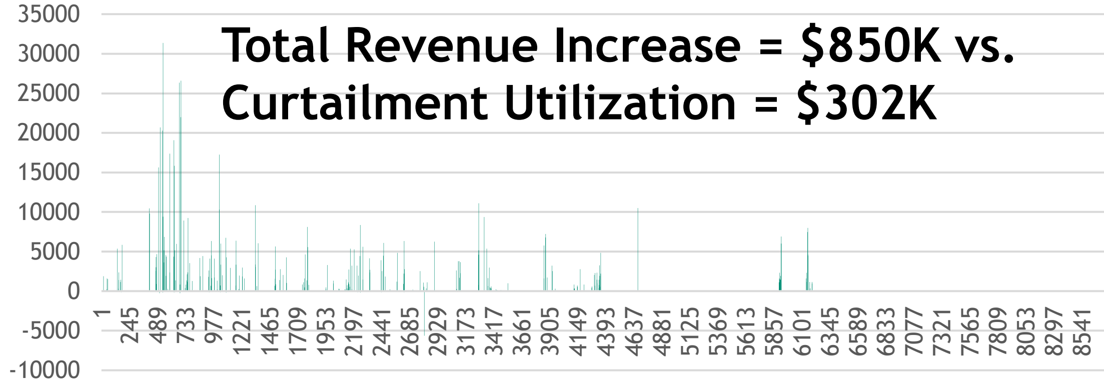
10MW/20Wh Case- LMP Improvement in $/MWh



Congestion Relieve Revenue $ vs. ESS size



10MW/20MWh Case - Region A Revenue Increase ($)



ENERGY STORAGE VALUATION – BTM PROBLEM

Given an energy storage device, a utility tariff structure, how would the device minimize the electricity bills for the customers?

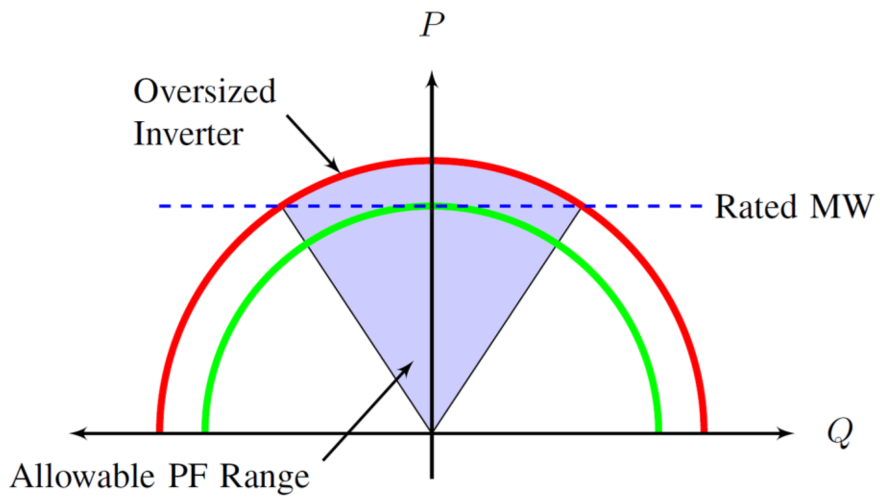
$$\min\{C_E^m + C_N^m + C_D^m\}$$

s.t. energy storage and inverter constraints

C_E^m is the energy charge of period m

C_D^m is the demand charge of period m

C_N^m (≤ 0) is the net metering charge of period m.



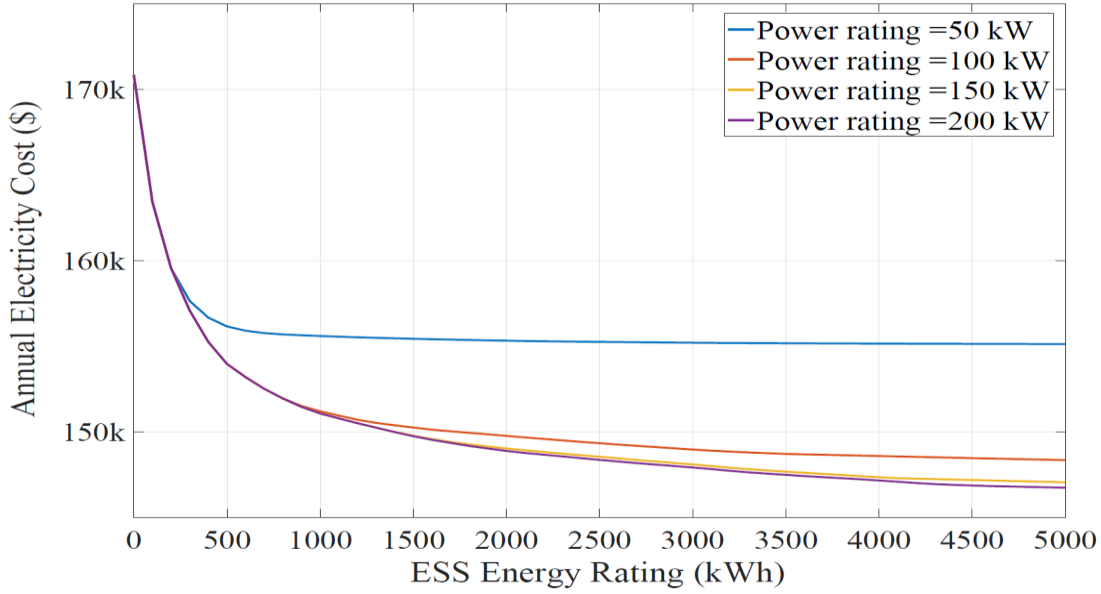
ENERGY STORAGE VALUATION – BTM PROBLEM - EXAMPLE

- An industrial customer in New Mexico is considered: a water treatment facility (300kW peak load) with 100kW PV.
- Fixed energy rate and TOU demand rate are applied.
- Penalty is applied for power factor lower than 0.9

Energy rate: $\text{pr} = 0.04537$ $[\$/kWh]$
Peak-hour (6am-9pm) demand rate: $\text{d}_{\text{pk}} = 24.69$ $[\$/kW]$
Off-peak (9pm-6am) demand rate: $\text{d}_{\text{opk}} = 6.12$ $[\$/kW]$
Net-metering rate: $\text{pr}_{\text{s}} = 0.03[\$/kWh]$

Case 1: TOU management without power factor correction

Case 2: TOU management with power factor correction



- Optimal size: 200kW/1MWh.
- Total saving: $30k (16.8%)
- Peak demands have been shifted to off peak hours.

EMERGING PROBLEM – EVALUATING LDES

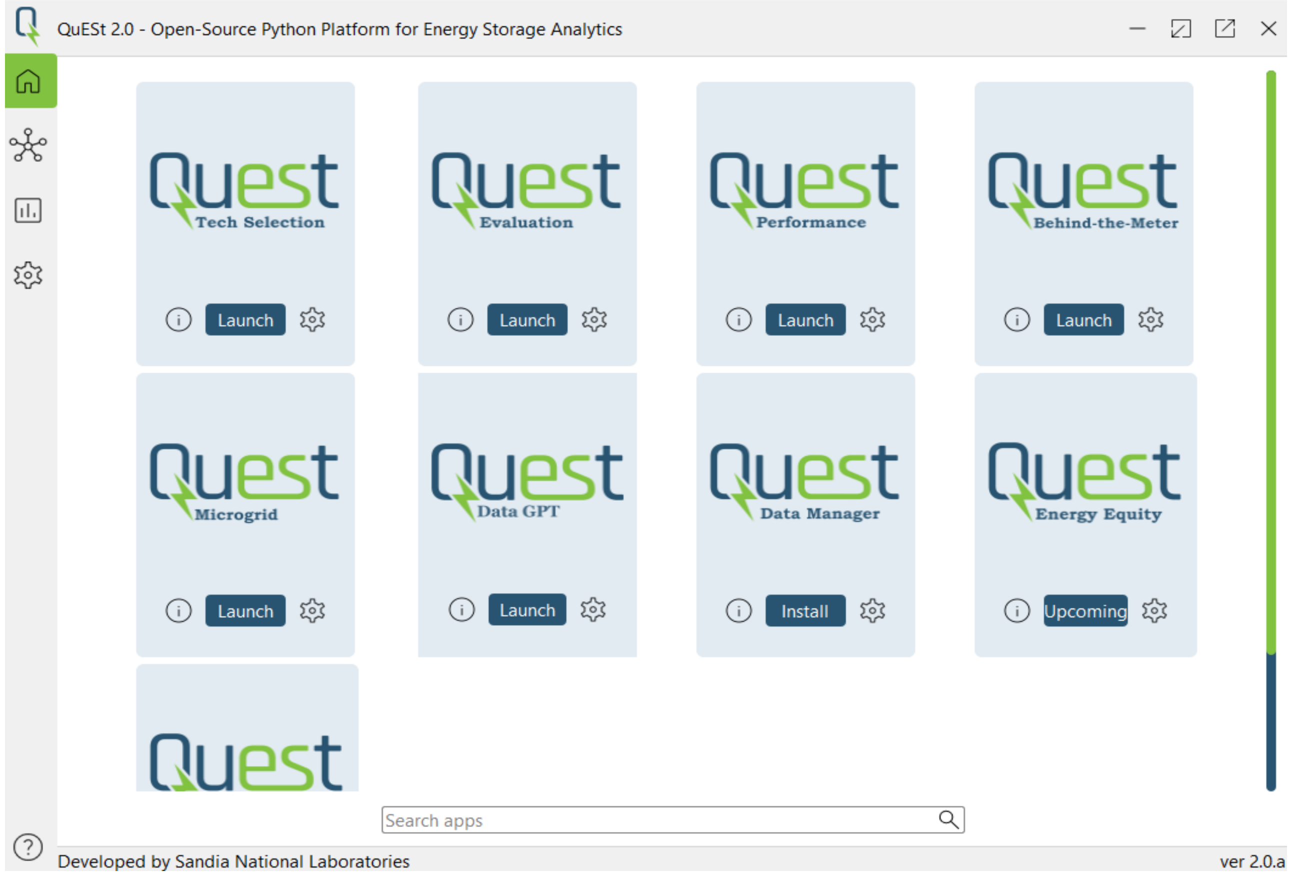
- **Market Structure Limitations:**
  - Existing market rules and structures favor short-duration storage, leaving LDES underutilized.
  - Lack of tailored market mechanisms to accurately value the unique capabilities of LDES.
- **Lack of Historical Data:**
  - Limited data on long-term performance and degradation of LDES systems.
  - Challenges in accurately modeling and forecasting system behavior over extended lifecycles.
- **Transition from Production Cost Modeling to Reliability Cost Modeling Framework:**
  - Shifting focus from purely cost-based metrics to reliability and resilience-based valuation.
  - Incorporating LDES into grid planning to assess its role in enhancing grid stability and reducing outage risks.
  - Recognizing the value of LDES in maintaining reliability during extreme conditions and supporting energy transition goals.

Software Tools

Name	Type	Developer	Format
Valuation Tools			
QuESt	Free	SNL	Python-based, open-source
Storage-VET™	Free	EPRI	Python-based, open-source
ESET	Free	PNNL	Web-based
energystoolbase	Commercial	Energy Toolbase	Executable, web-based
BatSIMM	Commercial	Ascend Analytics	Executable, web-based
Design Tools			
MDT	Free	SNL	Executable
DER-CAM	Free	LBNL	Executable
DER-VET™	Free	EPRI	Python-based, open-source
REopt	Free	NREL	Web-based
Homer	Commercial	Homer Energy	Executable, web-based

QuESt 2.0

In Version 2.0, QuESt is being transformed from a software to a platform.



QuESt 2.0 includes 3 main components:

- QuESt App Hub works like an apps store that provides access points to multiple apps.
- QuESt Workspace provides an environment for integrating multiple apps into a work process
- QuESt GPT is a data analytic tool for the characterization and visualization of large datasets.

Available on Github: https://github.com/sandialabs/snl-quest/tree/QuESt_2.0.b/quest/snl_libraries
Installation Webinars and Feedback: https://www.sandia.gov/ess/tools-resources/quest

Acknowledgements

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