Energy Storage Industry Learnings Forum
Workshop 4

November 9, 2021

Using Zoom – Asking questions

- Asking questions if you are accessing the webinar using your computer or smartphone
  - Click "Raise Hand" and the hosts will be notified that you would like to ask a question. The facilitator will then call your name and you will be able to unmute yourself.
- If you are accessing the webinar via conference call
  - If you would like to ask a question during the Q&A portion, on your phone's dial pad, hit *9 and the host will see that you have raised your hand. The host will unmute your microphone, you in turn will need to unmute your microphone by hitting *6 and then you can ask your question. Your number will appear on the screen.

AESO Stakeholder Engagement Framework

ESILF transparency

- The ESILF recognizes not all of the AESO's stakeholders will be represented within the ESILF and to support the AESO's commitment to transparency, the following is regularly updated on the AESO website on www.aeso.ca:
  - Forum membership
  - Agendas
  - AESO or member presentations
  - Relevant discussion materials
  - Meeting summaries

Stakeholder participation

The participation of everyone here is critical to the learning process. To ensure everyone has the opportunity to participate, we ask you to:

- Listen to understand others' perspectives
- Disagree respectfully
- Balance airtime fairly
- Keep an open mind

Welcome and Introductions

Ata Rehman,

Director, Grid Planning & Operations Engineering, AESO

Agenda

Est. Time	Agenda Items	Presenter
9:00 – 9:15	Welcome & Introduction	Ata Rehman
9:15 – 9:45	Presentation 1: Battery Energy Storage	Varun Chhibbar, Hitachi Energy
9:45 – 10:15	Discussion	Luis Garrido
10:15 – 10:45	Presentation 2: Stand-alone energy storage economic analysis in Alberta's market	Juan Arteaga, University of Calgary
10:45 – 11:15	Discussion	Luis Garrido
11:15 – 11:30	Wrap up and next steps	Biju Gopi

Presentation 1
Battery Energy Storage: unlocking new revenue and stabilizing electric grids

Varun Chhibbar, Hitachi Energy

Unlocking new revenue and stabilizing electric grids

Maximizing the value of energy storage

Varun Chhibbar, Regional Sales Manager, Grid Automation

2021-10-29

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Presenter

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Varun Chhibbar, P.Eng

Hitachi ABB Power Grids
Regional Sales Manager, Grid Automation
Calgary, Canada
varun.chhibbar@hitachienergy.com

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Grid Edge Solutions

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Who we are

As a pioneer in energy management and optimization, Hitachi ABB Power Grids is a trusted partner in the evolving global energy ecosystem.

Our Grid Edge Solutions are leading energy innovation and transition

The e-mesh™ portfolio includes energy storage and digital automation solutions. Our global footprint covers more than 700 MW and 220 references.

Hitachi ABB Power Grids helps customers increase profitability and unlock new revenue streams by reducing energy cost, maximizing renewable integration and lowering CO_2

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e-mesh portfolio

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Applications
SaaS Apps for improved performance

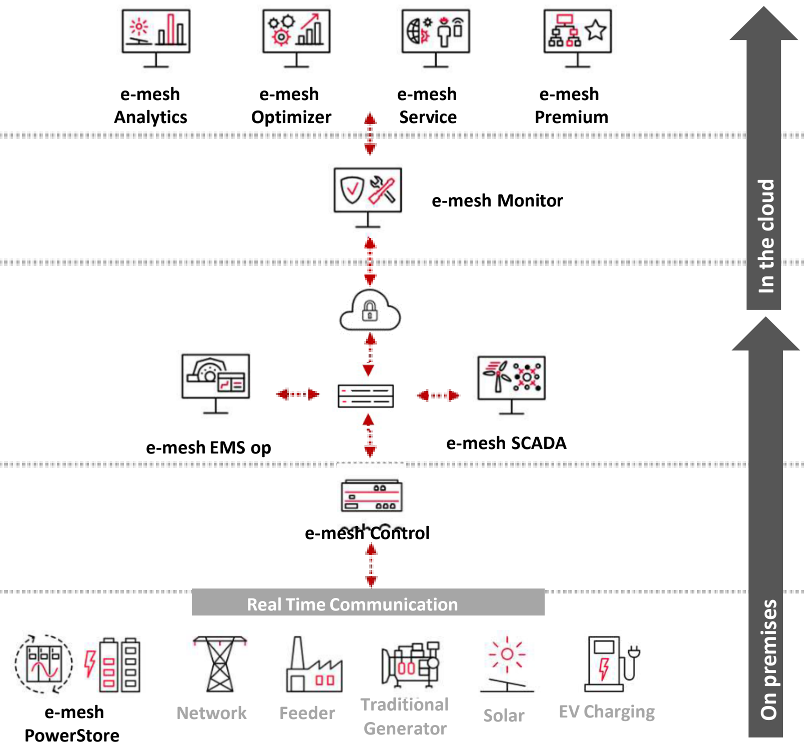
Monitor
Cloud enabled remote monitoring and control

EMS
On-premises energy management solution

SCADA
On-premises plant automation solution

Control
Intelligent and efficient power management

PowerStore
Smart battery energy storage solution



- Energy forecast, production and optimization planning
- Business KPI dashboards and reports
- Improved productivity and profitability

- Monitoring and control
- Bi-directional data flow
- Remote access

- Monitoring & control
- Optimal energy production
- Operational & maintenance cost reduction

- Renewable power generation grid code compliance
- Network voltage control
- Feeder & Load demand management

- Smart battery energy storage solution
- Support for various applications including islanding, seamless transition, black start, spinning reserve, etc.

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e-mesh PowerStore

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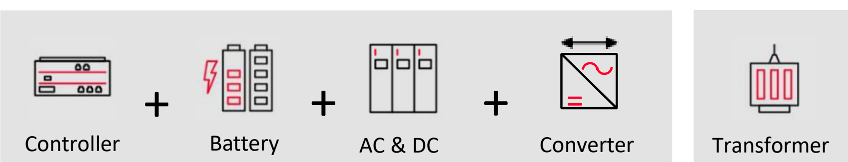
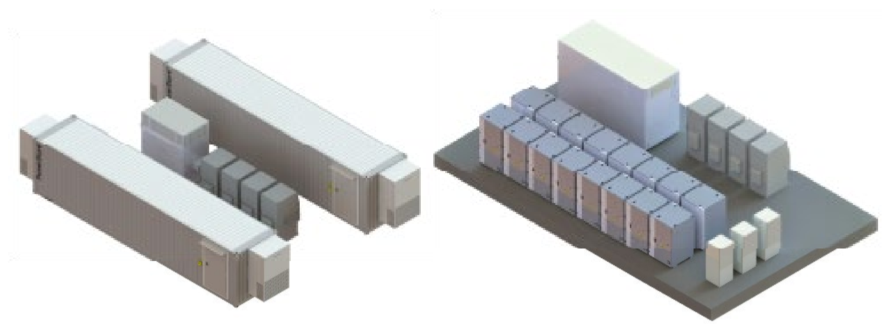
PowerStore Integrated: PS250 & PS500

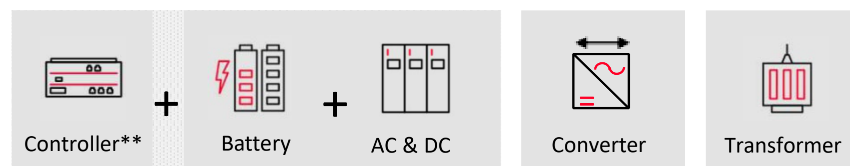
The complete PCS and battery modules are integrated into a single outdoor enclosure*.



PowerStore Modular: PS1000

The PCS and battery are housed in separate enclosures* to achieve flexible power and energy ratings.





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ESCRI BESS: location at the edge of National Electricity Market (NEM)

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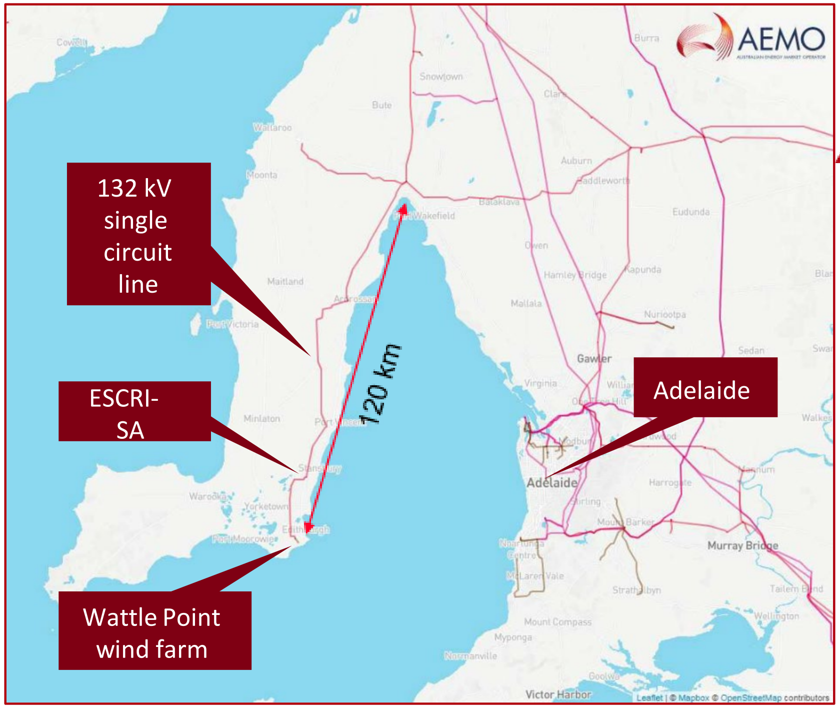
Utility scale 30MW/8MWh BESS near the end of a long radial line in proximity to a wind farm



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Integration at ElectraNet's Dalrymple substation

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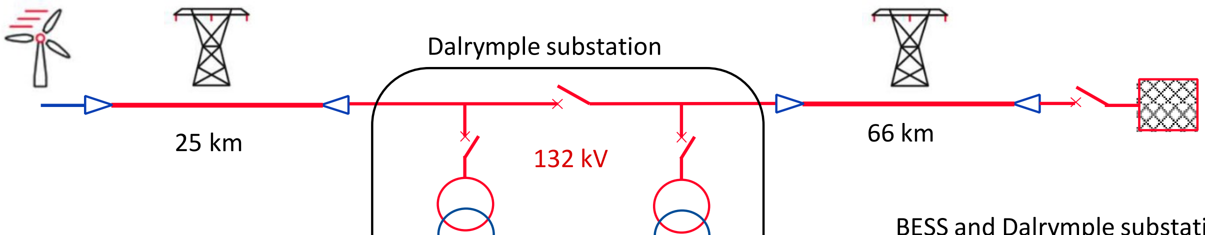
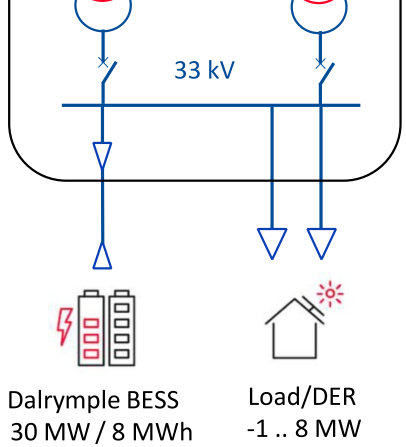
Wattle Point Wind Farm
91 MW
(55 x Vestas V82 directly
coupled induction generators)

BESS building

BESS and Dalrymple substation

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ESCRI Dalrymple Battery Energy Storage System (BESS)

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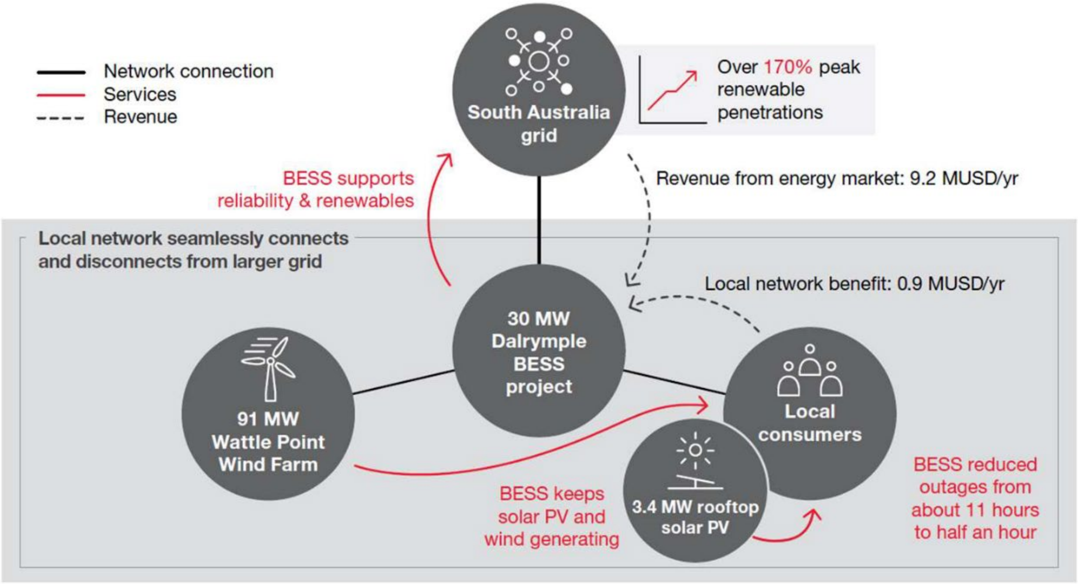
Showcasing the benefits of BESS with high power Grid Forming Mode, smart controls, and automation



Total revenue streams of the PowerStore BESS offset project capital cost within 2 years

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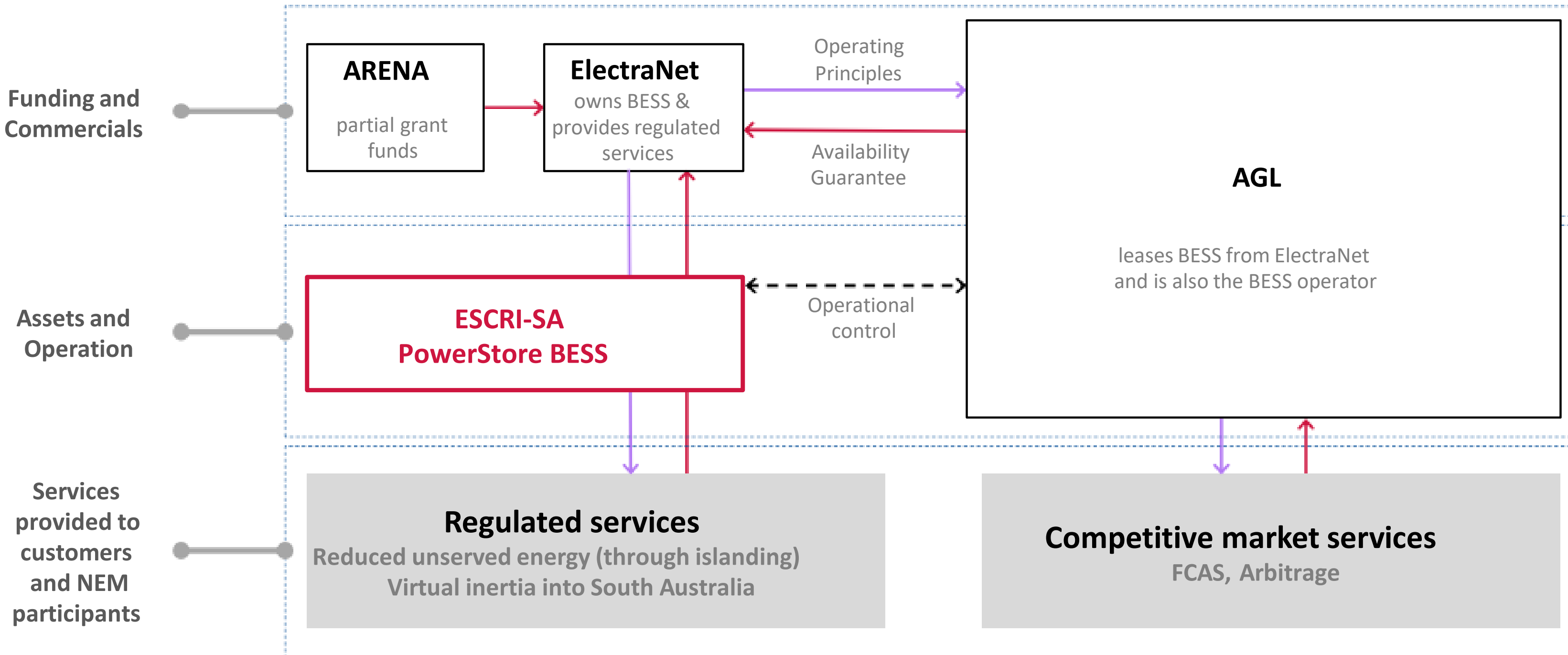
Commercial arrangements



Enabling both regulated (“wires”) and market (“generation”) services

Protections Goals and Primary Modifications

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- Ensure satisfactory performance under both grid-connected and islanded conditions, as well as transition
  - Support both System Integrity Protection Scheme (SIPS) and Islanding Detection Scheme (IDS)
- Primary modifications required:
  - Transmission system auto-reclose
    - Adjusted to prevent out-of-phase reclose
  - Existing transformer automatic voltage regulation schemes at substation's 33 kV connection bus
    - Allow BESS to perform voltage regulation function

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Protection philosophy

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- Simulation studies (PowerFactory DIgSILENT)
  - RMS* dynamic models of BESS, wind farm, protection elements
  - Review adequacy/operation/coordination of protection when
    - islanded
    - grid-connected
    - transitioning between the two states
  - Examination of stability and fault ride-through of BESS and wind farm in islanded operation
    - Wind farm curtailed to <30MW within 150 msec
    - BESS controls wind farm power to regulate its state of charge
    - Minor setting adjustments to distribution network

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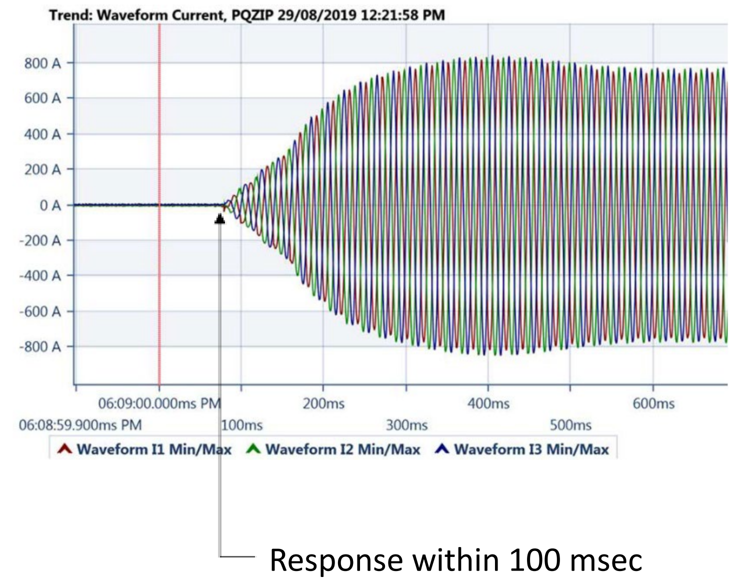
System Integrity Protection Scheme (SIPS)

- Remedial action scheme (RAS) to prevent system blackout
- 3 discrete stages

	Event	Response
1	Active import power at Heywood Interconnector exceeds 800MW threshold or rate of increase >1.67MW/s	Fast MW injection from BESS
2	Predictive Out-of-Step Trip Scheme detects impending loss of synchronism	Trip 200 MW of load in South Australia
3	Existing Out-of-Step Trip Scheme detect loss of synchronism	Sever interconnection to prevent disturbances spreading into rest of NEM



Islanding Detection Scheme (IDS)

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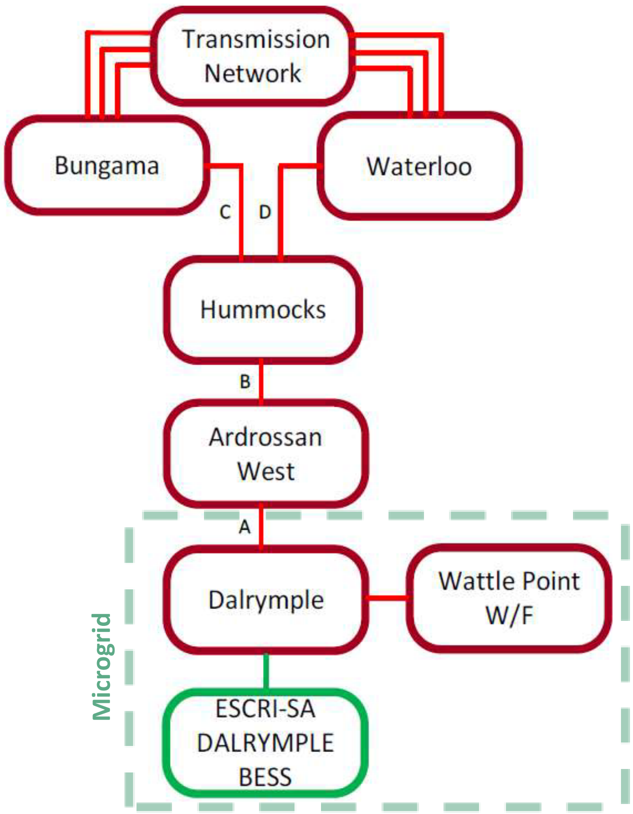
- Selected remote IDS monitoring close to interconnection
  - Four Peripheral Units monitor switchgear and protection systems at four substations near interconnect to detect islanding
    - Central Unit at Dalrymple substation monitors switchgear and protection systems at the substation
    - If IDS detects disconnection, Central Unit initiates trip at Wind Farm and indication to VSG controller BESS controls frequency/voltage
  - On restoration of upstream network, IDS notifies Network Control Operator that microgrid may be resynchronized
  - 15 circuit breakers, 32 disconnectors and 16 protection relays are monitored by the IDS



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Unplanned islanding with the wind farm

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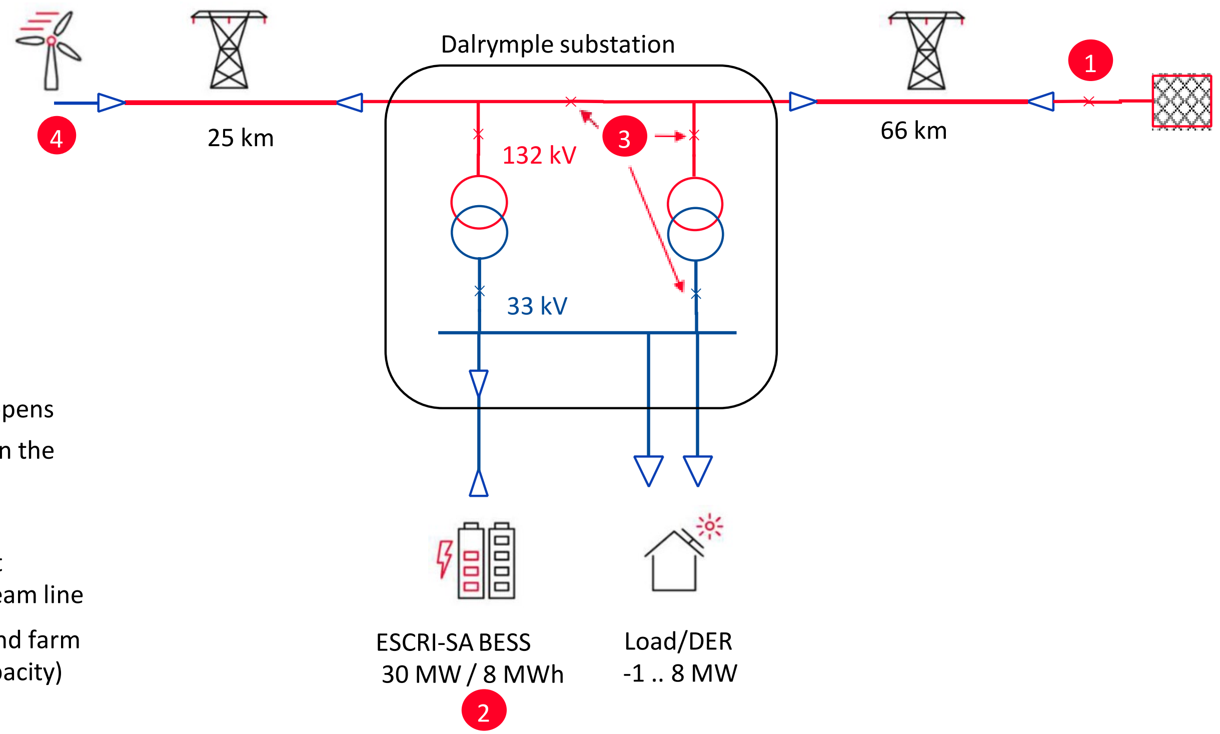
Sequence of events

Pre-event conditions

- Wind farm online
- BESS running unloaded on the NEM
- Local load ~ 4 MW
- All breakers closed

Event

1. 132 kV breaker at the upstream substation opens
2. BESS becomes the only grid forming source in the now islanded microgrid and instantaneously supplies the area
3. Some 80 msec later the protection system at Dalrymple substation disconnects the upstream line
4. At about the same time protection at the wind farm trips 4 out of 5 collector groups (~80% of capacity)



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Unplanned islanding without the wind farm

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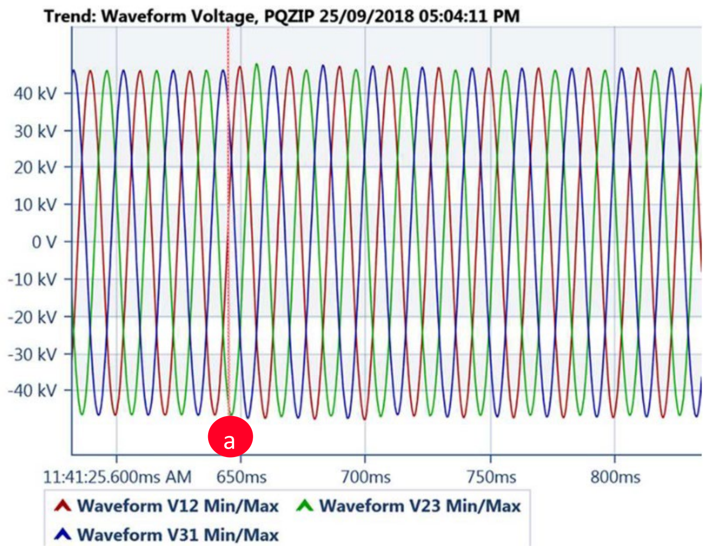
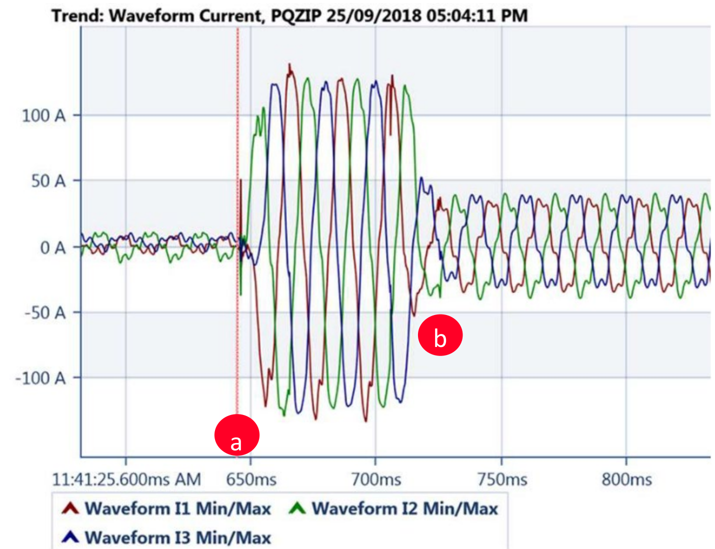
The islanding instant – BESS voltage and current waveforms





- a: 132 kV breaker at upstream substation opens = islanding takes place
- b: Upstream line is disconnected

The grid forming BESS performs a seamless transition into islanded state without interruptions

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Islanded Operation

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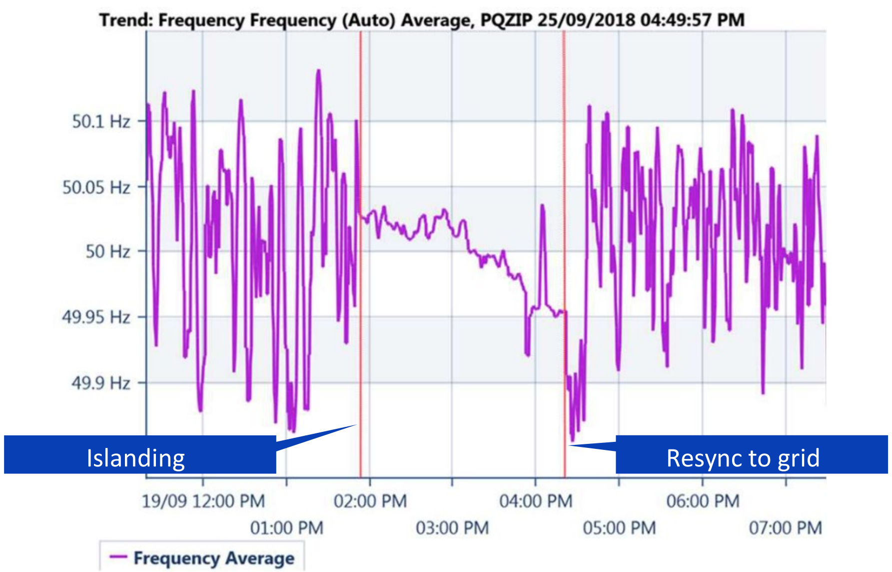
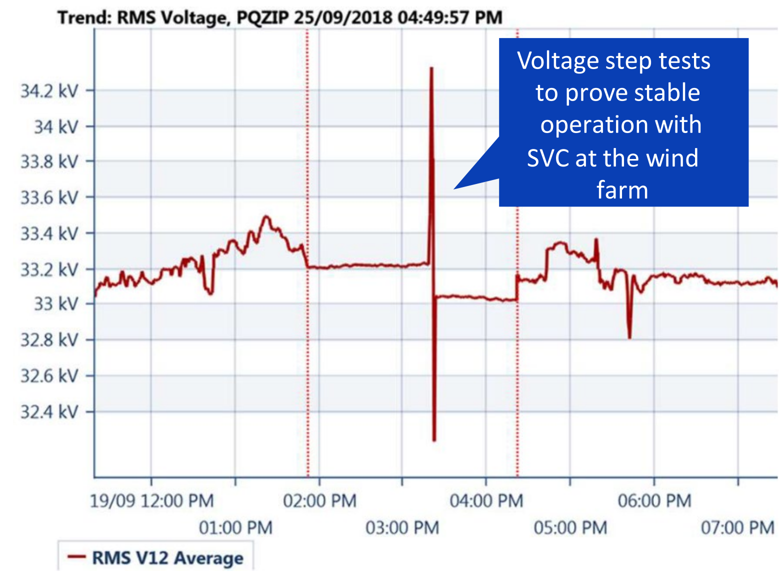
Frequency performance: grid-parallel vs islanded



Voltage performance: grid-parallel vs islanded



BESS regulates frequency and voltage

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South Australia Islanding Event: ESCRI BESS Inertia Response

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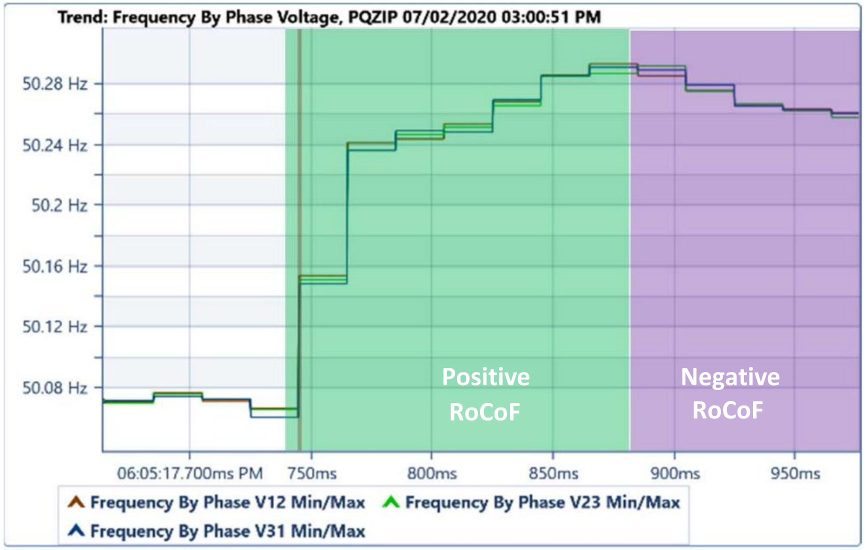
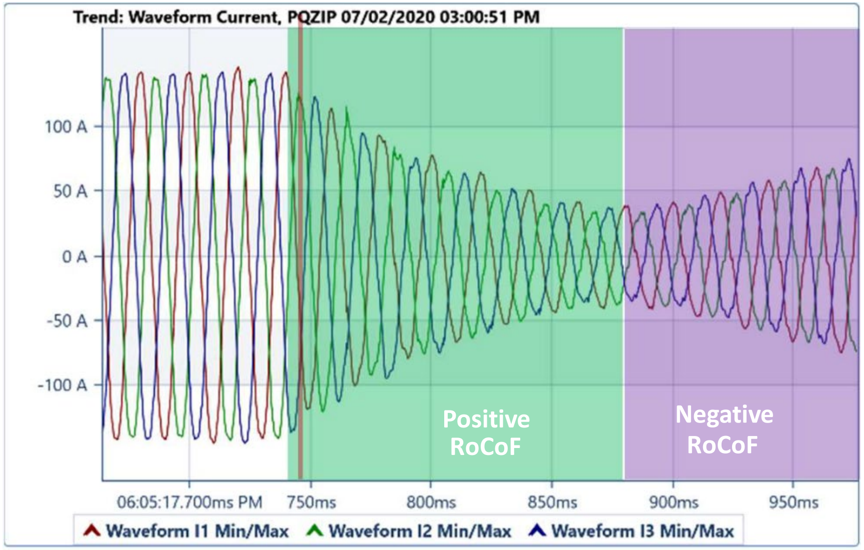
Frequency measurement by high speed data recorder



VSM Response – Current responds prior to frequency measurement (red vertical line)



Grid forming inverter responds to frequency change prior to high speed data recorder – 300-msec view

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Black start of the local 33 kV distribution network

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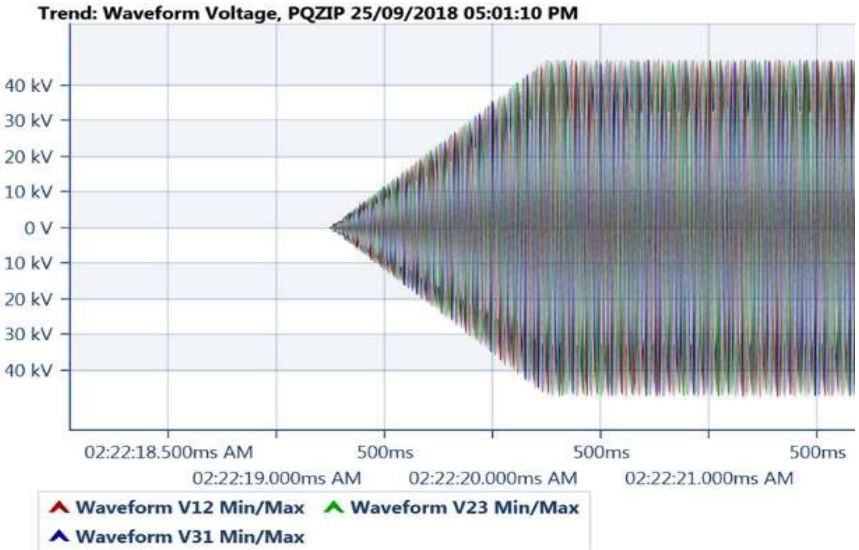
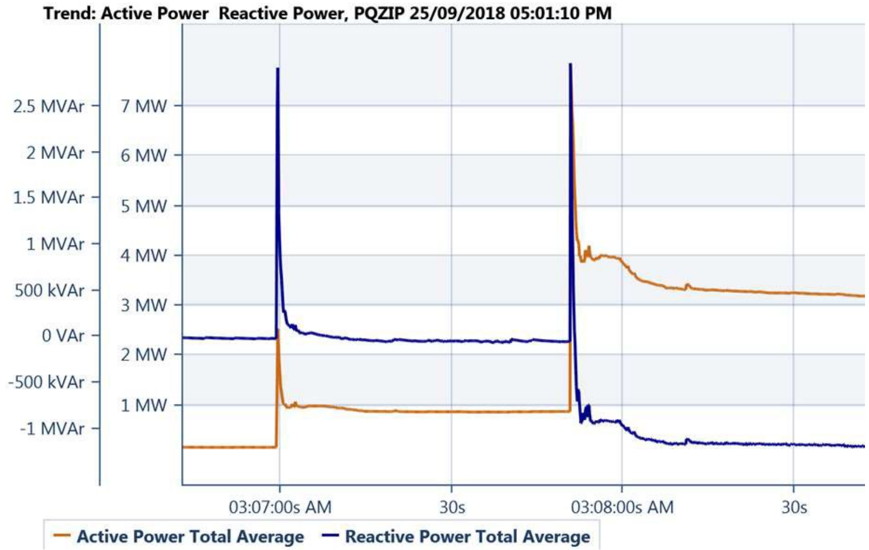
BESS ramps voltage up to energise transformers



BESS picks up 33 kV load feeder – P/Q profiles



Soft energisation of large transformers and pickup of 33 kV load feeders in islanded operation.
Voltage ramp effectively eliminates transformer inrush. Feeder pick up at full voltage presents no issues

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Key proven functionality and revenue streams

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Regulated system services

- **Reduction of unserved energy (i.e. outage time)** in the Dalrymple area through seamless transition into islanded operation with/without wind farm

  → reduced outage time from 11 to 0.5 hours (both planned/unplanned) over two years of operation

- **Virtual inertia reduces constraints on Heywood AC interconnector** (~200 MWs equivalent of synchronous inertia into South Australia's system)

  → reduced binding RoCoF constraint by estimated 72% over two years of operation

Competitive market services

- **Frequency Control Ancillary Services**

  → earned $AU 22.6 million over two years of operation

- **Wholesale energy market trading** (energy arbitrage)

  → has not participated intensively to date due to battery capacity reserved for network services and operator's preference to focus on contingency FCAS

Not monetised at present

- **Black start** of the local 33 kV network (indirectly monetised through potential reduction of outage time)
- **Fault level/system strength support** through provision of fault current in both grid-parallel and islanded operation
- **Fast active power injection** (30 MW in 250 msec) as part of System Integrity Protection Scheme
- **Voltage regulation** with automatic activation outside of ±5% of nominal
- **DER curtailment** through frequency shifting when islanded

Enabled by Hitachi ABB Power Grids PowerStore™ platform with e-mesh™ secondary control and automation system

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Discussion

Luis Garrido, Project Manager, AESO

Presentation 2
Stand-alone energy storage economic analysis in Alberta's market

Juan Arteaga, University of Calgary

Stand-alone energy storage economic analysis in AB's market

Stacking sources of revenue

Juan Arteaga
Postdoctoral Fellow
Electrical and Computer Engineering

November 9th, 2021

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Outline

- Energy storage in the U.S.
- Alberta market analysis
- Where is Alberta standing
- Stacking revenue from transmission services

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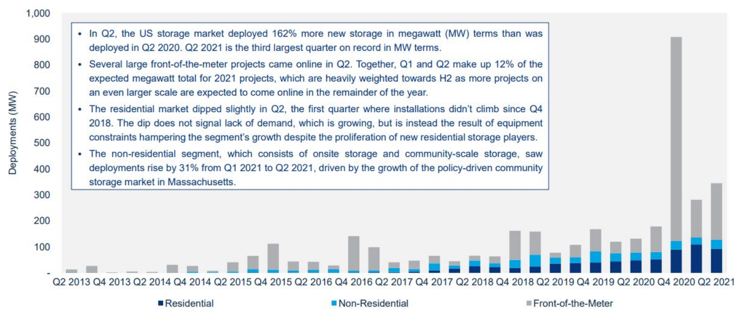
Energy storage in the U.S.

The U.S. energy storage market added 345 MW in Q2

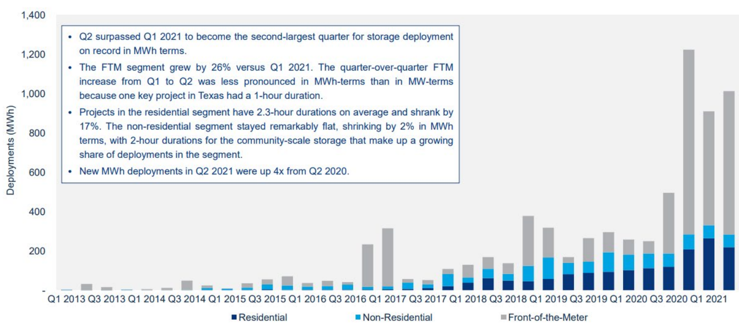
H1 2021 is expected to make up only 12% of 2021 MW total, based on projects coming online in H2



Source: Wood Mackenzie Power & Renewables

U.S. energy storage market deployed 1,013 MWh in Q2 2021

Market added slightly more megawatt-hours in Q2 than in Q1 with a mix of 1-, 2-, and 4-hour durations

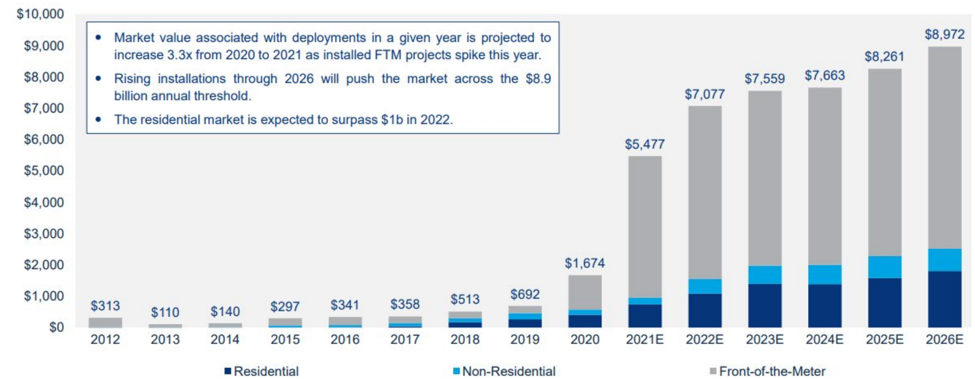


Source: Wood Mackenzie Power & Renewables

U.S. energy storage will be a $8.9 billion annual market in 2026

A cumulative $45 billion in market value will propel growth from 2021 to 2026

U.S. annual energy storage market size, 2012-2026E (million $)



Source: Wood Mackenzie Power & Renewables. Note: Market size is reported as energy storage system deployment revenue (product of deployments and installed system prices).

- Projects and market value are growing

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Mandate vs Market

State Energy Storage Targets as of April 2020

State	Goal / Target / Mandate
California **2010 bill** **2013 regulation**	1,325 MW by 2020 (Target)
Oregon **2015 bill**	Minimum 10 MWh, up to 1% peak load by 2020 (Mandate)
Massachusetts **2016 bill** **2017 regulation** **2018 bill**	200 MWh by 2020, 1,000 MWh by 2025 (Target)
New York **2017 bill** **2018 regulation** **2019 bill**	1,500 MW by 2025, 3,000 MW by 2030 (Target)
New Jersey **2018 bill**	600 MW by 2021, 2,000 MW by 2030 (Goal)
Nevada **2017 bill** **2020 regulation**	1,000 MW by 2030 (Target)
Virginia **2020 bill**	3,100 MW by 2035 (Mandate)

FERC

- Order 755
  - Pay for performance
- Order 841
  - ESS full capability
- Order 2222
  - Small DER services

- Either way energy storage is being deployed and used on the grid

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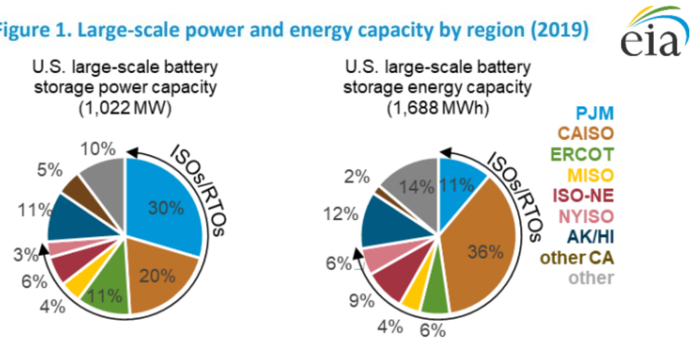
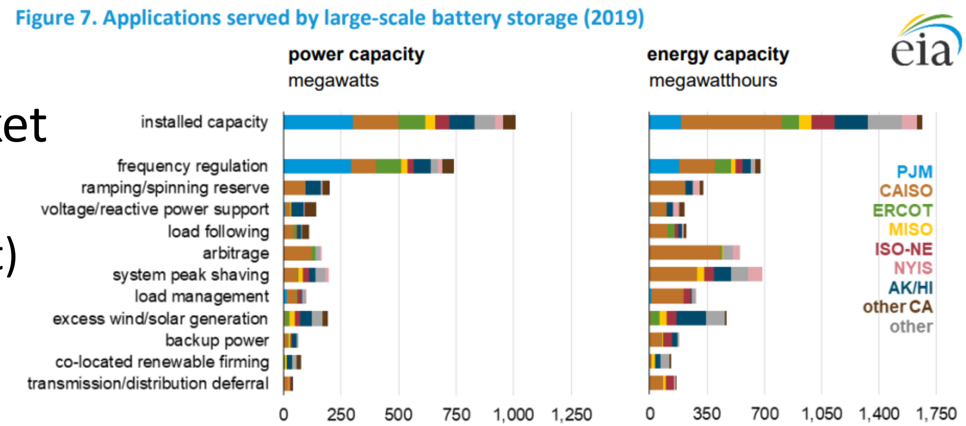
Figure 1. Large-scale power and energy capacity by region (2019)



Source: U.S. Energy Information Administration, 2019 Form EIA-860, *Annual Electric Generator Report*

- 50% of the capacity is in CAISO and PJM
  - PJM Power
  - CAISO Energy

Figure 7. Applications served by large-scale battery storage (2019)



Source: U.S. Energy Information Administration, 2019 Form EIA-860, *Annual Electric Generator Report*

- Use cases drawn by policy / market characteristics
  - PJM frequency regulation (market)
  - CAISO multiple applications (mandate)

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Where is Alberta standing?

- 2019 AESO Energy Storage Roadmap
  - No mandate is mentioned or envisioned for the future
  - A market re-design is envisioned for Fair Efficient Open Competition
  - The door is open for stacking transmission and market sources of revenue

Market design - potential future state

In the future, energy storage assets will be able to fairly access markets for which they meet the technical requirements. ISO rules for qualification and participation in the various energy, and ancillary services markets will: provide clarity for energy storage assets given their unique operating characteristics; support the AIES needs for reliability; and, ensure the FEOC operation of the markets.

The market systems and ISO rules will enable operators of these energy storage facilities to easily and clearly offer into and operate their assets in the markets. In addition, the AESO system controllers will have software applications to monitor and control these energy storage facilities in support of power delivery and balancing across the AIES. This will allow for the reliable operation of the system.

Bridging the gap

- Determine and define:
  - system asset types
  - market participation asset types
  - requirements for participation in the EAS markets
  - requirements for hybrid assets in the EAS markets
- Assess whether energy storage installed as a regulated transmission asset should be permitted to participate in electricity markets, and if so, under what rules
- Explore and understand how self-supply should work for energy storage when market participants are charging the asset versus charging from the AIES

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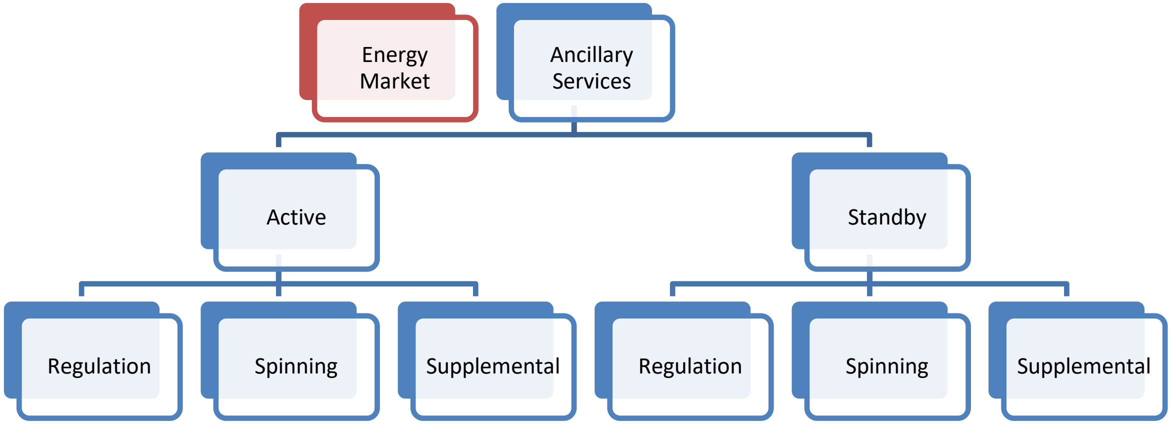
Market Analysis

Optimization-based simulation to estimate upper-bound profit and expected participation of a battery in the following markets:



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1 Optimization Model

$$\max \sum_{t=1}^{T} [(\xi_t - P_t^{Ec})\lambda_t^E + P_t^{ActReg}(\lambda_t^E + \lambda_t^{EqActReg}) + P_t^{ActSpn}(\lambda_t^E + \lambda_t^{EqActSpn})$$
$$+ P_t^{ActSup}(\lambda_t^E + \lambda_t^{EqActSup}) + P_t^{StbReg}\lambda_t^{PrStbReg} + P_t^{StbSpn}\lambda_t^{PrStbSpn}$$
$$+ P_t^{StbSup}\lambda_t^{PrStbSup} + P_t^{StbReg}Ac_t^{StbReg}\lambda_t^{AcStbReg} + P_t^{StbSpn}Ac_t^{StbSpn}\lambda_t^{AcStbSpn}$$
$$+ P_t^{StbSup}Ac_t^{StbSup}\lambda_t^{AcStbSup} - OC_h] \quad (A.1)$$

Subject to:

$$\xi_t = P_t^{Ed} + P_t^{ActReg}D_t^{ActReg} + P_t^{ActSpn}D_t^{ActSpn} + P_t^{ActSup}D_t^{ActSup}$$
$$+ P_t^{StbReg}Ac_t^{StbReg}D_t^{StbReg} + P_t^{StbSpn}Ac_t^{StbSpn}D_t^{StbSpn} + P_t^{StbSup}Ac_t^{StbSup}D_t^{StbSup} \quad (A.2)$$

$$OC_t = (\xi_t + P_t^{Ec})VOM \quad (A.3)$$

$$SOC_t = SOC_{t-1} + \eta P_t^{Ec} - \xi_t$$

$$SOC^{int} \geq P_1^{Ed} + P_1^{ActReg} + P_1^{ActSpn} + P_1^{StbReg} + P_1^{StbSpn} + (P_1^{Ac}$$

The objective is to maximize ESS's profit by allocating portions of its capacity to different services.

The simulation runs one year of hourly scheduling and calculates the market revenue

Other costs are added after the market scheduling (i.e., transmission tariff)

Financial metrics are calculated based on the estimated yearly profit (NPV, CAGR)

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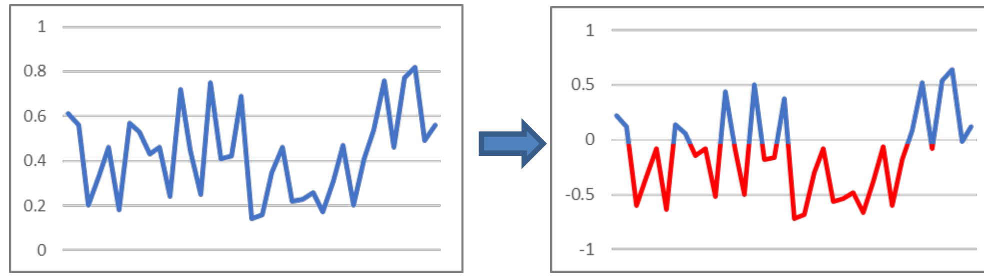
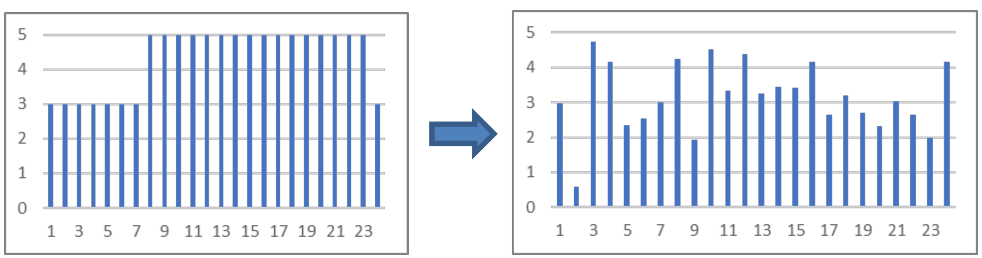
The current Alberta market rules are used as baseline

Two possible policy changes are examined and compared





Allowing hourly changes in the offer made by AS providers (No block)

Adding a regulation down service (RegDN)

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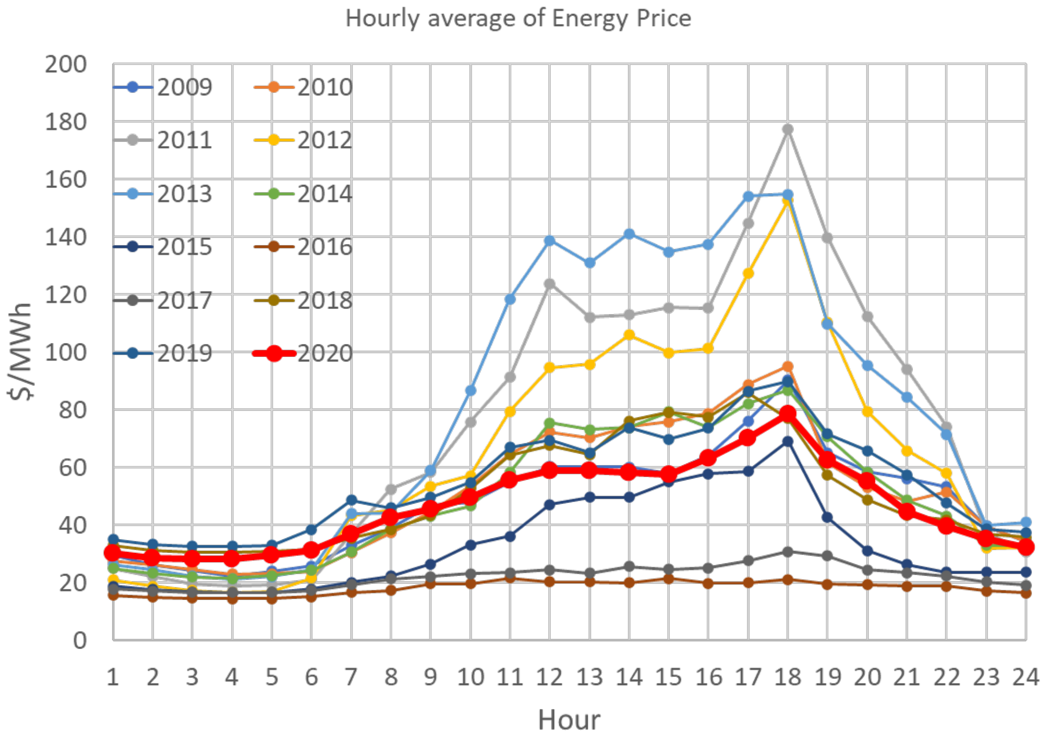
Simulation based on 2020 prices and ancillary services directives



- ESS's size
  - 15MW/30MWh Lithium-ion Battery
- ESS's capital cost
  - $550 kWh
  - $1,200 kW

Arteaga, Juan, and Hamidreza Zareipour. **"A price-maker/price-taker model for the operation of battery storage systems in electricity markets."** IEEE Transactions on Smart Grid 10.6 (2019): 6912-6920.

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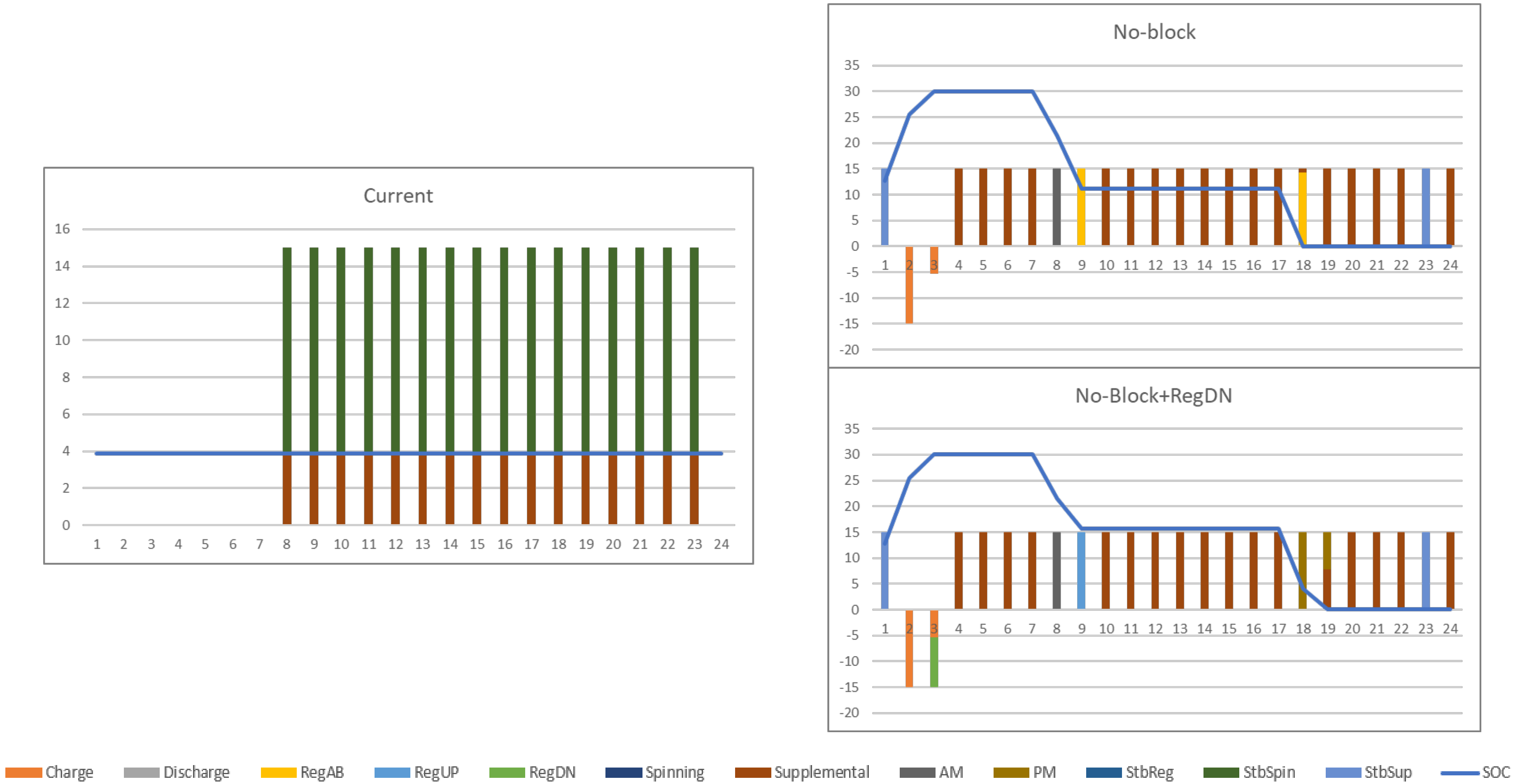
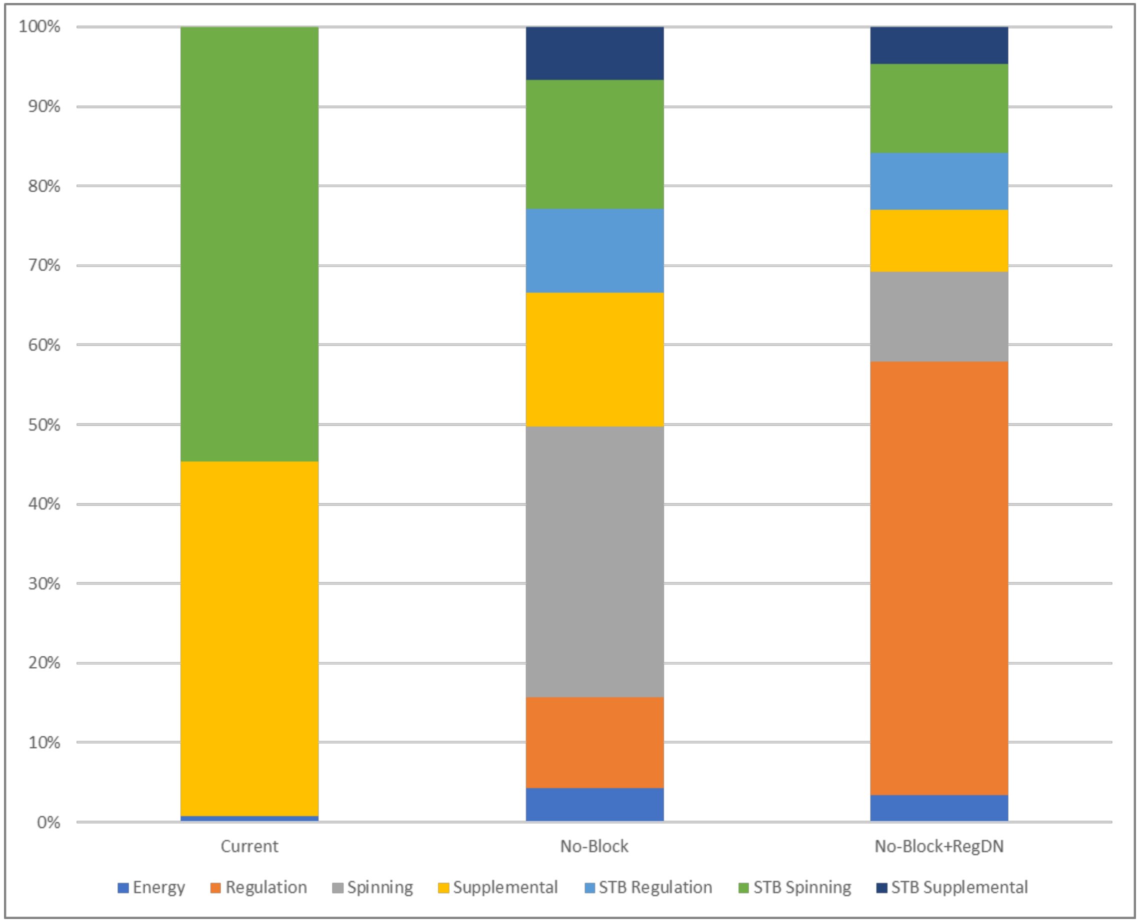

Current
No-block
No-Block+RegDN
Charge
Discharge
RegAB
RegUP
RegDN
Spinning
Supplemental
AM
PM
StbReg
StbSpin
StbSup
SOC

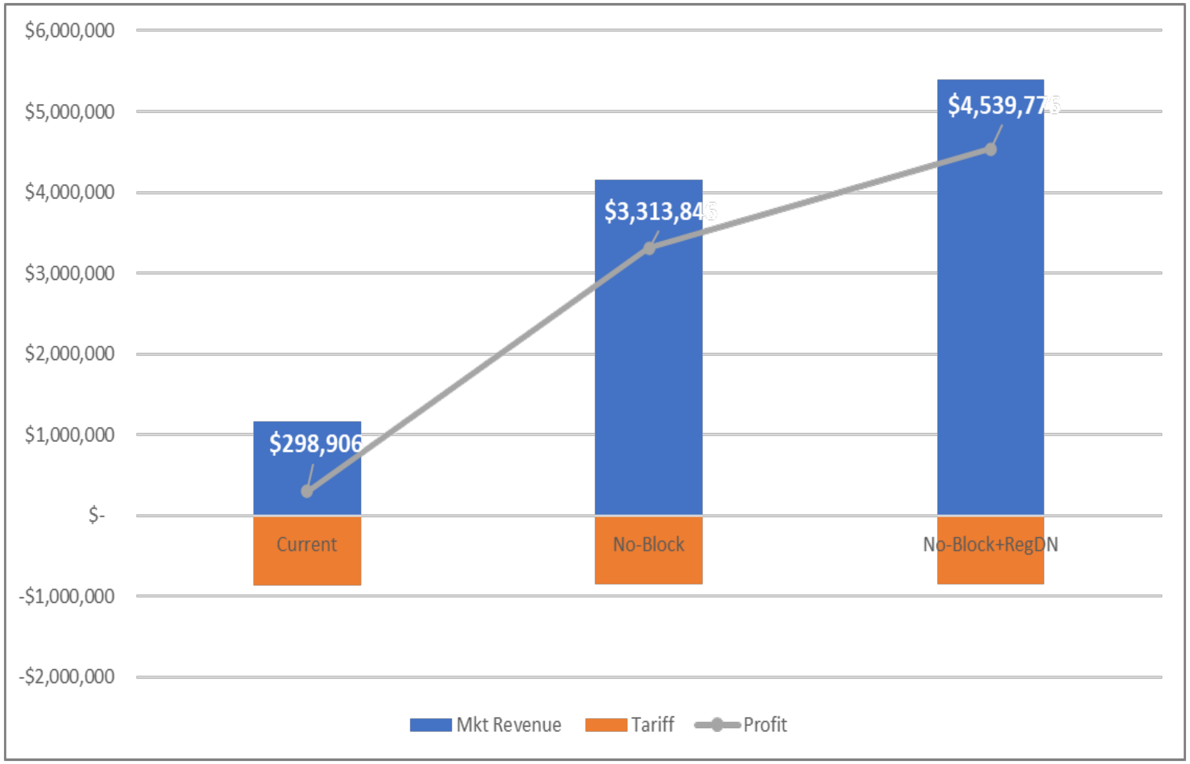
Operation comparison (continued)

- Significant change in operation with small changes in policy



Profit comparison

- Profit estimation is an upper-bound, considering perfect knowledge of prices and dispatches for all services.
- The Tariff includes DTS and STS charges



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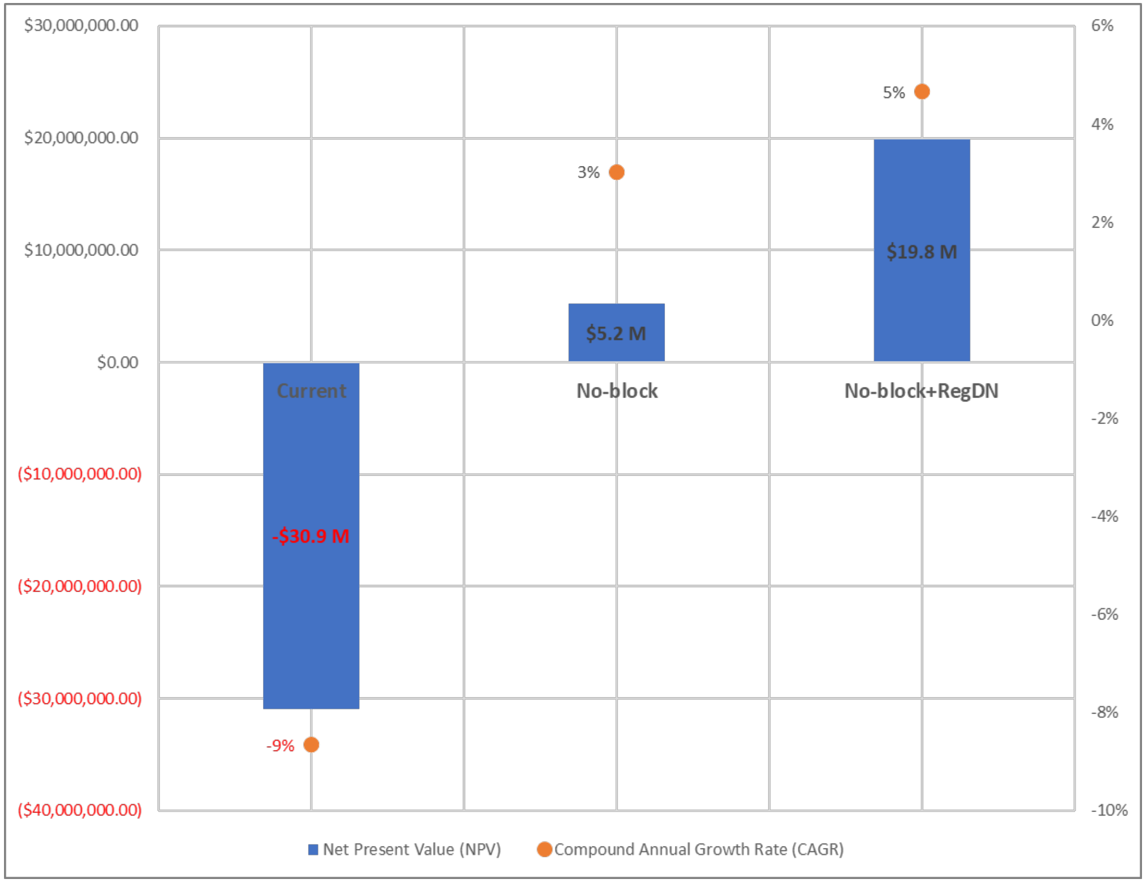
Financial metrics comparison

DTS and STS transmission costs



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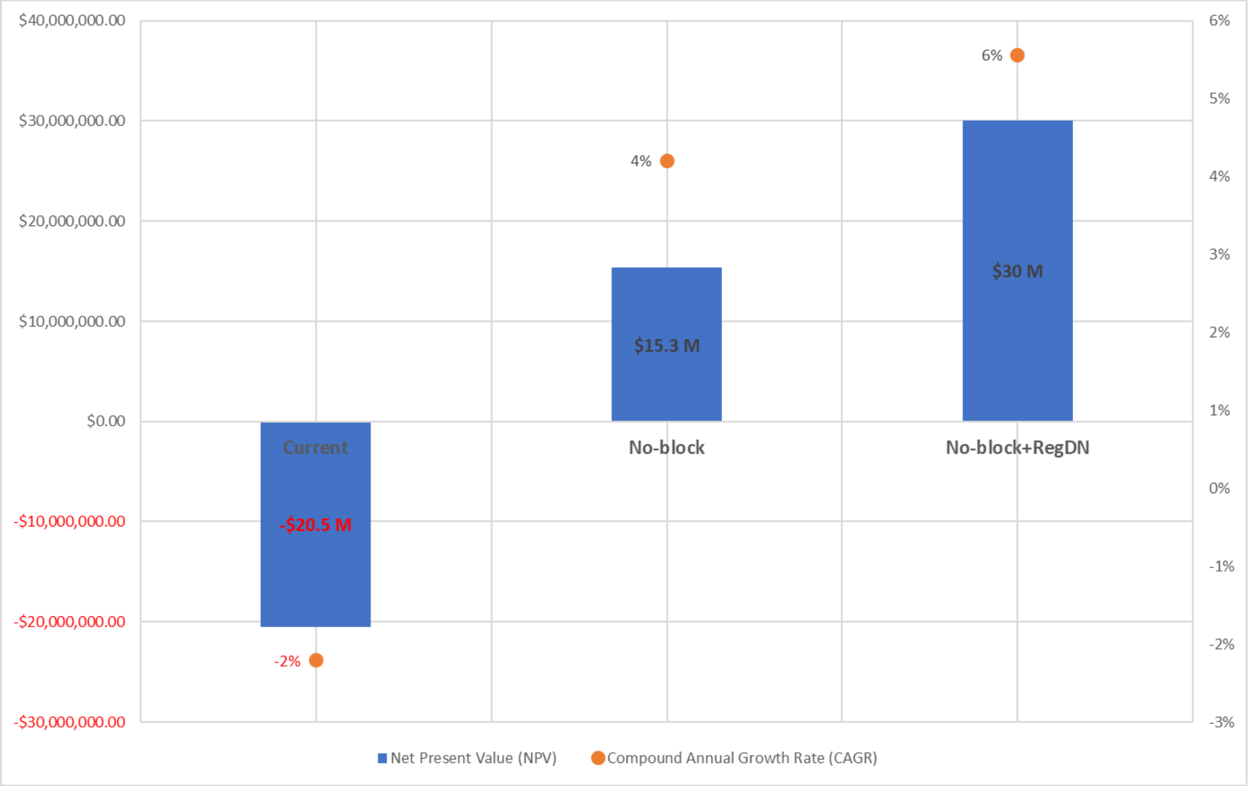
Financial metrics comparison

No transmission cost



Market analysis summary

AESO has a big say on how ESS's would behave in the market depending on the market rules and regulations.

Economic feasibility of ESS's is more likely in a less energy intense market environment.

Transmission tariff adjustment is not core to reaching economic feasibility of ESS's in Alberta.

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Storage as Transmission Asset Analysis

Financial Storage Rights

- Financial storage rights similar to financial transmission rights
- ISO operates storage facility to maximize social welfare
- Storage rights are auctioned

Storage Rights Auctions

- Physical capacities of storage are auctioned
- Owner yields storage operation maximizing profit
- Ownership and operation are separated

Review Policy on Functional Classification

- Allow storage to provide both services
- Owner maintains operation maximizing profit
- Profits are shared with ratepayers

- CAISO
- PJM
- ERCOT
- MISO

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Transmission simulation overview

- The objective is to assess the potential financial gains and risks of adding a transmission service to an existing ESSs’ market operation.
- A transmission network operator expects occasional and predictable congestion on a corridor and solicits third-party solutions.
- The interested solution alternatives compete in an auction to obtain the contract.
- Privately owned ESS who’s main source of revenue is its participation in the electricity market.

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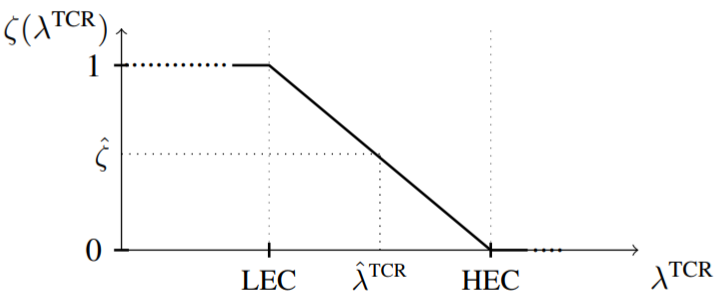
Hybrid cost-value customized pricing

COST

γ – Opportunity Cost

VALUE



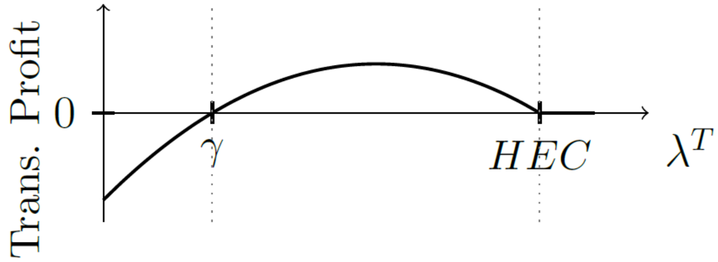
LEC – Lower Estimated Cost

HEC – Higher Estimated Cost

λ^T - Price Transmission service

ζ - Probability of contract

Expected contribution of the transmission services



$$E(\lambda^T) = \zeta \cdot (\lambda^T - \gamma)$$

λ^T - Price Transmission service

ζ - Probability of contract

γ – Opportunity Cost

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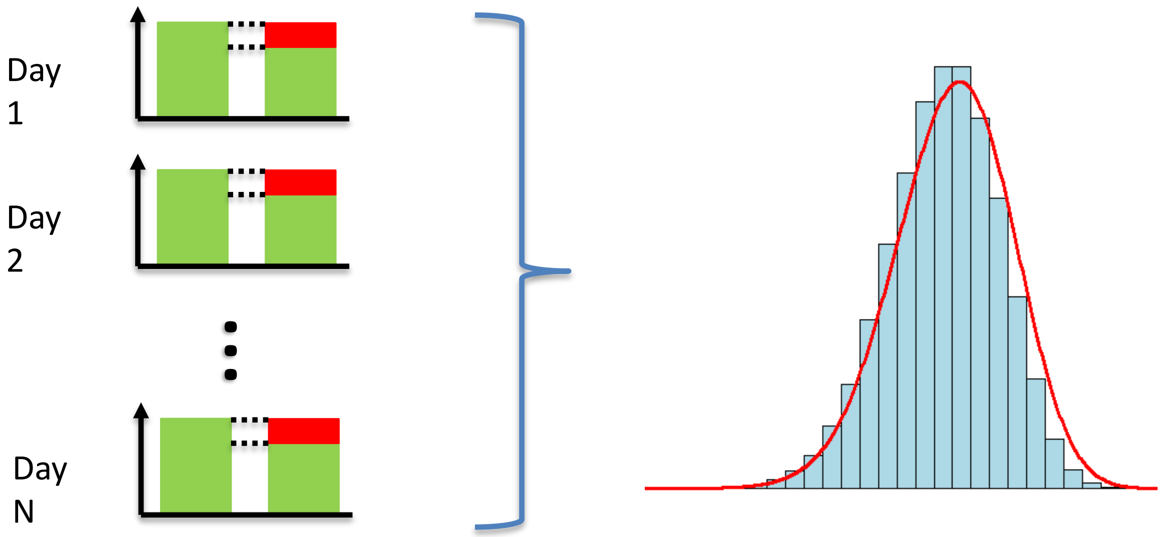
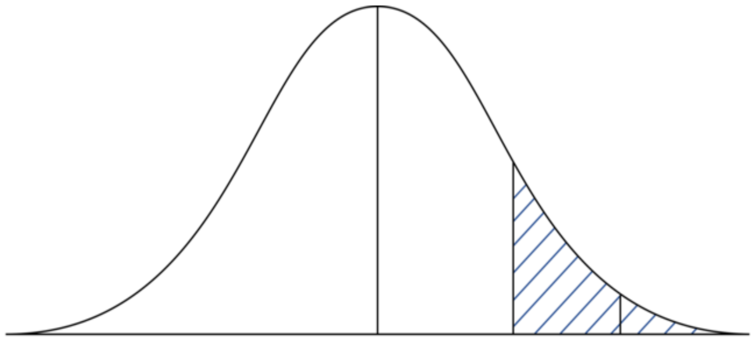
Empirical PDF for the long-term opportunity cost



CVaR for Risk mitigation



$$VaR^{\beta}(\lambda^T) = \min\{\varepsilon \in \mathbb{R} : \int_{f(\lambda^T,\gamma)\leq\varepsilon} p(\gamma)d\gamma \geq \beta\}$$

$$CVaR^{\beta}(\lambda^T) = (1-\beta)^{-1} \int_{f(\lambda^T,\gamma)\geq VaR^{\beta}} f(\lambda^T,\gamma)p(\gamma)d\gamma$$

β - Confidence interval

ε - Threshold for VaR calculation

- Characterized and Discretized into the Risk Function

$$F_{\beta}(\lambda^T,\varepsilon) = \varepsilon + (1-\beta)^{-1}\sum_{s=1}^{S}\pi_s[f(\lambda^T,\gamma_s)-\varepsilon]^+$$

S - Set of cost scenarios, index by s

π_s - Probability of occurrence of scenario s

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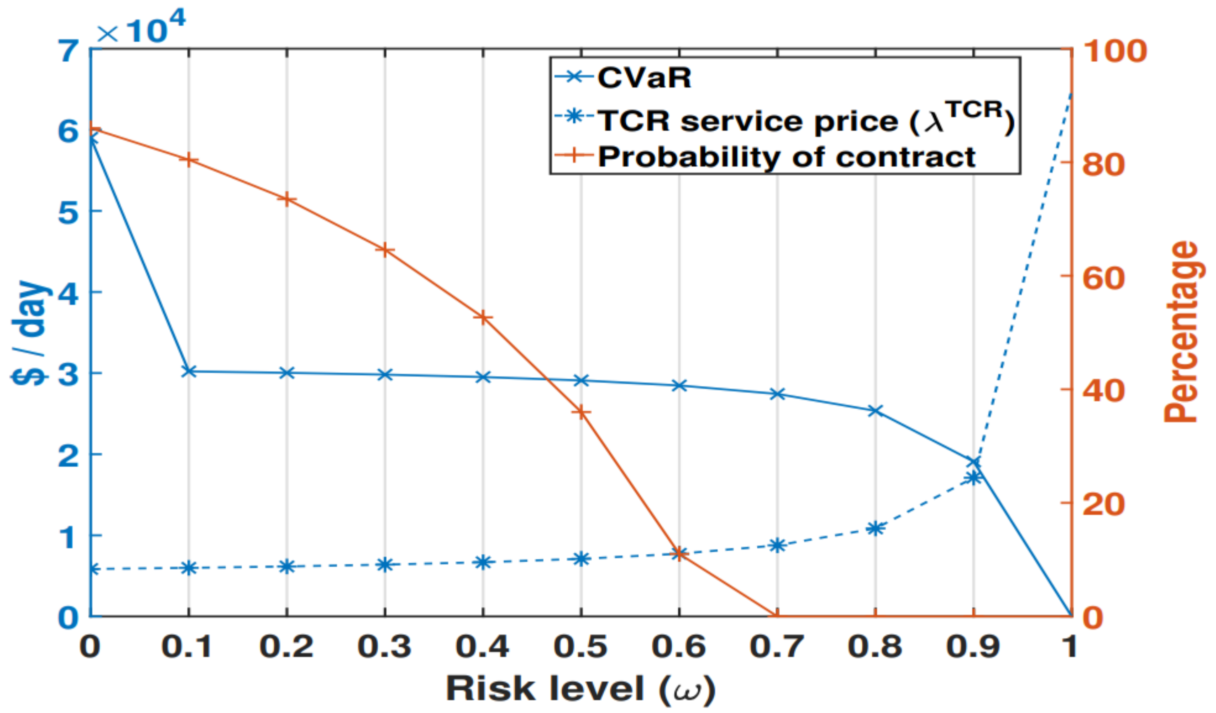
Results



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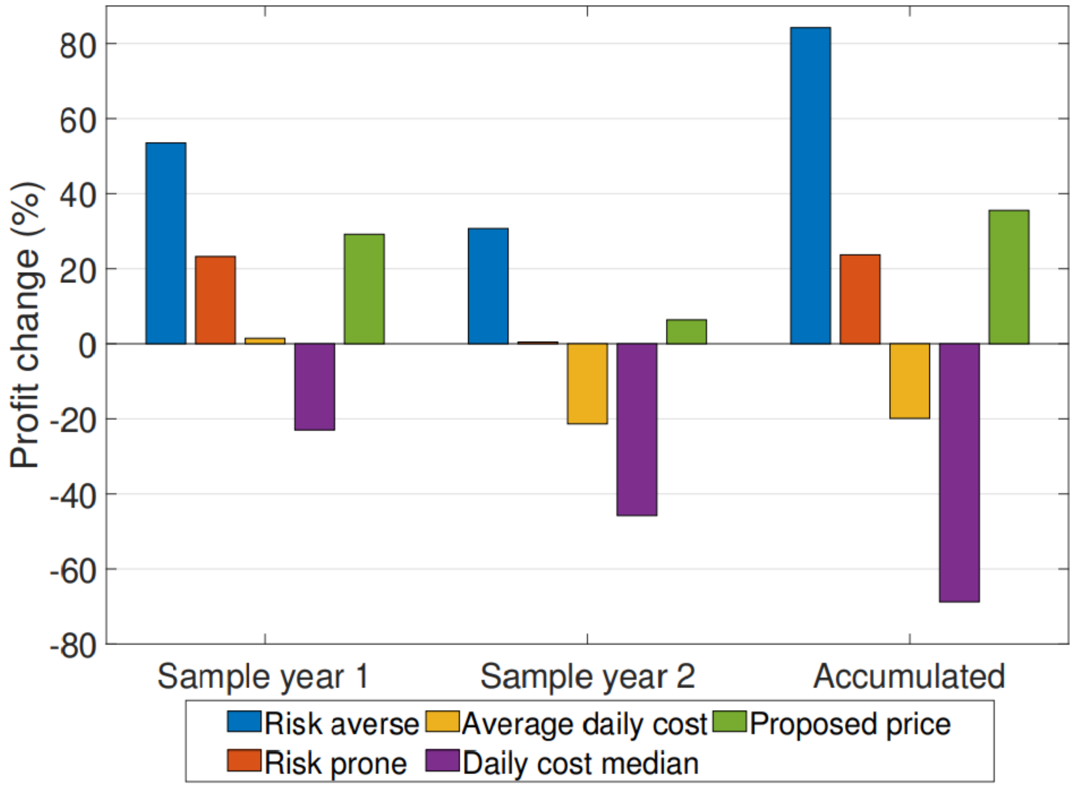
Results (continued)



Transmission analysis summary

There is a potential win-win outcome when allowing ESSs to provide market and transmission services

ESS's gains for the additional services highly depend on alternative solution's prices and potential market revenues

Arteaga, Juan, Hamidreza Zareipour, and Nima Amjady. **"Energy storage as a service: optimal pricing for transmission congestion relief."** *IEEE Open Access Journal of Power and Energy* 7 (2020): 514-523.

Questions

Juan Arteaga

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Discussion

Luis Garrido, Project Manager, AESO

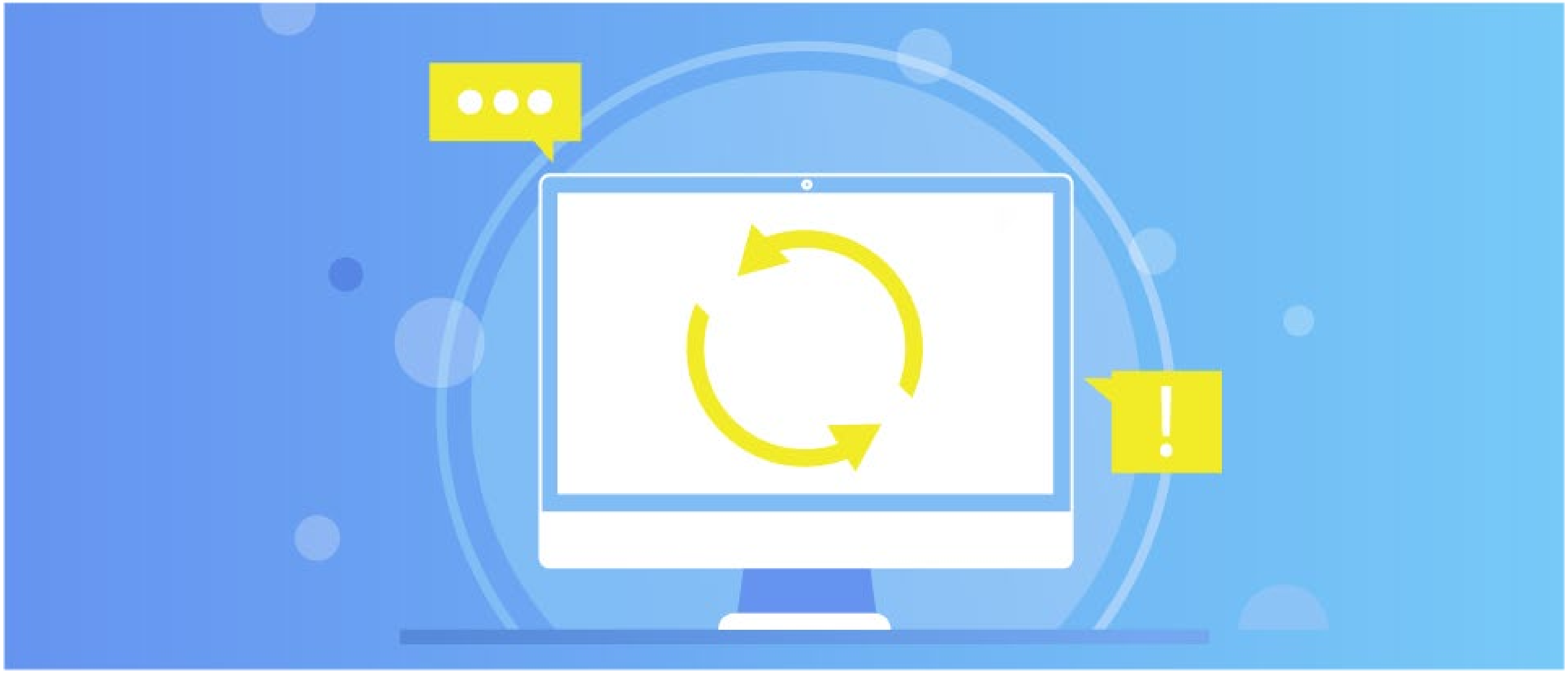
Next Steps

Biju Gopi,
Manager, Operations Engineering & Market Support, AESO

Wrap up and next steps

- Launch Zoom poll
- Next Steps
  - Thank you for participating in today's Workshop, which is the last one for 2021. We will reach out to members in Q1 2022 with respect to next steps for this Forum.
- **Please send your Energy Storage questions to:**
  - Email: energystorage@aeso.ca

Contact the AESO



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Thank you